COMMENTS BY THE STATE OF NEVADA ON NRC's PROPOSED NEW LICENSING STANDARD FOR YUCCA MOUNTAIN

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The State of Nevada submits the following comments in response to the Commission's Notice of Proposed Rulemaking, "Implementation of a Dose Standard After 10,000 Years," published in the Federal Register on September 8, 2005 (70 Fed. Reg. 53313). NRC's proposed rule applies solely to the licensing of DOE's proposed Yucca Mountain geologic repository for the disposal of high-level radioactive waste.

I. INTRODUCTION

Before addressing the substance of the proposed NRC rule, Nevada expresses dismay at the way the rule was promulgated. NRC's proposal grew from a closely coordinated and largely secret interagency effort involving DOE, EPA, and NRC to circumvent the D.C. Circuit Court of Appeal's (the "Court's") invalidation of previous EPA and NRC Yucca Mountain standards. Those standards, drafted specifically to facilitate licensing of Yucca Mountain, included a 10,000-year compliance period that the National Academy of Sciences found would make compliance "rather easy" but had no scientific basis. *See, e.g.*, "Technical Basis for Yucca Mountain Standards," National Academy of Sciences (1995) at 55; SECY-96-120 (June 3, 1996) (in which NRC insists that Yucca standards be "reasonable" and "implementable"); EPA's "Evaluation of Potential Economic Impacts of 40 CFR Part 197" (June 2001) (in which EPA brags that its 2001 Yucca rule will have no adverse impact on DOE in its pursuit of Yucca licensing or on Yucca costs); LSN DEN001378183 (in which DOE urges OMB and EPA to adopt an "implementable" standard that "should reflect the Administration's commitment to geologic disposal, which is central to the utility's lawsuit and legislative proposals"); LSN DEN001232832 (in which a senior DOE official opines that NRC's Part 63 was "probably written by the Brocoum/VanLuik axis" and that it "may be a DOE/NRC/nuke community juggernaut"). In fact, even senior DOE scientific experts believed the NRC 10,000 year compliance period was "fundamentally unsound." *See* LSN DEN001216767.

This interagency effort included secret meetings and exchanges of draft rule language between the regulators (NRC and EPA), meetings and exchanges with the regulated entity itself (DOE), and even the direct interference of the Office of Management and Budget ("OMB"), part of the Executive Office of the President. OMB, which has no nuclear regulatory experience, apparently ran last minute interference on behalf of DOE to further limit NRC's ability to raise legitimate safety issues in its review of the Yucca Mountain license application. As Nevada's November 2005 comments to EPA explain in detail, this secret interagency effort produced an EPA proposed rule that is arbitrary, unsupported scientifically, and unlawful in virtually every important respect. Section IX of those comments describes the collusive history of the framing of the new EPA rule.

NRC's currently proposed rule is similarly arbitrary, unsupported scientifically, and unlawful. It has a tainted and disgraceful origin. NRC violated its own "Principles of Good Regulation" – in particular "Openness" and "Independence" – when it participated in secret negotiations with DOE, its regulated entity, to limit NRC's own ability to raise legitimate and substantial safety issues. NRC's secret negotiations also violated its stated regulatory principle that "nuclear regulation is the public's business." *See* NRC Inspector General Report OIG-05-A-23 (September 30, 2005) at 14. NRC's bargaining away of its independence, abandonment of openness principles, and shameless abdication of its regulatory responsibilities surely stands as the low point in the agency's history.

NRC Staff presented the proposed NRC rule to the Commission for its approval on August 10, 2005 (SECY-05-0144), almost two weeks before EPA published its proposed rule in the Federal Register. This lockstep coordination between EPA and NRC, which also included overlapping comment periods on the NRC and EPA proposals, makes it especially difficult for Nevada and other interested stakeholders to comment on the NRC rule. While EnPA requires consistency between the NRC and EPA rules, commenters have no way of knowing what will be the final EPA rule that NRC will have to implement. Nevada must therefore insist on the right to another round of comment before the NRC, should EPA's final rule depart substantially from its proposed rule. Because of this overlap and uncertainty, Nevada also incorporates into these comments, by reference, its entire suite of comments on the EPA rule. Those comments are accordingly attached to this document. As explained below, Nevada also believes it is entitled to a formal hearing on certain NRC proposed findings of adjudicatory fact in its proposed rule, and Nevada requests such a hearing before NRC issues a final rule.

II. GENERAL COMMENT

A common initial reaction to a standard that purports to limit releases for one million years (or more) is that such a limit is ridiculous, for no one can possibly predict that far into the future. However, this reaction fails to account for the critical fact that the EPA and NRC standards at issue here are repository design standards, not release standards. Once the repository is licensed and constructed, and the radioactive waste is emplaced irretrievably (as planned), the standard will cease to have any application or meaning. Once the man-made waste packages fail (as they inevitably will), and releases occur, the releases will obey the laws of nature, not man.

The EPA and NRC dose standards at issue here have no meaning or application except in quantitative performance assessments used in the next few years for NRC licensing purposes. These assessments use assumptions about future human knowledge, behavior and society, mathematical models, present-day scientific principles, and available scientific knowledge about Yucca Mountain and its environs to predict future releases and doses. Since the radioactive materials being disposed of have half-lives of many thousands (even millions) of years, the performance assessments must include calculations of releases of radioactive materials over very long time frames. If we confine our calculations to short time frames, then we will have scientifically reliable predictions, with little or no reliance on assumptions that cannot be proved scientifically, but we will have failed to do a calculation that tells us what we need to know -- whether Yucca Mountain will prevent or limit releases in the distant future while the wastes remain hazardous. This was the fundamental defect in NRC's and EPA's original standards. By limiting compliance calculations to 10,000 years in the face of a DOE-designed waste package claimed to last at least that long, these standards were carefully crafted to tell us nothing about whether the repository system as a whole would be adequate for safety. The repository system includes the natural features of the site, which must limit or prevent releases following eventual and inevitable package failures from corrosion.

We can be sure that some things in these long-term performance assessments will eventually turn out to be wrong as, for example, scientific knowledge increases and human living patterns evolve. But, if we are prudent in the assumptions we make, avoid making assumptions where additional scientific studies will fill the gap, do the calculations as best as we can, and make sure the regulatory framework and design standard are right, then the calculations (performance assessments) will tell us what we need to know: whether or not there is reasonable assurance Yucca Mountain will be a safe repository that will protect future generations.

Therefore, the key question is whether compliance with a tiered design standard, including a 350 millirem/year standard applied to the median of DOE's calculations for the post-10,000-year performance assessment period, will tell us that a repository at Yucca Mountain will be safe and protect future generations. EPA, in its rulemaking, did not squarely pose this question, let alone answer it. Nevada poses it to NRC and, in view of the comments that follow, the inescapable answer is "No." NRC must do more to assure a safe repository because the EPA standard cannot adequately protect the public health and safety.

III. NRC'S RULE VIOLATES FUNDAMENTAL PRINCIPLES OF ADMINISTRATIVE LAW

A. Background

NRC's proposed amendments to 10 C.F.R. Part 63 include numerous NRC proposed findings of fact that apply only to Yucca Mountain and that would otherwise be the subject of NRC's Yucca licensing review and hearing. These include proposed findings of fact:

(1) that the performance assessment for the period after 10,000 years must use a time-independent log-normal probability distribution for deep percolation rates of from 13 to 64 millimeters per year;

(2) that models and data used to develop FEPs ("features, events and processes") for the assessment period before 10,000 years are sufficient for the post-10,000-year assessment period;

(3) that seismic analyses for the post-10,000-year period may be based on seismic hazard curves developed for the pre-10,000-year period;

(4) that seismic effects in the post-10,000-year period may be limited to effects on the repository's drifts and waste packages;

(5) that igneous effects in the post-10,000-year period may be limited to effects on waste packages;

(6) that the effects of climate change in the post-10,000-year period may be limited to increased water flux through the repository;

(7) that different types of corrosion of the waste packages must be considered in the pre-10,000-year period but only general corrosion at a constant rate may be considered in the post-10,000-year period; and

(8) that effects of climate change in the post-10,000-year period may be expressed by steady state (time independent) values.

In making those determinations of adjudicative fact, NRC primarily followed EPA's lead. EPA made similar determinations in its own proposed rule, and invited NRC to do the same. However, as the discussion below shows, EPA had no authority to make those determinations, and NRC cannot ratify EPA's misuse of rulemaking or engage in similar misuse of its own.

B. <u>Basic Legal Principles</u>

Whether a particular administrative action should be classified as rulemaking or adjudication is a classic question of administrative law. A rule is the product of rulemaking, while an order is the product of adjudication. The Administrative Procedure Act ("APA") defines a "rule" as "an agency statement of general or particular applicability and future effect designed to implement...law or policy...." 5 U.S.C. § 551(4). A "rule" is contrasted with an "order," which is defined as "a final disposition...of an agency in a matter other than rule making but including licensing." 5 U.S.C. § 551(5). Under the APA, rules typically resemble legislation, applying to classes of people, with future effect, and based on general considerations, while orders resemble judicial decisions, applying only to named parties, with present or retroactive effect, and based on facts that are specific to the parties in interest.

This classic distinction between rules and adjudications is embodied in a pair of pre-APA due process cases, *Londoner v. Denver*, 210 U.S. 373 (1908) and *Bi-Metallic Investment Co. v. State Board of Equalization*, 239 U.S. 441 (1915). In *Londoner*, the Supreme Court held that an individual property owner was denied due process when the City refused to grant him a hearing to challenge an individualized property assessment. Seven years later, the plaintiff in *BiMetallic* cited *Londoner* for the proposition that it was entitled to a hearing on an across-the-board property tax increase, but the Supreme Court disagreed. According to the court, *Londoner* was a case where a relatively small number of people were affected on individual grounds, but in *BiMetallic* no individual was singled out based on facts unique to each individual; the assessment applied to a group of people. These two cases continue to be cited today. *See, e.g., Vermont Yankee Nuclear Power Corp. v. NRDC*, 435 U.S. 519 (1978). In modern terminology, we now say *Londoner* involved adjudication while *BiMetallic* involved rulemaking.

The modern pronouncement on the difference between a rule (and rulemaking) and an order (and adjudication) is the 1947 Attorney General's Manual on the APA. *See, e.g., Bowen v. Georgetown University Hospital*, 488 U.S. 204, 216-225 (1988)(Scalia, J., concurring); *American Mining Congress v. Mine Safety and Health Administration*, 995 F. 2d 1106 (D.C. Cir. 1993). The Manual states that "[t]he entire [APA] is based upon a dichotomy between rule making and adjudication...rule making is an agency action which regulates the future conduct of either groups of persons or a single person; it is essentially legislative in nature, not only because it operates in the future but also because it is primarily concerned with policy considerations....conversely, adjudication is concerned with the determination of past and present rights and liabilities." Manual at 14. The APA specifically defines licensing as adjudication because, like prototypical adjudications, licensing involves "a determination of a person's right to benefits under existing law so that the issues relate to whether he is within the established category of persons entitled to such benefits." Manual at 15. Nevertheless, it was recognized that initial licensing (as in Yucca Mountain) also resembled rulemaking because licenses "may also prescribe terms and conditions for future observance." Manual at 52. However, instead of classifying initial licensing as rulemaking, the Congress developed certain limited statutory exemptions from adjudicatory procedures in initial licensing cases. Manual at 50-53.

The foregoing discussion supports two critical distinctions between a rule and an order. First, a rule addresses the future while an order addresses the past or the present. Second, a rule is based on general policy considerations or on what are sometimes called legislative facts, generalizations about people and things, while an order is based on specific facts about things and individuals, sometimes called adjudicative facts. Whenever the courts have allowed agencies like NRC to lift issues from adjudicatory hearings and resolve them by rulemaking, the rules involved *legislative* facts and policy considerations. No agency may resolve a controversy over an adjudicative fact, relevant only to a single adjudication, by rulemaking. *See, e.g., Heckler v. Campbell*, 461 U.S.

458 (1983); *Broz v. Heckler*, 711 F. 2d 957 (11th Cir. 1983). The proposed NRC rule blatantly violates this principle.

C. Significance of EnPA

Nothing in the Energy Policy Act of 1992 ("EnPA") expressly amends the APA's distinction between adjudication and rulemaking. The APA provides that subsequent statutes may not be held to amend the APA unless they do so expressly. 5 U.S.C. § 559. EnPA does contemplate Yucca "rules" that by their nature depend on some facts relevant only to Yucca, and Congress is free (within Constitutional constraints) to call something a "rule" even if, under traditional administrative law principles, it would not be. However, even assuming for purposes of argument that EnPA amends the APA's definition of "rule," EnPA provides for rules that are very limited in scope. The grant of Yucca rulemaking power to EPA in EnPA is based on the previous delegation of rulemaking authority to EPA in Section 121 of the Nuclear Waste Policy Act, which in turn relies on the delegation (and division of power between NRC and EPA) in Reorganization Plan Number 3 of 1970. Therefore, EnPA authorizes EPA to issue only a Yucca-specific standard that meets the definition of a "standard" in the Reorganization Plan, *i.e.*, a rule that is confined in scope to "limits on radiation exposures or levels, or concentrations or quantities of radioactive materials in the general environment outside the boundaries of locations under the control of persons possessing or using radioactive material." EPA's findings of adjudicative facts must be limited to those needed to support such a limited rule. EPA's fact-finding exercise under EnPA must also be based on the findings of fact of the National Academy of Sciences, which made certain factual determinations to support its recommendations for Yucca Mountain standards.

Therefore, EnPA authorized only those EPA findings of adjudicatory fact that (1) are based on what the Academy considered necessary to support an EPA rule; and (2) are essential to promulgate limits on radiation exposures, concentrations, or quantities beyond the boundary of the Yucca Mountain site. The EPA proposed rule goes well beyond these limits, making findings of fact (including findings (2) through (8) summarized above). Those findings of adjudicatory fact are unauthorized and are of no legal effect. Since the EPA rule is of no legal effect in making these findings, it cannot serve as authority for NRC to make similar findings in its proposed rule.

EPA also invites the NRC to make certain findings of adjudicatory fact (finding (1) above) that it did not itself make. However, an invitation to NRC to resolve an issue by rule is not a "standard" that NRC must implement within the meaning of EnPA, even if some of EPA's other findings of fact may be considered such.

D. NRC's Rule Violates Legal Principle

In sum, NRC's proposed rule fails to heed the fundamental distinction between rulemaking and licensing, and cannot be justified because of EnPA. EPA's findings, NRC's proposed incorporation of them in its rule, EPA's invitation to NRC to make still additional findings, and NRC's apparent acquiescence in this invitation, also constitute massive and completely unlawful intrusions into NRC's licensing function, and involve EPA in matters well beyond its expertise. In the past, NRC has objected strenuously to this kind of EPA intrusion for these very reasons. *See, e.g.*, Memorandum for the Commissioners from the Executive Director for Operations, April 6, 1990 (LSN NRC000024406) and letter to the Administrator of EPA from NRC's Chairman, dated May 11, 1983 (LSN NRC000024461). There is no reason why NRC should now abandon its principled objection to EPA's intrusion into its licensing function.

This intrusion is even more unjustified because it apparently came at OMB's insistence. The "International Peer Review of the Yucca Mountain Project TSPA-SR" (2002) had found (at pg. v.) that the pre-10,000-year features, events and processes ("FEPs") were not necessarily reliable in predicting performance after 10,000 years, and so EPA wisely drafted a proposed rule that (unlike the current proposal) allowed NRC to propose additional FEPs in the 10,000-year assessment period. OMB, however, recommended removing that language from the rule (the OMB mark-up is in the EPA rule docket). In response, EPA obediently struck from draft section 197.36(c)(3) the phrase, "NRC may specify, by regulation, additional features, events and processes that DOE must consider because they may significantly affect the magnitude of the peak dose."

It is almost certainly the case that OMB struck the proposed language at DOE's insistence, since OMB has no expertise whatsoever in high-level nuclear waste performance assessment. This DOE-directed modification of the EPA proposal led directly to the EPA (and corresponding NRC) provisions requiring that the post-10,000-year performance assessment be based on pre-10,000-year assessment data and models, and to a corresponding need to draft a few exceptions so that NRC might consider some few additional repository safety issues where failure to do so would apparently have shocked even the conscience of the beleaguered souls involved in the secret interagency negotiation process.

Moreover, as explained in Nevada's comments on the EPA rule, especially the Appendices to these comments, these factual findings by EPA and corresponding limits on NRC's ability to raise safety issues are without any technical basis and are contrary to sound science. They violate both EnPA and the Atomic Energy Act, and are therefore invalid for this independent reason.

E. Effect of EPA's Intrusion and NRC's Violation of Law

As indicated above, NRC's improper use of rulemaking to resolve adjudicatory factual issues results in: (1) matters being resolved by an agency (EPA) with no expertise; (2) a violation of fundamental principles of administrative law; and (3) an unlawful usurpation by EPA of NRC's traditional licensing function. It also constitutes an unlawful abrogation of Nevada's right, under Section 189 of the Atomic Energy Act, to an NRC licensing hearing on these factual issues. All of NRC's proposed findings of adjudicatory fact (including, specifically, findings (1) through (8)) must be struck from NRC's proposed rule.

Also, as indicated in Nevada's comments to EPA, these factual findings are premature, insofar as they are based on Yucca data and performance assessments as of 2005. The NRC (and EPA) rules must be sufficiently flexible to account for data and models used in the actual DOE license application, but as currently drafted they cannot do so. As a consequence, the NRC and EPA rules, in all likelihood, will be incapable of actually being applied as written.

Indeed, since the EPA and corresponding NRC rules are premised on ostensible findings about increased "uncertainty" and unnecessary "over-conservatisms" after 10,000 years, based on documents available to EPA in 2005, the rules could easily have the perverse effect of discouraging DOE from reducing uncertainties and adding realism to the post-10,000-year performance assessment in the license application in order to preserve the purported uncertainties and conservatisms that form the basis for the rules. Such a result would turn the practice of performance assessment on its head.

Invoking the only potentially lawful alternative to striking the factual findings from the rule, NRC could grant Nevada a formal hearing on all of the findings. Nevada believes it is entitled to such a hearing under section 189 of the Atomic Energy Act, if NRC insists on including the findings in its final rule. But such a hearing would be premature in the absence of a DOE license application.

IV. NRC'S SPECIFICATION OF A DEEP PERCOLATION RATE IS UNFOUNDED

The starting point and critical element of DOE's Yucca Mountain analyses is the water entering the Mountain. As indicated above, NRC proposes to specify that, for the post-10,000-year period, the performance assessment shall simulate climate change by assuming constant climate conditions, and that the constant value to be used shall be based on a log-normal probability distribution for deep percolation rates of from 13 to 64 mm/yr. This proposal is unsupportable.

A. The Proposal Suffers from Legal and Scientific Defects

First, as explained above, NRC's climate and infiltration proposal constitutes an improper use of rulemaking to resolve adjudicatory facts.

Second, NRC's proposal requires distinctions between the post-10,000-year performance assessment and the pre-10,000-year performance assessment that are arbitrary and have no basis in sound science. As Nevada's comments to EPA explain (especially Dr. Thorne's reports on "Climatic Considerations Relevant to the Draft EPA Rule" and "The Role of Uncertainties in Defining the Proposed Standard"), there is no step-change in our capability to project climate change at 10,000 years. Both of these reports are incorporated by reference into these comments.

Third, NRC's proposal wrongly presumes that future climate conditions at Yucca can be bounded by the observed range of conditions over past glacial-interglacial cycles, and that only long-term average responses are of relevance. In the distant future, Yucca average climate conditions could be wetter or drier than NRC's assumed constant state. Even if Yucca were to be drier on average, global warming could cause substantial reorganization of atmospheric systems, both before and after 10,000 years, leading to an increase in the number and intensity of storm events at Yucca Mountain. Intense storm events may have a disproportionate effect on infiltration because of the susceptibility of arid environments to event-driven infiltration and the highly non-linear relationships that are involved. Hydrologic response thus will be significantly underestimated by assuming steady-state hydrology based on average annual precipitation.

The Center for Nuclear Waste Regulatory Analysis ("CNWRA") confirms these propositions. *See, e.g.*, TPA Version 4.1, research by Stothoff (1999) ("The exponential response to net infiltration to climate change suggests that cumulative net infiltration may be underestimated unless perturbations in the climate cycle are considered," and "The simulations are too short to include infrequent large events, so that the estimate may not be a true mean annual average"); and Stothoff, et al. (1996). *See also* Dr. Thorne's report, "Climatic Considerations Relevant to the Draft EPA Rule," for additional considerations and details.

Fourth, the range of precipitation values assumed by NRC (up to 321 mm/yr) is lower than that used by DOE in its most recent assessment (Bechtel, 2004a), which assumes a range of up to 455 mm/yr. There is no justification for NRC's having adopted significantly lower values than those of DOE.

Fifth, current estimates of net infiltration are highly uncertain. For example, the site-specific point values reported by Flint, et al. (2002) for Yucca range from zero to several hundred mm/year. Winterle, et al. (1999), in a CNWRA report to NRC, conclude that some of the evidence used to derive site-scale estimates is biased, and that DOE estimates should be doubled. The Winterle analysis of perched groundwater suggests a most likely range of mean annual infiltration of from 13 to 26 mm/year. In contrast, the proposed rule is based on the assumption of 5 mm/year for current climate. This clearly underestimates the uncertainty in current estimates, which in turn are used in extrapolation to future climate states. Moreover, NRC fails to explain why it proposes to use the geometric rather than the arithmetic mean in its infiltration estimates, or why using a log-normal distribution in the performance assessments is appropriate.

The extrapolation of net infiltration values to future climates, as suggested under the proposed rule change, is also based on highly simplified, one-dimensional modeling and arbitrary assumptions. As noted above, the net infiltration numerical values specified under the proposed rule are based on reports by Stothoff (1999), and Stothoff, et al. (1996), which underpin the TPA Version 4.1 report. NRC uses a one-dimensional representation of the near-surface hydrological response. In the face of criticism, USGS moved from a 1D hydrological model (INFIL v1) to a model that allowed some lateral flow redistribution (INFIL v2) for the most recent assessments (Bechtel, 2004b). But recently, Woolhiser and Fedors (2000), reporting to NRC, undertook a comparative analysis based on the KINEROS model and concluded that the role of lateral distribution of runoff, and hence the re-focusing of infiltration, is significantly under-represented in INFILv2. In other words, despite moving from 1D to incorporate lateral flow in

INFILv2, the representation is still inadequate. This has important implications for the spatial distribution of net infiltration and flow processes in the unsaturated zone, and for spatially averaged response. The 1D hydrological model is not an appropriate basis with which to pre-specify hydrological response post-10,000 years.

The limitations of the underlying analyses that are used by EPA to support the proposed rule change are clearly set out by CNWRA. With respect to infiltration modeling, Stothoff (1999) page 24 notes that "[t]here are obvious limitations in the approach, as lateral redistribution, stratification, fast pathways, vegetation and matrix-fracture interactions are not considered." The limitations of the TPA analyses are also clearly defined by CNWRA (2004). Nevada notes the caveats in the TPA Version 4.1 report (CNWRA, 2004, p1-9), in which these results are reported: "The results are limited by the use of simplifying assumptions and models, and parameters based on limited data. As a consequence, these results are for illustration only. Moreover, the manner in which these analyses were conducted or the assumptions and approaches used should not be construed to express the views, preferences, or positions of the NRC staff regarding implementation of regulations at Yucca Mountain." It appears that results have been taken out of their scientific context by NRC in an attempt to substantiate an arbitrary and unjustified rule. The TPA code is designed to be used "as a tool to assist NRC in its evaluation of performance assessments in any license application by the U.S. Department of Energy" (CNWRA, 2004, p xvii), and not to pre-empt those assessments.

Sixth, in considering long-term response, it is not sufficient to assume a stationary hydrological system. Woolhiser and Fedors (2000), in their work for NRC, comment that hydrological response under future climate states is very difficult to judge "because the soils, vegetation and the watershed geomorphic characteristics would also change." It cannot be assumed that the effect of climate variation beyond 10,000 years is limited to water flow. However, water flow is clearly dependent on the evolution of the hydrological system on these timescales. This is a complex topic that requires proper scientific evaluation, rather than arbitrary pre-specification by NRC.

Stothoff (1999) notes that "[e]very performance assessment to date has assumed hydraulic properties and soil thickness remain constant over a glacial cycle." NRC has located sites that are analogues of Yucca Mountain and investigated soils and vegetation. Stothoff (1999) reports that "Field observations have been made that suggest that hydraulic properties have varied over glacial cycles" and goes on to describe likely effects, specifying that "during wetter portions of the glacial cycle, soil genesis processes are likely to have been enhanced, and it may be that YM soils were significantly deeper and finer-textured than at present." Drier and warmer conditions may have led to vegetation replacement and (p. 20) to "drastically-enhanced erosion over the repository footprint." He concludes (p. 23) that "changing soil texture and thickness during a glacial cycle may have a profound effect on MAI [mean annual infiltration]." Also, Stothoff (1999) states that "mean annual infiltration will have more complex behaviour over a glacial cycle when the response of mean annual infiltration to changes in soil thickness is considered as well as the response to meteorological factors."

Seventh, NRC's proposal is insupportable because it is based on the past work of USGS personnel that is the subject of continuing criminal and civil investigation due to the apparent falsification of infiltration data and associated quality assurance records. NRC's notice specifically references USGS work in its discussion of climate and precipitation, and the percolation rate studies by Mohanty, et al. (2004), cited by NRC, and the work referenced by Mohanty, et al. and by Stothoff (1999) both indicate reliance on USGS work. Moreover, the average deep percolation rate of about 4 percent under current conditions taken by NRC as a "given" has no cited support, but must also be based on USGS studies. As the e-mails in Exhibit No. 1 hereto indicate, and as the existence of ongoing investigations suggest, these USGS studies have numerous quality assurance, modeling, and other difficulties that make them unreliable. For NRC to rely on them in specifying infiltration rates by rule is akin to estimating profit and loss ratios based on figures provided by Enron.

Eighth, there is no clear indication in NRC's proposal whether or how NRC's own guidance on establishment of infiltration rates in NUREG/CR-6565, "Uncertainty Analysis of Infiltration and Subsurface Flow and Transport for SDMP Sites," has been applied, if at all. The NUREG has important insights on how uncertainties must be accounted for and cannot be ignored by NRC.

Finally, there is no indication of any scientific peer review of NRC's calculations and judgments, contrary to the Information Quality Act ("IQA") and OMB's regulations. NRC overwhelmingly relies on EPA and indirectly on its key source, the Cohen report. The IQA imposes data quality and peer review requirements on key scientific sources that are relied upon by NRC. NRC failed to subject its key information sources to peer review.

B. <u>NRC's Proposal Ignores the Potential for Better Future Data</u>

Even if NRC's proposal had some minimal scientific validity, which it does not, specifying an infiltration rate years before DOE's license application is even filed is premature and unwise, especially given the likelihood that significant new models and data of greater reliability will soon be available. As Dr. Thorne points out in his report on "Climatic Considerations Relevant to the Draft EPA Rule," new models are now available for projecting future climate changes, and the spatial and temporal resolution of these models is likely to be enhanced in the near future. There is no reason to exclude *a priori*, as NRC has done, potential future anthropogenic influences on Yucca Mountain climate. Moreover, DOE's October 12, 2005 "Action" memo indicates that DOE and its contractors are drafting a plan of action for "review, validation, augmentation, and replacement of USGS work products as they support infiltration models and maps." NRC cannot go forward with specification of infiltration rates when the entity most directly affected (DOE) considers its (and USGS's) infiltration data and models so unreliable that they must be replaced at considerable taxpayer expense. And how will NRC explain its rule if, in the near future, one or more of the supporting authors is indicted for crimes committed in connection with the very work NRC relies upon?

V. NRC MUST DO MORE TO ASSURE SAFETY

EPA invites NRC to judge post-closure performance after 10,000 years on the median of the distribution of DOE's Yucca performance realizations, and NRC carries this concept forward in its proposed rule.

A. Use of the Median is Unsound and Unlawful

In choosing the median, EPA ignored the NAS's clear recommendation to use the mean, a recommendation Congress and the Court told it to heed. This is so obvious an error that for NRC to proceed with blinders on would be extremely irresponsible. Indeed, the claimed scientific arguments in support of an abrupt switch in the performance assessments from the mean to the median as the measure of compliance at 10,000 years are simply junk science.

Moreover, applying the median to the assessment results to date will sever EPA's 350 millirem/year standard from the actual dose effects of the repository, since using the median of a positively skewed distribution effectively discounts high dose calculations. (In the Yucca Mountain case, applying a 350 millirem/year median standard is roughly equivalent to a 1000 millirem/year mean standard.) The result is a measure of compliance that is not health-based, as the law requires, because it fails to account for significant doses that exceed the standard. Using the median also discourages the important investigation of high-dose calculations, since they will have little or no effect on compliance. And it is inconsistent with prior NRC and EPA policy, with no adequate explanation. These and other problems with using the median are explained in Dr. Thorne's report, "The Role of Uncertainties in Defining the Proposed Standard," and in the report by Drs. Florence and Vasquez, "Some Comments on the Proposed Yucca Mountain Compliance Standards," which were submitted with Nevada's comments on the EPA proposed rule and are incorporated herein by reference (they were also incorporated by reference into Nevada's comments on the EPA rule).

B. NRC Must Allow Broader Judgment in Using Assessment Results

1. NRC Must Consider All Relevant Information

NRC does not carry out its responsibilities as a nuclear regulator by adopting a carbon copy of EPA's rule. That is not what NRC does in regulating reactors and it is not what it should do here.

EPA stated in the preamble to its proposed rule that "NRC has the authority to consider not only the magnitude of the peak, but also the timing and overall trends of dose projections as it evaluates the license application." 70 Fed. Reg. at 49039. NRC's proposed rule should, but does not, discuss this important topic. Related to this is the unnecessarily prescriptive requirement by EPA that the post-10,000-year performance assessment should end at 1,000,000 years. The Academy stated that the period of geologic stability was "on the order of" one million years, and if the trends in dose projections are not clear or heading upward and geologic stability is maintained, extending the assessment beyond one million years may be required to establish the performance of the entire repository system including, especially, the natural barriers. In fact, some of DOE's results do not show a peak before a million years. One should not take these time scales too literally. The point is that the peak depends on assumptions about the corrosion of the waste packages. These assumptions are based on shaky facts. With a change in the assumptions about package corrosion, the peak that occurs in the distant future in DOE's simulation could in the real world come much earlier, in thousands or even hundreds of years. The important factor both NAS and the Court required was to capture the peak, because that is the measure of the performance of the geologic system in containing the radioactive leakage from the waste packages.

2. NRC Must Consider Statistical Significance

NRC's proposed rule should, but does not, set a requirement for assuring the statistical significance of DOE's modeling results that will frame NRC's licensing decision. For the purpose of developing a set of results, DOE runs its model approximately 300 times, supposedly using random variations of the individual parameters and submodels. Since there are potentially more parameters than runs, and many potential models, this small number of runs may be insufficient to create statistically significant results. Monte Carlo calculations are known to converge very slowly. NRC's rule, therefore, should have a provision requiring DOE to prove mathematically that its results are statistically significant. Without such proof, the results should not have any status. Furthermore, EPA and NRC should require that DOE demonstrate that adequate and verifiable controls are in place so that no high runs are rejected; otherwise, the modeling will lack transparency, and DOE will have the opportunity to selectively skew its results.

3. There Must be Defense-in-Depth

EPA's extremely lax post-10,000-year standard is an envelope within which NRC must operate, not a mandated standard for the NRC. There must be defense-in-depth, which has been the *sine qua non* of NRC licensing. For example, in reactor licensing EPA sets a standard of 25 millirem/year for the allowed public radiation dose, but NRC fleshes out that standard with individual barrier requirements and a tighter radiation standard based on the ALARA principle. However, a meaningful defense-in-depth standard is missing from the NRC rule. Indeed, DOE officials confirm this. *See* LSN DEN001214905 (in which a DOE official states, "My discussions with NRC staff, who drafted Part 63, lead me to understand that the intention of the NRC re defense in depth is that no requirement is intended – whatever we do is ok with them." In the case of Yucca Mountain, the arguments for tightening EPA's standard are even stronger. In reactor licensing NRC conducts an inspection and enforcement program that can plausibly be counted on to catch and correct safety problems before they get out of control. Moreover, in the case of reactors there is a substantial body of experience; at Yucca Mountain, NRC is dealing with a first-of-a-kind repository, and errors will be irreversible after repository closure. This calls for greater caution in setting the standard. In short, a more robust treatment of multiple barriers and defense-in-depth, such as that used in nuclear power reactor regulation, is needed here.

As mentioned, the time of waste package failure is likely the most uncertain aspect of the Yucca performance assessments. There is a significant likelihood that doses approaching 350 millirem/year from waste package failure, which DOE projects to occur after 10,000 years, could well occur much earlier—within thousands or hundreds of years after repository closure. Should this happen, it will be too late to adopt additional remedial measures to reduce doses to below the 15 millirem/year pre-10,000-year standard. In other words, what is at issue is not only what happens after 10,000 years, but also what happens before then if the assumptions used in licensing turn out to be wrong. Protecting against such a contingency is exactly what defense-in-depth is all about. In acquiescing to EPA's 350 millirem/year (about 1000 millirem/year mean) standard, NRC would be approving a repository design standard that is unprecedented in its laxity.

Including a defense-in-depth requirement, especially a requirement pertaining to the expected performance of natural barriers, would offer an essential protective feature for coping with early package failure. It is called for by the IAEA recommendation (DS154, April 2005 draft) that "the overall performance of the geologic disposal system shall not be unduly dependent on a single barrier or function."

4. NRC Must Reject Speculative Protection Measures

The new rule cannot consistently exclude unlikely unfavorable contingencies and yet accept in performance evaluation protective measures proposed by DOE whose application is, at this point, purely speculative. We refer specifically to the drip shields that are part of the DOE design and are supposed to prevent early waste package corrosion by channeling dripping water around container surfaces. DOE does not plan to install these drip shields at the time it emplaces waste packages, presumably because the titanium shields are so expensive and installation of the shields would complicate retrieval of the waste packages if that becomes necessary. DOE says it will install them before the repository is closed, which could be in three hundred years. In these circumstances, a DOE licensing commitment is essentially meaningless. There is no reliable way to commit future decision-makers on this point. Moreover, it likely will not be physically possible to maintain the passages and remotely operate the electric underground transportation system that would be necessary. On October 26, 2005, NRC acknowledged receipt of a report from CNWRA, "Structural Performance of Drip Shield Subjected to Static and Dynamic Loading," which concluded: "Results show that the drip shield as designed, and under the assumptions made in the simplified analyses, may not be able to maintain its configuration for the loadings evaluated in the report." In short, unless DOE commits to install these drip shields in the repository with the waste packages, it should not be allowed to rely on their presence in making its case for licensing.

5. "Reasonable Expectation" is the Wrong Standard

NRC must disabuse EPA of its mistaken impression that there is some significant difference between "reasonable assurance" and "reasonable expectation." NRC represented to the Court that there was no significant difference. The Court has already disposed of this issue by ruling that the parties had agreed that the two terms were "substantively identical." *NEI,* 373 F.3d at 1300-1301. In any event, this matter of implementation is clearly for NRC to decide, and not EPA.

6. NRC Must Clarify that Compliance with the EPA Rule is Not Sufficient for Adequate Protection

Section 801 of EnPA requires that NRC's regulations be modified, as necessary, to be "consistent with" the EPA final standards in Part 197. EnPA does not say that NRC is limited to slavishly copying EPA's standards into its regulations. Nor does EnPA say that EPA's standards are themselves sufficient for safety. Indeed, EnPA's legislative history is clear that "the provisions of [EnPA] section 801 are not intended to limit the Commission's discretion in the exercise of its authority related to public health and safety." H.R. Rep. No. 102-1018 at 4446 (1992). Consistent with Congressional direction, in the last round of rulemaking on EPA's 2001 standard, NRC went to considerable lengths to independently assess the sufficiency of EPA's standards. *See, e.g.*, 66 Fed. Reg. 55733, 55754, 55756, and 55760.

NRC must also either assess the sufficiency of EPA's new proposed rule, or moot the issue by clearly stating that compliance with EPA's rule will be necessary but not sufficient for NRC licensing. An assessment of safety sufficiency will show that the EPA proposal is clearly insufficient. The reasons are explained above, in Nevada's comments on the EPA proposed rule, and in the additional comments that follow.

EPA bases its proposed 350 millirem/year median standard on so-called natural background, which includes indoor radon exposure. The use of background radiation dose at one location has never been proposed or adopted by any regulatory body as a basis for protection of human health and safety from the risks of man-made radiation imposed at another location. In fact, all radiation regulation, prior to this proposal, has its basis in the health risk of added incremental increases in dose, not existing natural background levels of radiation.

EPA not only has proposed the unprecedented use of background radiation dose in Colorado as a regulatory basis for Nevada's Amargosa Valley, but has further "cooked the books." EPA proposes to include average indoor radon dose as a constituent of so-called "natural background," even though it is highly variable geographically, from building to building, and even within the same building, and more important, its concentration can be mitigated. EPA itself -- in fact, the very same office that promulgated the Yucca Mountain standard -- has a major program underway to mitigate the effects of indoor radon, one that the agency ignores in setting the Yucca Mountain standard. If EPA had taken reasonable account of its own radon mitigation program in making the Colorado/Amargosa Valley comparison, it would have arrived at a radiation standard about an order of magnitude lower than its 350 millirem/year standard.

According to EPA's source document, indoor radon accounts for 87 percent (or 610 millirem/year) of the 700 millirem/year average annual dose in Colorado. The proportion in Nevada, according to the same source document, is 74 percent of the average 221.8 millirem/year dose (or 164 millirem/year). According to EPA (EPA Doc. #402-K-93-008), ambient outdoor radon occurs in a range of 0.2 to 0.7 pCi/L (picocuries per liter), accounting for a background dose of from 40 to 140 millirem/year. No rational health standard can be derived from this variety in exposures even assuming, contrary to all available evidence, that the health risks from naturally occurring radiation are acceptable and that people choose where to live based on informed consideration of differences in natural radiation levels. Indoor radon exposure is highly variable, and average values for locations (such as Colorado) have little to no practical validity or relevance when compared to the projected peak doses from the Yucca Mountain repository.

EPA never provided any data supporting its assumed 350 millirem/year level of background at Amargosa upon which its standard is based. Nevertheless, without analysis or question, NRC adopted the same unsupported assumption when it adopted EPA's proposed standard.

It is astonishing that the same organization within EPA that proposed this basis for the Yucca Mountain standard is the sponsor of a significant national indoor radon mitigation program, and a contributor to an international indoor radon mitigation program associated with the World Health Organization. Over 500,000 homes in the U.S. are known to have undergone radon mitigation and the EPA information program is expanding yearly. *See* http://www.epa.gov/radon. According to EPA, "[r]adon is estimated to cause many thousands of lung cancer deaths each year. In fact, the Surgeon General has warned that radon is the second leading cause of lung cancer in the United States. . . ." Further, "[t]he U.S. Congress has set a long-term goal that indoor radon levels be no more than outdoor levels; about 0.4 pCi/L of radon is normally found in the outside air. EPA recommends fixing your home if the results of one *long-term* test or the average of two *short-term* tests show radon levels of 4 pCi/L (or 0.02 WL [working level]) or higher. *See* 15 U.S.C. §2661. With today's technology, radon levels in most homes can be reduced to 2 pCi/L or below. You may also want to consider fixing if the level is between 2 and 4 pCi/L." (http://www.epa.gov/iaq/radon/pubs/consguid.html#installtable)

EPA describes most of Colorado as a highest potential dose zone, greater than 4 pCi/L, and Nye County, Nevada, where Yucca Mountain is located, as a moderate potential zone—2 to 4 pCi/L. (http://www.epa.gov/iaq/radon/zonemap/nevada.htm). In 1989 and 1990-1991 surveys, 14 percent of homes in Beatty, near Yucca Mountain, were found to exceed 4 pCi/L radon. A radon abatement program has since been established in

Nevada. http://health2K.state.nv.us/BHPS/rhs/RadonInNevada.htm For its Yucca standard, EPA has irrationally proposed a dose level for Nevada residents that, in a closely related part of its own regulatory program, it considers sufficiently dangerous to warrant reduction, sometimes at considerable expense. Moreover, EPA's standard is inconsistent with Congress's long range radon exposure goal and irrationally assumes that its national radon reduction program, adopted at Congressional direction, will fail.

Finally, exposures to 350 millirem/year median may well be chronic, since leaks from the repository may continue for exceptionally long periods. As Dr. Thorne points out in his "International Literature and Health Effects of an Annual Effective Dose of 350 mrem," application of EPA's 350 millirem/year standard implies a lifetime additional fatal cancer risk of almost 5 percent. Neither the NRC, nor any other regulatory body, has ever considered such a high level of risk to be acceptable. And, of course, using this as a standard for the median DOE simulation result amounts to allowing 1000 millirem/year exposure on average.

Clearly, the 350 millirem/year median standard has no rational basis, and the risk it implies is an unreasonable one within the meaning of the Atomic Energy Act. Therefore, NRC must add additional protection of the public in its Yucca licensing regulations. In a closely related NRC regulatory program, applicable to the licensing of low-level radioactive waste disposal facilities, NRC has established a performance assessment standard of 25 millirem/year. 10 C.F.R. § 61.41. Since the regulation has no specified compliance period, it applies to the peak dose, just like the Yucca standard. What possible justification can there be for NRC to accept 350 millirem/year as an acceptable level of risk for high-level radioactive waste disposal when it has specified a dose less than one tenth of this as acceptable for low-level radioactive waste disposal?

Adoption of Nevada's suggestions herein regarding such things as using the mean value in compliance calculations and providing for defense-in-depth will add necessary elements of safety. However, ultimately, NRC must either convince EPA to adopt a more reasonable and protective standard, or NRC must add its own dose standard to supplement EPA's inadequate one. Prior NRC practice, and the practices and policies of other standard-setting organizations, indicate clearly that such a supplemental dose standard must be in the range of 15-25 millirem/year.

Finally on this point, adoption of EPA's rule with no added protections would require NRC to revisit its "S-3" rule, currently codified at 10 C.F.R. §§ 51.51. This rule currently includes the so-called "zero release" assumption that the long-term effects of disposing of spent fuel and high level waste will be essentially zero because there would be no releases that would harm people or the environment after the repository is sealed. *See Baltimore Gas & Electric Co. v. Natural Resources Defense Council, Inc.*, 462 U.S. 87, 93-94 (1982). This assumption would continue to be reasonable if the 15 millirem standard extended through the time of peak dose. But with a 350 millirem median standard (or a 1,000 millirem mean standard) applicable to post-10,000-year period, this can no longer be reasonable. The health risks implied by exposures of 350-1,000 millirem/year are far from negligible and, as noted above, are far in excess of doses NRC, EPA, and other standard-setting bodies have considered acceptable for members of the public. Lifetime doses of 350-1,000 millirem/year, which could well occur, imply an increase in fatal cancer risk of about five percent or more and therefore a repository that meets the EPA standard (but nothing more stringent) will cause many thousands of additional fatal cancers. Moreover, with no reprocessing available or even likely, there is no basis for assuming the zero release assumption is counterbalanced by other conservatisms in the S-3 rule. However, amending the S-3 rule would be completely unnecessary if NRC were to adopt more reasonable and suitable protective standards.

C. NRC's FEP Limitations are Unreasonable

Elsewhere in these comments, Nevada has objected to NRC's self-imposed limits on its ability to raise significant safety questions, especially its limits on FEPs. In its previous rule, NRC insisted that DOE develop a "clear technical basis for the event sequences included/excluded," 66 Fed. Reg. 55741, and NRC does not and cannot explain why it has retreated from this sound technical position.

For the most part, these limits are expressed in proposed § 63.342(c). However, proposed § 63.114(b) appears to include another limit on post-10,000-year performance assessments. The limit (if it is intended as such) is left entirely unexplained. Either it should be deleted, or NRC should offer some explanation and justification for it in another round of rulemaking so that Nevada can offer useful and informed comments.

Within proposed section 63.342(c)(ii), NRC permits limiting the effects of a volcanic event "to that causing damage to the waste package directly." In DOE's analyses waste packages begin failing after 10,000 years, and by one million years most, if not all waste packages will have completely failed. There is no credible safety rationale supporting NRC's directive that the effects of an igneous event directly impacting bare spent fuel need not be analyzed after the containers have failed.

VI. INCORPORATION BY REFERENCE OF NEVADA'S COMMENTS ON EPA'S PROPOSED YUCCA RULE

NRC's proposed Yucca radiation protection rule adopts almost in its entirety EPA's proposed Yucca radiation protection rule. Nevada has filed extensive comments and appendices criticizing EPA's proposed rule. As discussed above, Nevada incorporates by reference its entire set of comments on the EPA rule, which are submitted with these comments, to the extent those comments relate to any part of EPA's proposal that was also proposed by NRC. Those EPA comments and appendices should be considered by NRC as essential elements of Nevada's comments on NRC's proposed rule. Moreover, to the extent NRC considers some of the above comments to be outside of the scope of this rulemaking, Nevada requests that these comments be considered as a petition for rulemaking.

* * * *

Exhibit 1

[redacted] 04/03/98 04:19:40 PM

To: [redacted]

cc:
Subject: Infiltration and UZ flow

[redacted]

I have some maybe bad and maybe good news that you should be aware of. [redacted] called me 2 weeks ago and said that he had tested the first sample of core from [redacted] at [redacted] and it had a concentration of 39 mg/l of chloride. This means that the flux is at most 2 or 3 mm/yr in this high infiltration zone ([redacted] is at the crest of YM). There are some implications that I did not realize until I talked them over with [redacted] yesterday: basically, either our infiltration model is wrong or our [redacted] flow model is wrong or both.
Infiltration model wrong? If we look at 2 analog sites, we see much different behavior than predicted by our infiltration model. At [redacted], the best estimate for infiltration is about 24 mm/yr in the center, under a wash, decreasing to about 10 mm/yr a mile away, decreasing to virtually nothing around G-tunnel (the southern edge). Also, the [redacted] method predicts a recharge of ~20 mm/yr. Our infiltration model predicts about 40 mm/yr--our [redacted] climate.
At [redacted], the [redacted] and [redacted] site in [redacted], there are drips in 2 parts of the tunnel: under a perched water body and under a wash. The drips under the wash are significant, but only immediately after the wash is flowing. Our infiltration model has virtually no infiltration in washes; what infiltration there is in washes is basically put there as a fudge factor. (I don't want to be too critical here--I could probably tear apart any of our models. Did somebody say seepage? And [redacted] did do us a great favor n helping us out for [redacted])
[redacted]-flow model wrong? Looking at the same analog sites, we see that flow is not ubiquitous. It is in isolated paths, typically associated with locally saturated conditions. If flow is in isolated paths, we would get high chloride in the [redacted] almost everywhere we look (amd

14

From: [redacted]
PostedDate: 05/11/1998 03:44:35 PM
SendTo: [redacted]
CopyTo:
ReplyTo:
BlindCopyTo:
Subject: [redacted] Flow (+climate+infiltration) section for [redacted] document
Body:
FYI. Still don't know quite how to handle the air temp glitch. I'm continuing to keep mum about this, but, from a scientific integrity standpoint, it is tempting to let the end users know exactly what was provided to them in terms of effectivley cooler future climate simulations. Problem is, I don't know how to do this without looking bad. If we can let it all pass without trying to attach QTN numbers to these results (the prefered choice), then I can forget about it and just concentrate on getting results out for the new model. If they (DOE) force us to put DTNs on these things, I would rather the truth come out sooner than later.
Don't need to respond to this, we can talk about it later.
---------------------- Forwarded by [redacted] on 05/11/98 12:24 PM
[redacted]

[redacted]

From: CN=[redacted]/OU=YM/O=RWDOE
PostedDate: 10/29/1998 07:41:37 PM
SendTo: CN=[redacted]/OU=YM/O=RWDOE@CRWMS
CopyTo:
ReplyTo:
BlindCopyTo:
Subject: Re: Design Features 23/24 - Period of Effectiveness
Body:
enjoyed the ranting and raving. We're trying to work with the engineers because thats where the funding's going. Leveling the top of the mountain seemed humorous but it gave me the chance to make some more cool figures. This little task is history now. Wait till they figure out that nothing I've provided them is QA. If they really want the stuff they'll have to pay to do it right.
[redacted]

[redacted] To: [redacted]
11/15/1998 08:44 PM cc: [redacted]
Subject: Thanks for the cool refs

This email is currently marked "Relevant and Not Privileged"

These references are pretty cool. Thanks for leaving them. It looks like usable stuff. Why can't I do this? What's my problem?

Well, maybe its that I'm just now getting the stupid data package off to the correct person. I re-sent it to [redacted], who responded from a laptop in [redacted] that I should just re-send it to [redacted] which I just did. Pretty soon the QA experts will want to know where the [redacted] and [redacted] precip files came from.

Here they are: [redacted], [redacted] Don't look at the last 4 lines. Those lines are a mystery that I believe somehow relate to the work [redacted] was doing in entering the 1994 data. These lines are not used by [redacted] (we stop at 9/30/94). I've deleted the lines from the "official" QA version of the files (which do not have headers). In the end I keep track of 2 sets of files, the ones that will keep QA happy and the ones that were actually used.

The files are the output from the [redacted] database that [redacted] and I had put together, which I still have but haven't looked at since 1996. So either the [redacted] data package has to look a lot like those files or I'm going to have start talking about the [redacted] database when the QA questions start. My guess is that we do not want to deal with the [redacted] database.

Here it is almost 2000, and I am still struggling with work done in 1995 and 1996.

12/17/98 06:57 PM
Sent by: [redacted]
To: [redacted]
cc:
Subject: Re: [redacted]

FYI: The work plan PA has put together as a result of the meeting this week includes model hand-offs (TBVs documented using NLP 3-15s) which will all eventually be QA'd using [redacted] (see attachment below). [redacted] is going to be the PA lead on the [redacted] for the FY98 model. We're not sure how smoothly this is going to go but this is the approach. Like you've said all along, YMP has now reached a point where they need to have certain items work no matter what, and the infiltration maps are on that list. If USGS can't find a way to make it work, [redacted] will (but for now they are definately counting on us to do the job). [redacted] totally supports paying for a USGS report on the FY98 model, but they fully realize the problems we're having with the Director's approval thing.

I've had no response from [redacted] concerning my response to his request for an FY99 work plan using the close-out funds. [redacted] has indicated that I can charge all my time this year to the 10506 account. There was also good indication this week that [redacted] is willing to support us in FY00 to continue on with model validation and uncertainty work, and to deal with FEPs addressing the infiltration maps. The 110k provided to USGS was in direct response to the telecon and was specifically intended for infiltration modeling work. I can no longer wait for USGS to figure this out; I'm moving ahead according to the [redacted] work plan we put together this week.

What I really need now are some warm bodies to review the work I've been doing.

Like [redacted] said, "Live by the sword, die by the sword!".

From: [redacted]
PostedDate: 12/18/1998 05:25:24 PM
SendTo: [redacted]
CopyTo:
ReplyTo:
BlindCopyTo:
Subject: Re: AP [redacted]
Body:
Wow! Thanks for this very thoughtful and philosophically charged wealth of advice. I here exactly what you say. YMP is looking for the fall guys, and we are high on the list. I got a strong feeling at the [redacted] meeting that high level folks are starting to pay very close attention to who they will come after when things hit the fan. Who got how much funding at what time will all be long forgotten when the lawyers start challenging credibility of results. It was made clear that this will be like the OJ trial, where results are completely thrown out because of minor procedural flaws or personal attacks on credibility. As [redacted] told the lawyer who was there, YMP doesn't stand a snowball's chance in hell of making this work if that is the approach.
As far as the 98 and 99 modeling, I'm starting the write-ups now. Much of this is already being covered in the MLPs and APs so I can kill 2 birds with the same stone. I much as I think [redacted] may help us out with some things, I am going to be very careful that [redacted] doesn't end up taking credit for our work.

[redacted]
12/17/98 08:47 PM
To: [redacted]
cc:
Subject: Re: AP 3.10Q

I agree with your analysis. We only win if we get the final product out. I have to think through this carefully but where I'm headed is this. [redacted] and I will make sure we get the 96 report done (you need to call [redacted] ASAP, just in case she needs input from you on Friday). You, on the other hand, need to start the FY99 report, assuming the FY96 gets approved. You need to lay out the changes you've made to the model, how you've tested or calibrated those changes (stream gage, neutron (I've already started working on a new neutron hole analysis which I had hoped to finish this vacation but won't be done until later I'm sure)), what the results are, and what difference it makes. Do this for the site scale as your basis for the change to the model and as the basis of the report. Then start another report, which uses the first report, to lay out the regional model. Both report will address past and future climates. That's where I'm heading but I'm not there yet. We can discuss this tomorrow.
[redacted]
The bottom line is forget about the money, we need a product or we're screwed and will take the blame. EVERYBODY will say they told us to go ahead without a plan or budget in place (even though [redacted] said no hires). This is now CYA and we had better be good at it. I seem to have let this one slip a little to much in an attempt to cover all our work (and get us the hell out of the long term problem of Yucca Mountain) but now it's clear that we have little to no choice. In all honestly I've never felt well managed or helped by the USGS YMP folks, in fact, as you know, I've often felt abandoned. This time it's no different, or worse, and we have to work together to get out of this one. I'm still overwhelmed trying to protect the rest of the program from the ravages of what's happening in [redacted] (funding, which we seem to be blamed for because we got funding) and the current [redacted] fiascoes in the [redacted]. That is to say we're not working on our own as we have for the past 12 years, now were being threatened (and carefully watched) by the people who use to simply ignore us. These are very dangerous time, both funding wise and professionally. Mark my words on this one, it will not be long before our technical credibility with be challenged in an attempt to discredit us and redirect funding!
Oh, by the way, you did a great job in response to [redacted] request. Bravo!!

(keep my last paragraph prvate or among friends, if you know who they are)

[redacted]

To: [redacted] Tucson, AZ [redacted]gov>
cc: [redacted]

03/15/1999 12:18 PM Subject: Re: Tiger Team Hell

This email is currently marked "Relevant and Not Privileged"

[redacted]

[redacted] and I have been trying to figure out what's really coming at us with the tiger team effort. So far we've learned that they don't have a solid plan of action yet. I've formulated a "potential impact list" that is prioritized according to what work gets impacted 1st: 1. FY99 support to [redacted] (includes all the workshop stuff), 2. regional recharge report, 3. site-scale infiltration modeling report. Some of the work the tt effort calls for was scheduled under 22001 QA anyway, but we started hearing rumors of things like re-doing all the QA work for the neutron logging data, which will stop us dead in the water.

Now I'm going to give you the inside scoop: I'm going to continue the regional modeling, even if it means ignoring direct orders from YMP management. I'm also going to be working on reports, even if it means ignoring direct orders from YMP management. [redacted] and I have a pretty clear vision of the type of work that needs to be done to stay alive for the long-haul, and it very definitely involves getting product out there for the users and the public to see. The Death Valley regional modeling work fits that bill. Screwing around with tiger teams does not. In the end, its going to be the reports that move everything else forward. Tiger team efforts will just be vaporized.

So, the work may be slowed, but I will not let it stop. At this point, I am still working to the plan that we've all spent a significant amount of time on to make things happen for FY99. That's the insider scoop. The position we will take for the [redacted] planners may be much different. So delete this memo after you've read it..

[redacted]

From: [redacted]
PostedDate: 03/15/1999 10:14:50 PM
SendTo: [redacted]
CopyTo: [redacted]
ReplyTo:
BlindCopyTo:
Subject: Re: [redacted] Hell
Body:

This memo actually hits the nail on the head. You are exactly right: One, yes, we will do the work, Two, yes, screw the tiger team (I don't know how yet but I'll figure it out), Three, yes, destroy this memo!

[redacted]

03/15/99 12:18 PM
To:
cc: [redacted]

Subject: Re: [redacted] Hell

[redacted]

[redacted] and I have been trying to figure out what's really coming at us with the tiger team effort. So far we've learned that they don't have a solid plan of action yet. I've formulated a "potential impact list" that is prioritized according to what work gets impacted 1st; 1. FY99 support to [redacted] (includes all the workshop stuff), 2. regional recharge report, 3. site-scale infiltration modeling report. Some of the work the tt effort calls for was scheduled under [redacted] QA anyway, but we started hearing rumors of things like re-doing all the QA work for the neutron logging data, which will stop us dead in the water.

Now I'm going to give you the inside scoop: I'm going to continue the regional modeling, even if it means ignoring direct orders from [redacted] management. I'm also going to be working on reports, even if it means ignoring direct orders from [redacted] management. [redacted] and [redacted] have a pretty clear vision of the type of work that needs to be done to stay alive for the long-haul, and it very definitely involves getting product out there for the users and the public to see. The [redacted] regional modeling work fits that bill. Screwing around with tiger teams does not. In the end, its going to be the reports that move everything else forward. [redacted] efforts will just be vaporized.

So, the work may be slowed, but I will not let it stop. At this point, I am still working to the plan that we've all spent a significant amount of time on to make things happen for FY99. That's the insider scoop. The position we will take for the [redacted] planners may be much different. So delete this memo after you've read it.

[redacted]

From: [redacted]
PostedDate: 04/22/1999 09:52:39 PM
SendTo: [redacted]
CopyTo:
ReplyTo:
BlindCopyTo:
Subject: status of new climate net-infiltration modeling
Body:
I thought I'd give you a "heads up" on the progress of work I've been doing with the results you've provided. Model simulations have been in progress but about 3 weeks ago I found a small error in the model input that was generated using the [redacted] data. The error was minor but would have created a QA nightmare so this was fixed and the simulations are being re-done (I'll send you a summary of the results when I get to this point).
I am about to submit a "developed datapackage" milestone consisting of the climate input files (7 files for the 7 sites you identified) that are being used by the net-infiltration model. The input files are basically re-formatted [redacted] export files with a minor amount of parameter estimation occurring to fill small gaps in the record (even for the high ranking sites, there are gaps all over the place).
Here's the weird news; to get this milestone through QA, I must state that I have arbitrarily selected the analog sites. At first, I was going to include your email as supporting information in the data package, and discuss the work we did using the worksheets consisting of candidate sites, but since there is no [redacted] for your results the message I am getting from QA is that I can't use or refer to those results. In other words, I was trying to give you credit for your part in all this, as well as provide all info possible for the traceability of the analog climates, but this seems to create problems rather then solving them.
So for the record, the seven analog sites have been arbitrarily (randomly) selected. Hopefully these sites will by coincidence match the sites you have identified.
[redacted]

P.S. please destroy this memo

[redacted]

From: [redacted]
PostedDate: 04/23/1999 08:56:58 PM
SendTo: [redacted]
CopyTo:
ReplyTo:
BlindCopyTo:
Subject: [redacted] help
Body:
I have to run this by you because I promised [redacted] and [redacted] that I would get back to them with a game plan next week:
[redacted] [redacted] and [redacted] are pushing me to get the QA work in place for the products they need from me and are suggesting that they can help me out with software QA issues and all the grunt work required to just do the modeling runs so that needed products can be finished for the modelers to use. They realize that I am somewhat overloaded with this task so they are willing to provide us resources in terms of computing power and warm bodies doing QA and running the code. The catch for us is that the [redacted] code will be on [redacted] (they can dedicate [redacted] [redacted] do the number crunching.... they will give us accounts so that we can [redacted] to these machines). I have been given a verbal promise that we will not lose control of the code, and the goal is to get the job done, not to take over our work. The [redacted] personnel would in essence be working for us, not the other way around.
I am thinking that If I want to remain viable team player on YMP (which may translate to continued funding), I need to show that we can get the job done and provide the modelers with the results they need. This is not going to happen if I rely solely on USGS YMP resources. For example, [redacted] can dedicate a person to do all of our software configuration management stuff and help us out with input parameter QA issues. This strategy sounds much more appealing to me now because I'm getting the impression that unlike USGS QA, the labs have the QA resources to actually get in there and do the work, instead of just creating more work for the [redacted] to do.
The other option would be to stall, and then when I'm in [redacted] I will just ignore all this, and we can let the site scale modeling go down the tubes. Dealing with this QA bullshit is really starting to make me sick.

From: [redacted]
PostedDate: 04/22/1999 06:43:32 PM
SendTo: [redacted]
CopyTo: [redacted]
ReplyTo:
BlindCopyTo:
Subject: Re: QA
Body:
What if you just download the raw files from [redacted] and say you used those?
Do they need to know any more than that? You don't really need to do an analysis just say this is the data I used. Maybe that would work.
[redacted]

[redacted]
04/22/99 03:27 PM
To: [redacted]
cc: [redacted]
Subject: QA
The QA bullshit grows deeper. I may need to say that I did everything by hand for the data package I am submitting that You and [redacted] reviewed. The program I wrote is not in the system and QA will be all over it like flies on $$$.
All references to [redacted] are being deleted.
Here's my question: When we go to start QA'ing the site-scale modeling work, will I get taken to the cleaners because I am not referencing either a tech procedure or a scientific notebook? In other words, would it be cost-effective to create a SN for the site-scale work and back-date the whole thing??
Can't wait to be far-far away from here!
[redacted]

[redacted] has been the main force behind dealing with the latest round of editorial reviews and pushing the report forward. When Director's approval is granted, I am assuming the FY96 model will be in the [redacted], although we may be required to submit additional supporting information (we are still in the process of finding this out). There is also a chance that the report will not be approved, and will require additional work and/or modifications. Unfortunately, the process of Director's approval is largely beyond our control. Past experience has shown that it is always best to assume additional work and/or modifications will be needed. At any rate we are still hoping for end of December on this, but cannot make any guarantees. If additional QA work is needed, it may become a problem because at present we are not in a good position to do this. I'd say a 50% probability of completion.

he 96 model includes only the current climate base-case net infiltration ap, and a wet and dry year current climate simulation. We still need ntil April to get the 97 future climate 100-year simulations into the DMS. Again, no guarantees, especially in light of major uncertainties that continue to exist, and thus I can only give a 50% probability of completion.

Bottom line is, our position for making any FY99 commitments at all is still poor to nonexistent.

From: [redacted]
PostedDate: 04/26/1999 02:40:15 PM
SendTo: [redacted]
CopyTo: [redacted]
ReplyTo:
BlindCopyTo:
Subject: Re: Recharge Emergency
Body:
I have the [redacted] files here. Not sure I know about the power-point format.
Something will be sent within the next 15 minutes.
Did you get the overnight.
Also, much bullshit is getting generated by the developed data package you reviewed. The USGS has already far exceeded the cost benefit ratio for this product.
[redacted]

[redacted]
09/28/99 05:21 PM
To: [redacted]
cc: [redacted]

Thanks for the enlightenment, [redacted]. I was definitely under the wrong impression on the work being done for SR and also regarding the nature of the P and T trends with a climate change.

Looking back over my emails i see that I misstated what was a discussion of changes relative to previous assumptions, NOT true out of that specific context. In fact, out of that context the opposite was true. The non-traceable and non-transparent statement after it was disconnected from its parent context and became flat-out wrong.

Now the real question is: is the climate [redacted] going to meet the need for the [redacted] and the [redacted] to have long term climate states (and infiltration changes accompanying those states) that are defensible???

I think showing it doesn't matter from a [redacted]-dose perspective is not sufficient to establish whether or not this part of the analysis is credible and has a defensible basis. We would all agree that showing that it has no impact on system performance does lower the burden of proof necessary to support the modeling (the confidence-burden), however.

Finally, the agreement to show only 10,000 year calculations in [redacted] and [redacted] is not an agreement that DOE was aware of at the upper levels of management, and is being revisited. We will likely need to show calculations, up to peak dose if necessary, in all 3 documents, if they clarify the content of the 10,000 year calculation. This is a dialogue that needs to be had internally, but my announcing to the NRC that we would do 10,000 years only led to a very negative reaction and caused a negative counterreaction in DOE management. NRC said whatever parts of the [redacted] they need to consult to understand the 10K year calculation will need to be Q, and the reaction of DOE management on the scene was -- OK, let's put all of that in the [redacted] and [redacted] rather than make the FEIS a Q document!

[redacted]
01/06/2000 04:01 PM
To: [redacted]
cc:
Subject: Re: AMR[redacted]

This email is currently marked "Relevant and Not Privileged"

[redacted] called. Yes, this is really happening. [redacted] and [redacted] will help but it seems I am stuck going to [redacted] on the [redacted] ([redacted] and [redacted] will also go for moral support). Responses to the [redacted] comments are due on the [redacted]

There is, of course, no scientific notebook for this work. All work is in the form of electronic files. I can show auditors input, output, and program files, but it is not clear to me how to show documentation of work in progress. They may be expecting to see something that at least looks like a scientific notebook documenting work in progress. I can start making something up but then the [redacted] projects will need to go on hold.

If I continue placing [redacted] tasks as 1st priority for January, I will be ill prepared for the audit, and will likely get hammered. That's fine by me. I am far more concerned about the [redacted] projects than I am about the [redacted]. But [redacted] will be rather unhappy, and I will need help trying to figure out a good excuse why 100% of my time did not go into the audit without revealing the [redacted] projects.

I am open for suggestions.

[redacted]

From: [redacted]
PostedDate: 03/07/2000 11:09:00 PM
SendTo: [redacted]
CopyTo:
ReplyTo:
BlindCopyTo:
Subject: developed daily precip record
Body:
believe it or not, this file is now 3.5 years old, but it is what was used. This developed record stops on day 274, 1995. The only real good thing about this file is we seem to be very close to getting it into the TDMS (the data was developed in a [redacted] turned to [redacted] worksheet that may now be required to go through qualification as a software routine, so things have yet again stalled). Someday I hope to have the time to update this to include an improved pre-1987 interpolation and all the new data after 1995, which includes some interesting events...... back to QA.
P.S. Hope this email doesn't trigger a [redacted] input request. I'll probably get fired.

Attachment: [redacted]

[redacted]
03/09/2000 07:39 PM

To: [redacted]
cc: [redacted]
Subject: vegcov01

This email is currently marked "Relevant and Not Privileged"

[redacted] has a user option which when set to 0 the vegtypes in the file [redacted] (created by the damn routine [redacted]) are ignored and a veg-cover term of 30 is just assumed. The real stupid thing is that this value is never used because the veg cover stuff (root-zone parameters) all get defined in the control file. The veg-type and veg-cover columns are just dummy place holders that are not even used by [redacted] (remember all those great ideas about correlating something, anything, to vegetation....). But because vegcov01 is where the bedrock ks is adjusted I have to drag the routine into the AMR. Damn it!

The main stupid thing is that as a 1st step I ran [redacted] with the user option set 2 to create [redacted] from [redacted], the output from [redacted]. This setting causes a veg cover estimate to be made based on vegtyp01, which are the vegtypes defined for the regional model (data from [redacted] and [redacted]). I was desperately trying to bring vegetation into the picture (still wasn't getting what I needed from the bugs and bunny crowd) but it didn't match up as well as I had hoped. I ran out of time, and it fizzled.

Now here is the majority stupid part. To create [redacted], which is used as input to [redacted], I re-ran [redacted] using [redacted] as input and set the option to 0. So the regional vegtypes made it into all the watershed files that were used in the AMR. Now I can't just re-write the routine to leave out vegtyp01 because the output will never match what ended up becoming the watershed files. Had I re-run [redacted] using [redacted], I could now re-write the code in 5 minutes, get rid of [redacted] altogether, and all would be cool.

So I would like to keep [redacted] as is, tell the story just as it happened, and then explain that we don't have to trace [redacted] because it was not used (we cannot bring [redacted] into the picture because then we have to deal with the input file which is the geospatial input file for the [redacted] region!). In fact we can just not even talk about the vegtype and vegcover stuff and just say those are dummy place holders that are never used so they don't need to be traced.

On second thought...do whatever you want. At this point I cannot re-produce the blocking ridge numbers using [redacted] and I have yet to re-visit the elevation stuff [redacted] was finding and who knows what will happen if we tried to run [redacted] on any of the source data going into the [redacted]. There is a bug in the top layer of the cascading bucket model, the soil ks conversion is off by a factor of 10, and even if I can re-produce the blocking ridges they're still wrong. Then there are those strange non-integer values that I saw for the 1st time in the Days and others input file during my testing of [redacted]. What is rock-type 1.33??? Oh yeah, the [redacted] data .... Jesus! I'm going nuts again! I'm going home now!

[redacted]

From: [redacted]
PostedDate: 03/30/2000 06:48:01 PM
SendTo: [redacted]
CopyTo: [redacted]
ReplyTo:
BlindCopyTo:
Subject: Installations
Body:
[redacted],
The programs, of course, are all already installed otherwise the AMR would not exist. I don't have a clue when these programs were installed. So I've made up the dates and names (see red edits below). This is as good as its going to get. If they need more proof I will be happy to make up more stuff, as long as its not a video recording of the software being installed.
[redacted]
---------------------- Forwarded by [redacted] on 03/30/2000 03:39 PM ---------------------------

[redacted]
[illegible]/2000 03:48 PM

To: [redacted]
cc: [redacted]
Subject: Installations

This email is currently marked "Relevant and Not Privileged"

[redacted],
The programs, of course, are all already installed otherwise the AMR would not exist. I don't have a clue when these programs were installed. So I've made up the dates and names (see red edits below). This is as good as its going to get. If they need more proof I will be happy to make up more stuff, as long as its not a video recording of the software being installed.
[redacted]

MOL.19980217.1087 is incomplete in that it does not contain all the information identified as part of the Records Package Cover Sheet. An Acceptance Inspection Report is among the missing information from the record. The record also contains a procurement Final Procurement Review for the calibration of a Keithley Digital Multimeter, Model 2001 that was completed prior to the receipt of the equipment and the equipment calibration, which does not appear appropriate.

MOL.19980217.1041 does not provide as found and as left data, does not include the acceptance criteria, it is not clear which LOT number this record is for (LOT M02210377), the calibration date should be established as the date when the form is completely approved (May 15 not May 14), the "Contents of Record" field states "S/Ns 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12" when it should read ID Nos. 1 through 14, and the third page of the record contradicts pages 1 and 2 with respect to the calibration date and M.O. number (M.O. G036220 vs. M.O. G033390). The calibration date and M.O. number discrepancies would lead an auditor to believe the record had been falsified. It gives the appearance that the proper signature page is not available and another record's signature page was used in its place. In fact, the signature page is the same as attached as page 3 to MOL.19980217.1042.

ALB.20050220.2577, EML1018

From: [redacted]
PostedDate: 04/22/1999 06:27:50 PM
SendTo: [redacted]
CopyTo: [redacted]
ReplyTo:
BlindCopyTo:
Subject: QA
Body:

The QA bullshit grows deeper. I may need to say that I did everything by hand for the data package I am submitting that You and [redacted] reviewed. The program I wrote is not in the system and QA will be all over it like flies on &%$. All references to [redacted] are being deleted.

Here's my question: When we go to start QA'ing the site-scale modeling work, will I get taken to the cleaners because I am not referencing either a tech procedure or a scientific notebook? In other words, would it be cost-effective to create a SN for the site-scale work and back-date the whole thing??

Can't wait to be far-far away from here!

[redacted]

[redacted]

[redacted]
12/17/98 05:57 PM

Sent by: [redacted]

To: [redacted]
cc:
Subject: Re: AP 3.10Q

FYI: The work plan [redacted] has put together as a result of the meeting this week includes model hand-offs ([redacted] documented using [redacted] which will all eventually be QA'd using [redacted] (see attachment below). [redacted] is going to be the [redacted] lead on the [redacted] the FY98 model. We're not sure how smoothly this is going to go but this is the approach. Like you've said all along, YMP has now reached a point where they need to have certain items work no matter what, and the infiltration maps are on that list. If USGS can't find a way to make it work, Sandia will (but for now they are definately counting [illegible]). [redacted] totally supports paying for a USGS report on the FY98 model, but they fully realize the problems we're having with the Director's approval thing.

I've had no response from [redacted] concerning my response to his request for an FY99 work plan using the close-out funds. [redacted] has indicated that I can charge all my time this year to the [redacted] account. There was also good indication this week that [redacted] is willing to support us in FY00 to continue on with model validation and uncertainty work, and to deal with [redacted] addressing the infiltration maps. The [redacted] provided to USGS was in direct response to the telecon and was specifically intended for infiltration modeling work. I can no longer wait for USGS to figure this out; I'm moving ahead according to the PA/Sandia work plan we put together this week.

What I really need now are some warm bodies to review the work I've been doing.

Like [redacted] said, "Live by the sword, die by the sword!".

KENNY C. GUINN
Governor

STATE OF NEVADA

ROBERT R. LOUX
Executive Director

OFFICE OF THE GOVERNOR
AGENCY FOR NUCLEAR PROJECTS
1761 E. College Parkway, Suite 118
Carson City, Nevada 89706
Telephone: (775) 687-3744 • Fax: (775) 687-5277
E-mail: nwpo@nuc.state.nv.us

November 18, 2005

EPA Docket Center (EPA/DC)
Air and Radiation Docket
U.S. Environmental Protection Agency
EPA West, Mail Code 6102T
1200 Pennsylvania Ave, NW.
Washington, DC 20460

Attention: Docket ID No. OAR-2005-0083

To whom it may concern:

In response to EPA's Federal Register Notice of August 22, 2005 (Federal Register / Vol. 70, No. 161 / Monday, August 22, 2005 / Proposed Rules), enclosed please find the State of Nevada's formal comments on EPA's "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada; Proposed Rule" (40 CFR Part 197).

After an exhaustive review process that encompassed EPA's proposed rule, as presented in the Federal Register Notice, as well as the reference materials cited in that Notice, Nevada concludes that EPA's proposed standard is inconsistent with the recommendations of the National Academy of Sciences (as required by the Energy Policy Act of 1993) and the July 9, 2004 ruling of the U.S. Circuit Court of Appeals for the District of Columbia. Not only is the proposed rule illegal, but it stands in stark opposition to three decades of environmental regulatory practice, contradicting EPA's own historical approach to public health and environmental protection and setting a disturbing and dangerous precedent for future regulation of radiological and hazardous materials.

Nevada concludes that EPA has no alternative but to withdraw the proposed rule and reissue a new draft standard that abandons the arbitrary and scientifically unjustified bifurcated radiation exposure limits; that continues strict groundwater protection requirements through the period of maximum exposure; that eliminates statistical gerrymandering through the use of median vs. mean calculations; that removes inappropriate and illegal intrusions into the NRC regulatory arena; and that returns to EPA's historical approach to radiation and environmental protection.

The only scientifically and legally supportable way to bring EPA's Yucca Mountain rule into compliance with the Court's directives and the NAS recommendations is to extend the 15millirem per year maximum exposure threshold, together with the 4 millirem groundwater protection requirement, through the period of maximum projected releases for the Yucca Mountain facility. This simple and straight-forward approach is the one Nevada recommended to EPA even before the current proposed standards was released. It remains the ONLY possible course of action that can result in a legally, scientifically and morally defensible radiation health protection regime for the proposed Yucca Mountain facility.

Sincerely,

Robert R. Loux
Executive Director

RRL/cs
Enclosures
cc Nevada Congressional Delegation
U.S. Nuclear Waste Technical Review Board
U.S. Advisory Committee on Nuclear Waste
Samuel Bodman, Secretary of Energy
David R. Hill, General Counsel, U.S. Department of Energy
Dr. Ralph J. Cicerone, President, National Academy of Sciences
Dr. Lars-Erik Holm, Chairman, International Commission on Radiation Protection
National Conference of Radiation Control Directors
National Council on Radiation Protection and Measurements

COMMENTS BY THE STATE OF NEVADA ON EPA's PROPOSED NEW RADIATION PROTECTION RULE FOR THE YUCCA MOUNTAIN NUCLEAR WASTE REPOSITORY

November 2005

Prepared by the Agency for Nuclear Projects
Office of the Governor
1761 E. College Parkway, Suite 118
Carson City, NV 89706
(775) 687-3744

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Appendix H
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Appendix I
Las Vegas Day 1 EPA Public Hearing 10/04/2005

(Appendices H and I are DVD's which will be submitted via Federal Express.)

I. Executive Summary

A. Overview of Proposed Rule

On August 9, 2005, the Environmental Protection Agency ("EPA") announced a second proposed rule setting forth the primary radiation protection standard to be used in evaluating the safety of the proposed Yucca Mountain nuclear waste repository in Nevada ("Yucca."). The new proposal, published on August 22, 2005, emerges as EPA's misguided attempt to respond to a 2004 court ruling that had invalidated the Agency's first Yucca radiation protection rule. 70 Fed. Reg. 49014.

In *Nuclear Energy Institute, Inc. v. EPA,* 373 F.3d 1251 (D.C. Cir. 2004) ("*NEI*"), the Court of Appeals for the D.C. Circuit (the "Court") vacated both the original EPA Yucca rule and the corresponding Nuclear Regulatory Commission ("NRC" or "Commission") radiation protection standard. The Court found that these rules, which terminated their compliance periods after 10,000 years, (a) were not "based upon and consistent with" recommendations of the National Academy of Sciences ("NAS" or "Academy"), as Congress required in the Energy Policy Act of 1992 ("EnPA"); and (b) did not protect against the anticipated peak radiation risks that are expected from the repository after man-made waste packages fail.

Just one day after the EPA announced its new rule, and in lockstep with the Department of Energy ("DOE") and EPA, NRC Staff on August 10 recommended to the Commission that NRC adopt as its new radiation protection rule for the licensing of Yucca an almost identical version of the proposed new EPA rule. On August 30, the Commission approved in a Staff Requirements Memorandum the same proposed NRC rule that its staff had recommended. SRM on SECY-05-0144 (Aug. 30, 2005).

The new standard proposed by EPA and NRC is nearly identical to the previous one. It suffers from virtually the same legal and scientific defects (and more) as the standard rejected by the Court and the Academy. The old rule established a 15 millirem/year individual protection standard for the first 10,000 years, and no limit thereafter. The new rule establishes the same 15 millirem/year standard for the first 10,000 years, and an extremely (and unprecedentedly) high 350 millirem/year standard thereafter. The old rule included no groundwater protection standard after 10,000 years, and that remains true for the new rule.

The disparity between the radiation dose limits before and after 10,000 years actually becomes far greater than the 23-fold difference between 15 and 350. That is because the *method* EPA directs for determining compliance with the "350" sharply diverges from that used for determining compliance with the "15," making the 350 millirem/year standard the functional equivalent of a much higher number, one so high that it affords essentially no public protection at all. EPA's new rule is not even health-based, as the law requires, because EPA's new compliance method would approve of the Yucca repository without regard for many of the actual radiation doses persons will suffer from it.

DOE can only predict long-term repository performance from the results of numerous computer simulations. Because these simulations produce different projections of dose rates in the accessible environment over long periods, DOE must use a statistical measure to summarize the disparate results. Under the proposed rule, the projected radiation doses before 10,000 years would be evaluated against the 15 millirem/year limit using the *mean* results of these various performance predictions, as NAS explicitly recommended. Yet, contrary to the NAS's recommendation, the doses after 10,000 years would be evaluated against the 350 millirem/year limit under a different statistical measure, using the *median* results of the performance predictions. This is no small variance. Because the median of DOE's Yucca performance predictions is nearly three times lower than the mean, the new median standard equates to 1000 millirem/year in mean-equivalent terms, or *70 times less stringent* than the 15 millirem/year standard EPA has for decades defended as appropriate to protect human health.

EPA's new rule would impose on future generations the laxest radiation protection standard in the world for a nuclear waste repository. The long-term individual protection standard would permit doses far higher than those EPA has consistently, until now, recognized as damaging to public health. The dose permitted at Yucca would be roughly *ten times* greater than what EPA, NRC and other regulatory bodies have previously allowed for *all* non-medical anthropogenic radiation sources combined.

EPA claims its new standard will provide adequate protection because its nominal second-tier limit would extend out to one million years. But the risks of EPA's lax second-tier standard are in fact not temporally distant ones, as EPA implies. In addition to providing essentially no protection for the long period after 10,000 years, EPA's new rule also *provides essentially no protection for the period before 10,000 years either.* This is because the timing of the predicted peak dose is simply an artifact of DOE's computer modeling runs. These runs depend entirely on DOE's optimistic predictions that its "miracle metal" waste containers, which have been tested only for short periods in laboratories, will not corrode in the hot, relatively humid, acidic repository environment at Yucca until after 10,000 years.

If that key assumption proves wrong, as EPA recognizes is possible, the peak may occur much earlier. But there is no backup in that case, because the rule lacks any requirement for "defense in depth," the *sine qua non* of nuclear safety and a principle both EPA and NRC claim to support. Defense in depth is necessary because once a repository is created, its impacts cannot be undone by future corrective actions. Thus, if Yucca is designed and licensed based upon a lax long-term dose limit of 350 millirem/year (1000 millirem/year mean-equivalent), people in thousands or even hundreds of years may be exposed to these or much higher levels of radiation. This regulatory failure becomes not just a problem for societies hundreds of thousands of years from now; it becomes an immediate problem for our great-grandchildren and their children.

While the proposed rule is indefensible from any standpoint of public health protection, it makes perfect sense in one respect: DOE's performance models suggest that once its Yucca waste packages fail, a median peak dose of around 300 millirem/year is likely. Not coincidentally, EPA proposes a standard just lax enough to narrowly "pass" the repository for an NRC construction permit, despite long-term radiation releases that would fail any other domestic or international public health standard. As with its prior rule, EPA has ignored the risk to life and health from radiation leakage from the proposed DOE repository and has tailored the licensing standard to fit comfortably above DOE's performance projections.

Somewhere along the way, EPA came to believe that its job was to facilitate the licensing of Yucca Mountain rather than to objectively evaluate its safety to human beings and the environment. Everything about the new EPA rule places expediency above public responsibility, and cynicism above science and the law.

B. Key Concerns with the Proposed Rule

EPA's new rule has numerous fatal defects. Among other things, and as explained further below, the proposed rule has the following problems:

- ***Failure to Adopt NAS's Peak Dose Recommendation.*** As the Court emphasized, NAS could hardly have been clearer that EPA's public health standard should remain in effect through the period of peak dose, and that no scientific basis exists to curtail that standard at 10,000 years. Like the old rule, the new one abruptly abandons EPA's health-based dose standard after 10,000 years with no scientific justification. The substitution of a second-tier standard 70 times less stringent, without scientific support, is an obvious effort to circumvent the "peak dose" approach referenced by the NAS and the Court, so as to "pass" the repository. In short, EPA has simply replaced an infinite dose standard, which cannot be violated as a matter of theory, with an extremely lax standard which (it thinks) cannot be violated in practice. In neither case will the standard provide any satisfactory test of geologic isolation.

- ***Failure to Adopt NAS's Statistical Measure Recommendation.*** Contrary to NAS's specific recommendation, the rule permits repository designers to design Yucca based on the anticipated *median* results of DOE's post-10,000-year performance analyses, rather than the *mean* results (or "expected values") of those analyses. This is directly contrary to the NAS's recommendation that the mean be used, and is unsound from the standpoint of elementary statistical science and mathematics.

- ***Failure to Adopt the NAS's Exposure Recommendations.*** The level of human exposure after 10,000 years permitted by the new rule far exceeds 2 to 20 millirem/year, which EPA previously recognized as the NAS's recommended acceptable range of radiation exposure. Until now, EPA has expressly adhered to that range. But EPA's proposed rule would exceed that range by a factor of between 17 (for the median) and 52 (for the mean), taking the high end of the recommendation. The new higher level, allowing a large number of additional cancer deaths over time, violates EnPA and the clear instructions of the Court.

- *Violation of EPA's Own Public Health Protection Standards.* In its prior Yucca Mountain rulemaking, EPA expressly rejected a two-tier regulatory approach applying a 150-millirem standard past 10,000 years, finding that neither EPA nor any other regulatory body would consider such a limit acceptable. EPA also rejected proposed standards of 70 millirem/year and even 25 millirem/year as providing insufficient protection of public health. EPA now does an about-face with no rational justification. Its new standard is so weak and inconsistent with long established national concepts of radiation protection that the President of the prestigious National Council on Radiation Protection has publicly opposed it.

- *Weakest Standard in the World.* EPA's proposed radiation protection standard would be the weakest peak dose standard applied anywhere in the world. It exceeds the maximum acceptable radiation exposure from man-made sources in all industrialized countries, and the proposed cleanup standard for other DOE sites with radioactive waste, roughly by a factor of 10.

- *Abandonment of NAS and International Consensus on Apportionment.* The NAS Report, OAR-2005-0083-0076 (hereinafter the "NAS Report"), identifies a "general consensus" among national and international bodies on a framework for public health protection from radiation releases. EPA has until now joined in this consensus, limiting to 100 millirem/year the amount allowed for continuous or frequent exposures from all non-medical anthropogenic radiation sources. The fraction of that total typically allocated to high-level waste disposal is 10 to 30 millirem/year. In flagrant violation of this apportionment principle, the proposed rule would allow a single source to far exceed the amount that could safely come from all sources. EPA discards its past positions without any rational justification.

- *Abandonment of Groundwater Protection.* The new standard would abandon any groundwater protection standard just after 10,000 years, arbitrarily eliminating this protection in the very manner criticized by the Court. Ironically, EPA successfully defended in Court (against a challenge by the Nuclear Energy Institute) the application of a separate groundwater standard for the repository. Now, it arbitrarily abandons that very standard after 10,000 years.

- *Misinterpretation of the Importance of Uncertainty.* The centerpiece of EPA's rule defense—an appeal to "uncertainty"—is untenable on multiple levels, and provides no foundation for the proposed rule. Uncertainties in the Yucca Mountain setting do not increase materially after 10,000 years. Moreover, even if there were a substantial increase in uncertainty, EPA fails to explain rationally how this would justify a looser standard rather than a conservative, protective one that applies through peak dose. EPA's use of the term "uncertainty" is chronically vague and fails to acknowledge that all of Yucca's uncertainties support a *more protective* rather than a loosened standard. Once again, EPA has departed from past positions with no rational reason. Moreover, EPA's assertions about uncertainty largely recycle positions that were already considered and rejected by NAS and the Court.

- *Rejection of Conservative Analysis.* EPA fails to provide any rational grounds to support its puzzling notion that a perceived over-conservatism in DOE's computer modeling somehow supports adoption of a lax radiation standard. There is no scientific basis for the proposition that conservatisms will necessarily increase after 10,000 years; in fact, the opposite is just as likely, or more likely. Moreover, to the extent conservatisms are unavoidable because of a lack of scientific knowledge, the rule never explains why EPA's traditional use of conservatism or bounding assumptions in the face of uncertainty would not be more appropriate. And information from EPA's key source on uncertainty, the Cohen report, confirms that, far from being conservative, DOE's modeling contains enormously optimistic assumptions about repository performance, particularly on the issue of corrosion of DOE's waste packages.

- *Certain Collapse of the Rule.* EPA bases its selection of 350 millirem/year on its conclusions about uncertainty and conservatism after 10,000 years. These conclusions are based on DOE's analyses that are relatively old and undergoing reevaluation. EPA fails to account for the likelihood that the analyses that DOE will use in its license application, or the analyses that NRC will rely on in its licensing decision, will be dramatically different from the ones relied on in the proposed rule. To the extent these are different, the essential premises for the EPA rule will disappear, with the result that the 350 millirem standard cannot possibly apply. At the very least, EPA must provide that its 15 millirem standard for the pre-10,000 year period will continue to apply in the post 10,000-year period if the pre- and post-10,000 year period performance assessments DOE uses in its application (or the ones used by the NRC in its licensing decision) exhibit essentially the same amounts of uncertainty or conservatism.

- *Misuse of Natural Background.* The proposed rule offers a spurious analogy to natural background radiation levels that is inconsistent with EPA's past practice, and is also predicated on a series of unsupported assumptions, including a misunderstanding of the role of radon in natural background radiation and an arbitrary selection of Colorado as a benchmark for comparison. In the past, EPA and other national and international radiation standard setting organizations have rejected such comparisons in defining acceptable levels of risk, and EPA offers no rational explanation for its change in position. Moreover, even if natural background or natural background variations were somehow considered relevant, EPA cannot explain how they are uniquely relevant to the post-10,000 year period.

- *Abandonment of Intergenerational Equity.* The new standard wrongly assumes it is ethically permissible, and consistent with EPA's duty to protect public health, to expose future generations to radiation levels far higher than we would tolerate today. EPA even attempts to fashion a "minimal" principle of intergenerational justice from sources that would offer a far higher regard to future generations than does the proposed rule. This is contrary to prior EPA positions without rational explanation, violates national policy expressed in NEPA, and violates an international convention on high-level radioactive waste disposal to which the United States is a party.

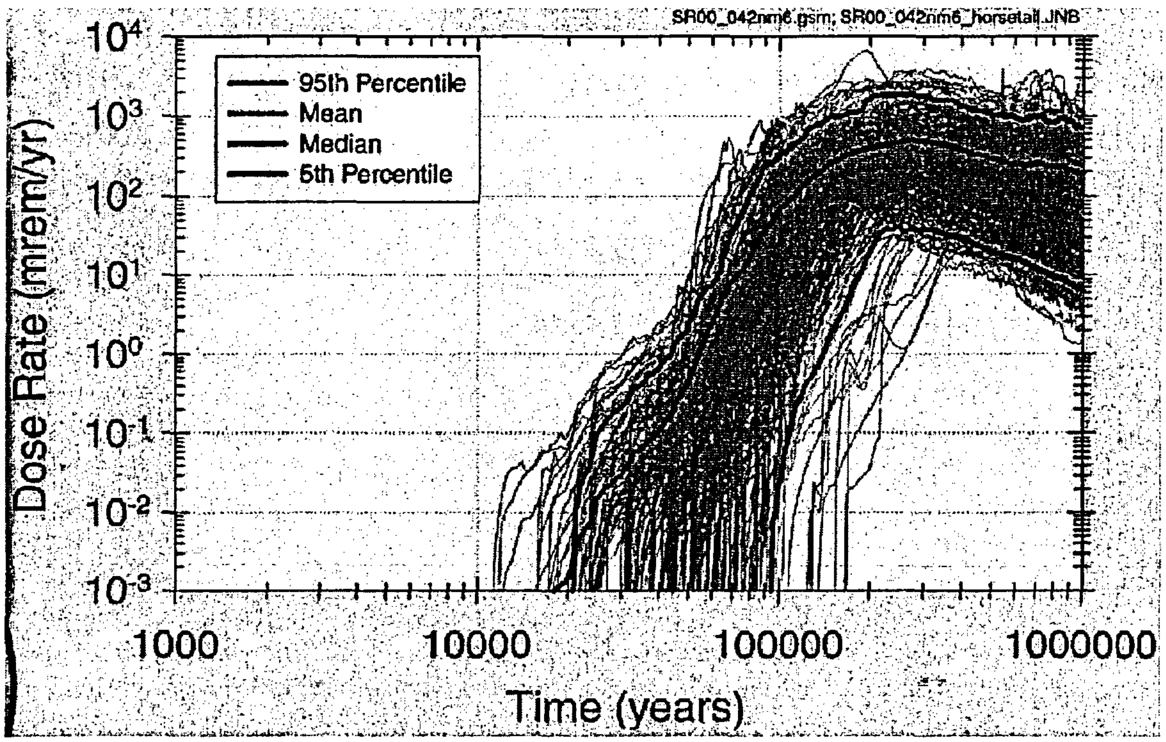
- *Untenable Modeling Constraints.* EPA proposes a series of modeling constraints that themselves violate NAS's recommendations. These constraints (arbitrary limitations on the NRC's selection of FEPs, or "features, events, and processes") also contain unexplained categorical exclusions and cannot be squared with sound science. Moreover, the effect of these constraints (especially the one limiting future climate states) is to eliminate the very uncertainties EPA uses to justify 350 millirem/year, making EPA's rule internally inconsistent.

- *Actions in Excess of Statutory Authority.* EPA's proposed rule would exceed the agency's lawful authority, intruding into DOE's role of preparing a licensing application and the NRC's role of resolving adjudicatory facts and making a licensing decision. Lacking statutory authority, EPA also proposes unlawfully to delegate part of its own rulemaking authority to the NRC.

- *Violation of the Information Quality Act.* EPA's proposed rule relies almost entirely on a single "scientific" study prepared by a consulting firm. That study was never subjected to peer review, in clear violation of the Information Quality Act. It is an unabashed repository advocacy piece riddled with errors and biases.

C. A Picture Worth 10,000 Words: Fitting the Standard to Yucca's Inferior Geology

The figure below, summarizing DOE's numerous performance projections for the Yucca repository, shows projected peak radiation doses from Yucca as a function of time, assuming DOE is correct in its optimistic assumption that its waste containers will last for at least 10,000 years. Nevada has added curves showing the mean and the median results of the performance runs over time. This figure is adapted from the Figure 12.1 of EPA's Cohen Report, which reproduced it from DOE's SSPA, Volume 2, Figure 3.1.2-1.



The figure illustrates several key points:

- **EPA has constructed its standard to fit the projected dose curves.** The standard is stringent when DOE assumes, based on optimistic projections of waste container longevity, that no releases will occur (those assumptions explain the non-existence of projected doses during the first 10,000 years). It is lax when DOE assumes a higher degree of threat.

- **There is no apparent large increase in uncertainty after the time of peak dose, as measured by the distance between the 95% and 5% curves.** The large uncertainty prior to the peak dose is the uncertainty associated with the projected time of waste container failures.

- **The selection of the median is outcome-determinative.** At peak dose, the mean is approximately three times greater than the median (note that the scale of the Y axis is logarithmic), and is well above even a lax 350 millirem/year standard.

- **The standard would impose an enormous intergenerational burden.** After peak dose occurs, mean and median dose levels decline only gradually for the next 800,000 years (again, note that the scale of the X axis also is logarithmic). This is because radioactive contamination continues to leak from the site over a very long period. Thus, for hundreds of thousands of years—a period more than two orders of magnitude greater than the entire history of human civilization—dose levels will remain close to peak dose. However, the benefits—if there are any—would only be realized by current generations.

- **If DOE is wrong about its waste containers, the 15 millirem/year standard will be grossly exceeded well before 10,000 years.** The figure illustrates that, if the waste containers fail in the first thousand years, dose rates will exceed 15 millirem/year and rise rapidly to mean levels of approximately 1000 millirem/year within 10,000 years. If waste containers fail in 200 years or less, as Nevada's eminent corrosion experts believe will happen, the human population will not have to wait for hundreds of generations to witness overexposures. Such overexposures will occur much sooner.

II. <u>Explanation of the Rule's Function</u>

To appreciate the importance of the rule proposed by EPA, and the implications of its many flaws, some understanding of how this rule will function is helpful.

To obtain a license for Yucca Mountain, DOE will have to use computer *simulations* and *predictions* to demonstrate, to the satisfaction of NRC, that its repository will likely comply with the standard EPA sets. Those computer simulations will be based on mathematical models, assumptions, and, sometimes where data is lacking, on "expert elicitation." If the simulations produce a reasonable prediction of compliance, NRC may assume that reality will correspond to the simulations and will grant DOE a license to construct the repository. It is essential that the standard, and the related NRC compliance determination, be sufficient to distinguish a safe repository from an unsafe one. To do this it is required that the standard and compliance regime be sufficiently robust to test the sufficiency of all of the proposed engineering and natural barriers.

DOE will not, however, be able to take future actions to actually guarantee compliance with EPA's safety standards. Because Yucca Mountain's wastes will remain lethal for, and likely outlast the Department of Energy by, millennia, and because those wastes will be buried deep within the ground, in an irretrievable fashion, DOE cannot guarantee that it or anyone else will always be able to monitor the site or take protective measures to ensure that EPA's dose limit is not exceeded. In fact, the NAS specifically rejected basing Yucca standards on assumptions about future generations' abilities to monitor the site and to take additional protective actions. And while future societies' behavior is inherently unknowable, the societies that suffer the brunt of Yucca Mountain's risks also may have no ability to impose their own engineering controls or safety standards on the waste. Indeed, because the site will be concealed deep beneath the ground, they may suffer the consequences of its failure without even knowing that it exists. If the site fails, these future generations probably will be able to do little or nothing about it.

EPA's standard thus will apply only to, and have importance only for, DOE's application for licensing. Once the license is granted, and (as planned) the site is closed and the option to retrieve the waste is gone, the EPA standard for all practical purposes ceases to exist. For that reason, the integrity of that standard, and of the licensing process, is of crucial importance. The standard and the licensing process provide potentially the only opportunity to ensure the safety of future generations. If EPA's standard is too lax, those future generations will have no remedy against the consequences of EPA's abdication of its protective role. Likewise, if EPA unlawfully tinkers with the licensing process, pre-setting assumptions and attempting to rig the outcome, the government's only opportunity to ensure that Yucca Mountain is safe will be lost.

III. Legal Context of the Proposed Rule

When it rejected EPA's previous compliance period, the Court understood that in ordering EPA to comply with the EnPA requirement that its rule be "based upon and consistent with" the NAS recommendations, it was not merely addressing a minor oversight. Instead, the Court enforced an important statutory responsibility grounded in the protection of public health and safety. As the Court noted, "[I]t was Congress that required EPA to rely on NAS's expert scientific judgment, and given the serious risks nuclear waste disposal poses for the health and welfare of the American people, it is up to Congress—not EPA and not this Court—to authorize departures from the prevailing statutory scheme." *NEI*, 373 F.3d at 1273.

As the Court recognized, that statutory scheme places limits upon EPA's discretion. Although EnPA affords the EPA administrator discretion "in the exercise of his authority related to public health and safety issues," *id.*, it provides no authority to establish standards that contravene NAS recommendations, or that betray EPA's fundamental statutory responsibility to devise Yucca standards that are protective of public health and safety. As EPA has earlier described the scope of its discretion, it is bound to "reach final determinations that are congruent with NAS analysis" whenever it can do so "without departing from the Congressional delegation of authority to promulgate, by rule, health and safety standards for the protection of the public." Background Information Document for 40 CFR 197, at ES-5.

EPA therefore must not treat compliance with the Court of Appeals' ruling and the NAS's recommendations simply as a matter of technical correction, by providing a nominal standard that fails to discharge EPA's fundamental obligation to set a Yucca radiation standard protecting the public from near and long-term radiation risks. Yet this is what EPA proposes to do. Nevada is alarmed by the lack of seriousness with which EPA apparently views this obligation, exemplified by its continued questioning of a "regulatory emphasis" on a peak dose standard, and its insistence that DOE's performance assessments will not even need to be "alter[ed]" or "changed fundamentally" to meet the new compliance period.

IV. Nevada's Proposal to EPA

On February 3, 2005, Nevada submitted formal but preliminary comments to EPA on a revised standard for Yucca. Nevada concluded that there was no logical, scientific, or legal reason why EPA could not and should not extend the 15 millirem/year radiation protection standard out to the time of peak dose from the repository, whenever that may occur. Nevada emphasized this approach in a face-to-face meeting with EPA officials on April 29, 2005. But Elizabeth Cotsworth, Director of EPA's Office of Radiation and Indoor Air (the office with cognizance over the new rule) candidly informed Nevada that its approach was the only one EPA was *not* considering, because it would result in a standard that was "not implementable," meaning of course that Yucca could not meet it.

V. Abbreviated Comment Period

Although Nevada appreciates that EPA extended the proposed 60-day public comment period to 90 days, Nevada continues to object to the short period afforded to the public to comment on this very complex proposed rule, with its equally complex and lengthy referenced sources. During the original Part 197 rulemaking proceeding, the public was given 180 days to comment. Nevada and its Congressional Delegation on several occasions formally requested at least 180 days for commenting on the proposed new rule, especially in view of the numerous and profoundly important issues it raises. Moreover, the license application has been substantially delayed and so affording additional time would not have affected DOE.

Problems with EPA's 350-Millirem Standard

VI. EPA's Two-Tiered Standard is Unlawful and Arbitrary

A. This Two-Tiered Approach Fails to Conform to the Court Decision and the NAS Report

Like its predecessor, EPA's proposed rule would after 10,000 years terminate its only radiation standard that protects public health. The only innovation in EPA's new approach is to propose a nominal second-tier standard, 70 times weaker in mean-equivalent terms, for the longer-term period in which all of DOE's modeling runs show leakage from the repository. That approach again abrogates the central point of the NAS and the Court: that the repository should safeguard citizens *at the time of the peak dose* that will occur from repository leakage, whenever that occurs. See *NEI*, 373 F.3d at 1273 ("NAS recommended that *the compliance period extend to the time of peak risk.*") (Emphasis added). Most importantly, EPA does not and cannot show that its standard will result in a safe geologic repository at Yucca Mountain.

So resistant is EPA to the straightforward peak dose requirement addressed by the NAS and the Court that the proposed rule even states that "[w]e do not want to place more regulatory emphasis on peak dose projections than can be justified." 70 Fed. Reg. 49030. EPA recognizes in its proposed rule that simply extending its 15 millirem/year standard to cover the period of peak dose "would be straightforward in responding to the Court decision," 70 Fed. Reg. 49032, and that its retention of a protective first-tier standard "might appear inconsistent" with a proposal that would allow peak doses shortly after that tier ends which far exceed 15 millirem/year. *Id.*

EPA's two-tier approach rests upon a severely crabbed reading of the Court of Appeals' ruling and the NAS recommendations, positing that as long as a standard is in place through the time of peak dose, it is irrelevant if that standard drastically exceeds that which NAS and EPA until now have recognized as protective of public health. That cynical reading cannot be reconciled with the text and context of the Court's ruling and the NAS recommendations. The Court cited multiple references in the NAS report calling for "the standard" to extend to the time of peak risk. *NEI*, 373 F.3d at 1271-73 (citing NAS Report at 2, 55-56, 119); *id.* at 1270 (NAS "unequivocally recommended a standard pegged to the time when radiation doses reach their peak").

The most natural and common-sense reading of these references is the "straightforward" one considered and then summarily rejected in the proposed rule: to extend the health-protective standard that EPA has already identified, consistent with NAS recommendations on risk levels, so that it clearly applies through peak dose. These references provide no support for the notion that merely providing a number through peak dose, even if it is far less stringent than the risk levels that NAS and EPA have previously deemed acceptable, can be "consistent with" NAS's approach and meet EPA's legal responsibility and duty to protect the public. For example:

- NAS clearly recommended that compliance with "*the standard*" be measured "at the time of peak risk, *whenever it occurs.*" NAS Report at 2 (emphasis added). Rather than suggesting any relaxation of the standard after 10,000 years, NAS only qualified the statement by noting that the occurrence needed to be "[w]ithin the limits imposed by the long-term geologic environment, which is on the order of one million years." NAS Report at 2.

- NAS's recommendation on the time frame of "the standard" was "based upon performance calculations provided to us," in which it "appears that peak risks might occur tens to hundreds of thousands of years into the future." NAS Report at 2, 119.

- NAS noted that a "general consensus exists among national and international bodies on a framework for protecting public health," placing a limit of 100 millirems per year on continuous or frequent exposures from *all* anthropogenic non-medical radiation sources. *Id.* at 4. Following this apportionment principle, this consensus would assign to high-level waste disposal only 10 to 30 millirem per year. *Id.* at 4.

- NAS provided EPA with a range of acceptable risk levels and dose limits intended to provide a "reasonable starting point for EPA's rulemaking." NAS Report at 5. The acceptable range of radiation exposure recommended by NAS extends from 2 to 20 millirems per year. EPA has already construed these levels as part of the "findings and recommendations of the NAS" within the meaning of EnPA, and has already rejected a proposed standard of 25 millirems per year as "above the upper limit recommended by the NAS." Response to Comments at 4-5.

• NAS's rejection of a 10,000-year threshold as having "no scientific basis" reflected its serious concern that limiting the standard in this manner might be "inconsistent with protection of public health."

• NAS particularly warned against calculational approaches that "may seem to simplify licensing," but could not support a finding that there be "no unreasonable risk to the public." NAS Report at 55.

EPA is apparently aware that in the proposed rule, the true compliance period effectively ends at 10,000 years. In its discussion of deteriorating repository performance, the proposed rule notes that "[i]f such a dramatic deterioration were projected to occur *close to the regulatory time period* it would be a more pressing concern for licensing decisions than if it were to occur many hundreds of thousands of years into the future (remembering that the uncertainty in performance projections increases with time)." 70 Fed. Reg. at 49028 (emphasis added). The reference to the "regulatory time period" in this sentence, contrasted with a point of time hundreds of thousands of years in the future, would be incomprehensible if EPA believed that the real compliance period extended through the period of peak dose.

In short, a rule that terminates the health-protective standard at 10,000 years despite the absence of any scientific basis, and thereafter applies a standard dramatically exceeding all established norms for radiation exposure, using a compliance method that ignores many exposures that are even greater, cannot possibly qualify as "based upon and consistent with" NAS's peak dose recommendation. Nevada is mindful that EPA, in its proposed rule, has attempted to construe the NAS recommendations as a "starting point," and to portray its proposed rule as a reasonable modification based upon policy grounds. But while the Court recognized EPA had "some flexibility" to craft standards in light of NAS's findings, it warned that "EPA may not stretch this flexibility to cover standards that are *inconsistent* with the NAS Report." *NEI*, 373 F.3d at 1273.

The proposed rule has done precisely that. Like its predecessor, it resembles *Natural Resources Defense Counsel v. Daley*, 209 F.3d 747, 754 (D.C. Cir. 2000), quoted in *NEI* for its rejection of the conclusion that a measure four times as likely to fail as succeed could show compliance with the law. Only in a world in which "'based upon' means 'in disregard of' and 'consistent with' means 'inconsistent with'", *NEI*, 373 F.3d at 1272, could a rule allowing long-term radiation levels to exceed EPA's health-based standard by orders of magnitude, and continuing to terminate the protective standard at the same arbitrary point in time, be construed as "based upon and consistent with" the NAS's peak dose recommendation.

B. <u>The Two-Tiered Approach Contradicts EPA's Own Decisive Rejection of Similar Standards on Public Health Grounds</u>

The proposed rule is the latest and perhaps least protective version of an approach that EPA soundly rejected in its previous rulemaking as incompatible with well-established public health and safety standards. In its June 2001 Response to Comments document addressing its previous iteration of Part 197, EPA thoroughly rejected a suggestion that it should consider gradually relaxing its Yucca Mountain radiation standard over the progression of time. The commenter making this suggestion had proposed allowing the 15 millirem/year standard to increase to 150 millirem/year from 10,000 to 100,000 years, and to 1.5 rem/year from 100,000 to 1 million years. EPA rejected this proposal as "flawed," offering the observation that "[n]o regulatory body that we are aware of considers doses of 150 mrem to be acceptable, much less 1.5 rem, for members of the general public." Responses to Comments at 3-8.

In its previous Yucca rulemaking, EPA vigorously defended 15 millirem/year as the appropriate public health and safety standard, rejecting additional suggestions that the standard could be relaxed to 70 millirem/year or even 25 millirem/year. EPA emphasized that "EnPA instructed us to write standards 'based upon and consistent with' the findings of NAS. The annual risk basis of the 15 mrem limit...is within the range of annual risk levels which NAS suggested." Responses to Comments at 4-5 (citing NAS Report at 5). A key part of EPA's rationale was therefore to conform its standards to risk levels suggested by NAS, corresponding to a range between 2 and 20 millirem/year. In its final rule, EPA observed that its adoption of the 15 millirem/year standard was based in part on the NAS Report, noting also that "[t]his level is 15% of the ICRP-recommended total dose limit. It falls within the range of standards used in other counties and the range recommended by NAS, and is also consistent with the individual-protection requirement in 40 CFR part 191." 66 Fed. Reg. at 32088 (June 13, 2001).

In its defense of the 15 millirem/year standard, EPA disagreed "particularly strongly" with a commenter who recommended a 70 millirem/year standard as "adequately protective," noting that the risk level associated with that standard "is about five times as high as the risk level associated with the individual protection limit. This is well above the NAS recommended level and unprecedented in the current regulations of this and other nations for this activity." Responses to Comment at 4-5, 6. EPA noted that a 70 millirem/year standard would result in "a risk level at Yucca Mountain that is significantly higher than any facility that falls under 40 CFR part 191, such as WIPP and future radioactive waste disposal facilities"; and would violate well-established norms of apportionment, because "70 mrem from one source is too high a proportion of the annual100 millirem recommended by NCRP and ICRP (excluding background, occupational, accidental, and medical sources)." *Id.* at 4-5. On similar grounds, EPA even rejected several suggestions for a 25 millirem/year standard, concluding that even that level would be "higher than that recommended by the NAS." *Id.*

The proposed rule fails entirely to support EPA's dramatic retreat from the consensus position of NAS and other regulatory and advisory bodies, including EPA's express rejection of a similar two-tier standard. EPA concedes that it earlier "rejected similar approaches" to that it now proposes, and expressly rejected a 150 millirem/year standard as one that "no regulatory body we are aware of" considered acceptable. 70 Fed. Reg. at 49031. Absent from EPA's new discussion is any reason to believe regulatory bodies would now consider that standard, much less one more than twice as lenient, acceptable for the general public. Instead, EPA's rationalizations seem to underscore the arbitrary and legally dubious nature of the new proposed rule. Most notably, EPA does not explain how its previous conclusion that such levels were inconsistent with the NAS's recommendations can now be dramatically reversed.

EPA suggests its rule is "unprecedented" because it was commanded by NAS and the Court to address time periods after 10,000 years. But that is no rationale. EPA never explains how a standard that is obviously inadequate can suddenly become adequately protective at 10,001 years. Nor can it, for EPA has no basis for assuming that human susceptibility to radiation will change. Additionally, EPA's suggestion that it need not be consistent with international precedents, because those precedents do not address long time frames, is demonstrably false. Many international and national bodies do recommend or impose regulation over long time frames, and none permits the type of two-orders-of-magnitude increase in risk that DOE's non-protective second-tier standard would allow. *See* Appendix A.

VII. The Proposed Rule Poses Unacceptable Public Health Risks

EPA's proposed rule is totally lacking any analysis of the health and safety implications of a 350-millirem (1000-millirem mean equivalent) standard. This is a remarkable oversight, particularly in light of the hundreds of thousands of years following peak dose that the waste will continue to be dangerous. Nevada is aware of no instance in which EPA has promulgated a health and safety standard without analyzing its health and safety effects. Such an oversight is not merely arbitrary and capricious; it represents irresponsible abdication of EPA's Congressionally defined regulatory role.

Had EPA performed any such analysis, the results would be obvious: the proposed standard creates a virtually limitless future of unreasonable risks. Nevada's health and safety consultant has completed the very analysis that EPA has declined to perform, and concludes (based on accepted correlations between radiation dose and adverse health effects) that exposure to a 350 millirem additional annual dose over a lifetime would create a 4.8 percent increase in adult risk of fatal cancer. Furthermore, the radiation dose that could be received in three to six years would be in the range over which a 40 percent increase in the cancer rate in children has been directly observed. *See* Dr. M. C. Thorne, *International Literature and Health Effects of an Annual Effective Dose of 350 mrem* (Nov. 10, 2005), attached at Appendix A. EPA offers no rationale explaining why such increases are acceptable. It should come as no surprise that the President of National Council on Radiation Protection (the premier expert U.S. body on radiation standards and science) strongly criticized the EPA proposal as inconsistent with long established national principles of radiation protection at a November 14, 2005 presentation to NRC's ACNW.

There are strong reasons to be concerned about the unprecedented magnitude of the health risks posed by the EPA rule. As noted in a recent analysis of EPA's new Yucca rule, the International Atomic Energy Agency's ("IAEA's") 2001 peer review observed that the government's own Yucca studies revealed potential uncertainties in projected radiation doses of four or more orders of magnitude. *Id.* at 35. Projected radiation exposures at Yucca could therefore be 10,000 times too high or 10,000 times too low.

Dr. Thorne has provided a summary of the international literature and regulations concerning dose standards to further support the view that 350 millirem/year constitutes an unreasonable and dangerous incremental anthropogenic radiation source. The full text of Dr. Thorne's report must be taken into account. He concludes among other things that EPA has selectively and misleadingly quoted from overseas and international sources in an effort to support its rule, and that the rule would allow an increase in cancer risk that no other regulatory body considers acceptable, even for geologic disposal. *See* Appendix A.

VIII. <u>The New Standard is Unprecedentedly Lenient and Out of Compliance with Radiation Protection Standards Worldwide</u>

The unacceptable health risks posed by EPA's proposed 350 millirem/year (1000 millirem/year mean equivalent) standard should not be surprising, for a 350 millirem standard is higher than anything EPA, or any other regulatory body, ever has approved before. The NAS report recognized an existing international consensus supporting substantially more stringent protections. *See* NAS Report at 41. NAS recommended a starting point for EPA's rulemaking consistent with that international consensus. As EPA itself has acknowledged, that would produce a standard in the range of 2-20 millirem/year, far lower than the standard EPA now proposes.

In its prior rulemaking, EPA recognized that deviating from this international consensus and from this NAS recommendation would be inappropriate, and rejected as unsafe proposals to set standards well below the 350-millirem standard it now proposes. When commenters on the original 40 C.F.R. Part 197 suggested a standard gradually decreasing in stringency, EPA responded harshly, noting that "*no regulatory body we are aware of considers doses of 150 mrem to be acceptable.*" EPA, Response to Comments at 3-8 (2001) (emphasis added). Likewise, EPA rejected a commenter's suggestion of a 25 millirem standard—which is more than *ten times lower* than the standard EPA now proposes—because that standard would be "(1) higher than that recommended by the NAS...; (2) inconsistent with [EPA's] generic disposal standards at 40 CFR. part 191...; and (3) even further outside the preferred EPA lifetime risk range." *Id.* at 4-5. And EPA

> disagree[d] particularly strongly with the commenter who recommended a 70 mrem standard as adequately protective. The risk level associated with 70 mrem is about five times as high the risk level associated with the individual-protection limit. This is well above the NAS-recommended level and unprecedented in the current regulations of this and other nations for this activity. It also is significantly inconsistent with the individual protection limit of 15 mrem CEDE/yr in our generic standards (40 C.F.R. Part 191). This would result in a risk level at Yucca Mountain that is

> significantly higher than that at any facility that falls under 40 C.F.R. Part 191.

Id. at 4-5 to 4-6.

Those past conclusions indicate that EPA has consistently viewed proposed standards much lower than the one it now proposes as unprotective of public health, internationally unprecedented, and beyond the limit of responsible regulation. This also applies to the EPA's proposal to adopt a two-tiered approach to the human intrusion performance assessment.

IX. The Collusive History of the Proposed Rule Undermines Its Integrity as a Public Health-Based Standard

Neither EPA's 40 C.F.R. Part 197 rulemaking (published in 2001) nor its current, revised proposal are the product of its independent judgment about the health and safety of the citizens of the United States. Like its predecessor, the proposed rule reflects the wholesale adoption of standards pushed on EPA by DOE and its industry allies as representing merely the standards *that could be met* by a repository at Yucca, not the standards that would protect the public health and safety in fulfillment of EPA's statutory responsibilities. As a result, the current proposal is not the product of reasoned decision-making and does not constitute a public health-based standard, as required by the Energy Policy Act of 1992.

A. EPA's Initial Part 197 Rulemaking

Congress required the EPA Yucca standard to be "based upon and consistent with" the recommendations of the NAS. But the ink had barely dried on NAS's 1995 report when DOE began applying pressure on EPA to adopt a standard that DOE believed it could meet at Yucca, the NAS report notwithstanding. As early as October 17, 1995, in a presentation before the Nuclear Waste Technical Review Board ("NWTRB"), DOE outlined its planned campaign to secure a standard Yucca would pass. DOE told the Board it was critical for EPA to carefully consider the time frame over which quantitative compliance would have to be demonstrated, and the level of risk which would be set, calling these standards outcome-determinative because the standards would determine whether "the site can either pass or fail." 10/17/1995 NTRB Transcript, at 15. DOE said it would be working with EPA during the rulemaking process in order to come up with a standard DOE would consider "implementable." *Id.*

In January 1996, then-OCRWM Director Daniel Dreyfus admonished both EPA and NRC that they needed to be very careful in addressing the NAS recommendations in their rulemaking actions, insisting that "whatever standard results from this process . . . must be implementable." Dreyfus further insisted, "Promulgating a standard that cannot be implemented may result in the *de facto* rejection of the Yucca Mountain site, or even a rejection of the option of geologic disposal. Such rejection will not avoid the consequences of long-term radioactive waste management, it will simply require society to resort to a different, and currently undetermined, long-term approach." 1/30/1996 Statement to NRC by D. Dreyfus, at 16.

Despite NAS's explicit direction to the contrary, DOE urged in a public meeting before the Advisory Committee on Nuclear Waste (ACNW) that "a time frame of no longer than 10,000 years" should be established for regulatory compliance, because "the longer the compliance time frame, the more difficult it would be for DOE to succeed in getting a license." 3/27/1996 ACNW Presentation by S. Brocoum, at 4. DOE threatened that "requiring quantitative compliance for periods over 10,000 years could significantly affect the viability of geologic disposal." *Id.* at 13. New OCRWM Acting Director Lake Barrett followed up with a public prediction that DOE could submit a License Application as early as 2002, but only "if we have reasonable EPA and NRC regulatory criteria." 4/30/1996 NWTRB Transcript, at 16. At the same time, DOE reiterated to EPA its need for both a compliance period limited to 10,000 years and a generous dose limit on the order of 100 millirem/year (4/30/1996 NWTRB Presentation by S. Brocoum, at 12), a figure far higher than any EPA standard then in existence from one radioactive source.

In October 1997, Barrett wrote to the NWTRB, urging that EPA and NRC adopt lenient standards and predicting severe consequences for their failure to do so. He cautioned that "[i]t is incumbent upon all knowledgeable participants in this process to be sure that the regulatory framework for the repository . . . is not constructed so as to defeat the nation's policy of geologic disposal." 10/22/1997 Written Statement by L. Barrett to NWTRB, at 6.

EPA's own documents confirm that it was working, in lockstep with DOE, to provide a standard Yucca could meet. In an economic analysis supporting the 2001 version of Part 197, EPA chronicled DOE's answers to a series of questions, none of which were relevant to determining what standard would protect public health and safety. Evaluation of Potential Economic Impacts of 40 C.F.R. Part 197: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada" (EPA, June 2001). Could DOE meet a strict standard at Yucca; and if so, for how long? If DOE were only able to meet a strict standard for a limited time, what was that time limit? How high did it expect doses to rise after that limited time? EPA had reason to ask, and answer, those questions only if it was attempting to determine what standards Yucca could pass.

The answers to those questions assured EPA that its 10,000-year limit would give DOE the pass it wanted. EPA well knew, as illustrated by the graph below taken from the EPA's rulemaking record, that extending the time of compliance with its 15 millirem/year standard to the peak dose would doom Yucca. So, ignoring the NAS recommendation and EnPA, it acquiesced to the 10,000 year cut-off desired by DOE. In this same economic analysis, EPA boasted that it had done what DOE had asked and even more: EPA said its Part 197 would not require DOE to abandon Yucca Mountain or even spend one additional dollar in order to comply with the radiation standard. *Id.* at ES-2.

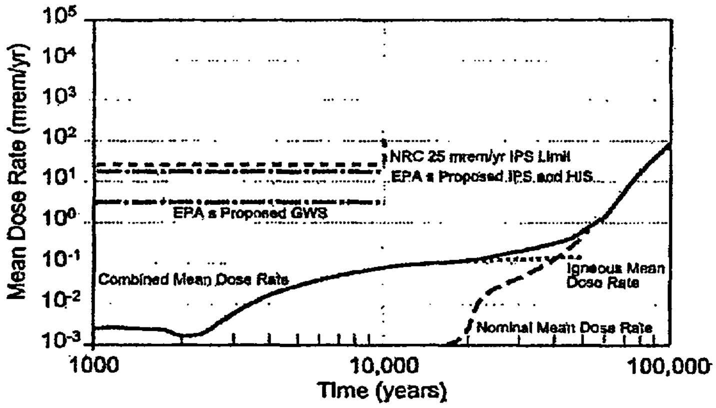


Figure 3-2 Comparison of Proposed Radiation Protection Standards with Expected Values of TSPA-SR Calculations for a Repository at Yucca Mountain for Nominal and Igneous Scenarios (Figure adapted from TRW00a).

EPA knew from DOE data of the ineffectiveness of the natural setting at Yucca to isolate waste, DOE's near total reliance on engineered waste containers, and DOE's calculations demonstrating that the waste containers might isolate wastes for 10,000 years but would certainly fail thereafter. Accordingly, EPA's 2001 Part 197 accommodated DOE completely, setting both a time of compliance and a dose level that DOE had advised EPA it could meet, and at the same time avoiding either a time of compliance or a dose level that DOE had advised it could not meet. The process had nothing to do with applying a health-based standard.

B. <u>EPA's Current Proposed Rulemaking</u>

The July 2004 *NEI* decision unsurprisingly focused on the NAS finding and recommendation that there was no basis for selecting a 10,000-year time of compliance and that the standard promulgated by EPA should provide protection to the time of peak risk or dose (which could be much later). The court's decision did not find a 15 millirem/year standard inappropriate for public health and safety, but it found EPA had no justification for eliminating that protection for future generations who might be born after 10,000 years. So EPA was sent back to the drawing board to develop a standard for peak dose whenever it might occur (within the time period of geologic stability).

DOE quickly stepped in to forestall the obvious solution to EPA's legal problem (*i.e.*, simply extending the 15 millirem/year standard out to the time of peak dose). On August 2, 2004 and November 24, 2004, EPA sat down with DOE representatives from the Yucca project to discuss how best to revise 40 C.F.R. 197 in order to satisfy the Court's mandate that it cover a time period beyond 10,000 years, while at the same time somehow ensuring its "implementability" by DOE. *See* 1/27/2005 EPA FOIA Response, at 3-7. The exact words spoken at those meetings may never be known, because EPA is concealing under a claim of privilege everything discussed and agreed to by EPA and DOE. *Id.* at 1. In asserting the privilege, EPA confessed that the withheld documents "reflect the internal discussions, advice, analysis, and recommendations that were being considered during meetings between EPA and DOE officials regarding aspects of very long-term modeling and their effect on EPA's response to the NEI decision." OAR-2005-0083-0028, at 3. EPA also described the withheld meeting notes as "discussions among senior EPA program and legal staff of EPA, NRC, DOE, and the Department of Justice concerning various legal options to respond to adverse rulings in the *NEI* decision." *Id.* Appendix at 2, 4.

Before initiating the current proposed rulemaking, EPA took another step to ensure any revised standard it might adopt would accommodate DOE. It hired S. Cohen & Associates to do a detailed analysis of DOE's Yucca Mountain performance assessments. The Cohen report confirmed that, despite DOE's tinkering with various inputs to its performance model since EPA's 2001 rule had been promulgated, certain basic premises persisted:

- DOE at Yucca could meet a strict 15 millirem/year dose standard for the short term, perhaps for as long as 10,000 years if the waste packages lasted that long.

- Over a longer period, after the inevitable failure of engineered barriers, the dose standard would have to be *much* higher if there was to be assurance Yucca could go forward.

Cohen's Figure 12-3 (DOE's Figure 1-13) below provides an illustration, showing the projected doses from Yucca over a time frame of one million years.

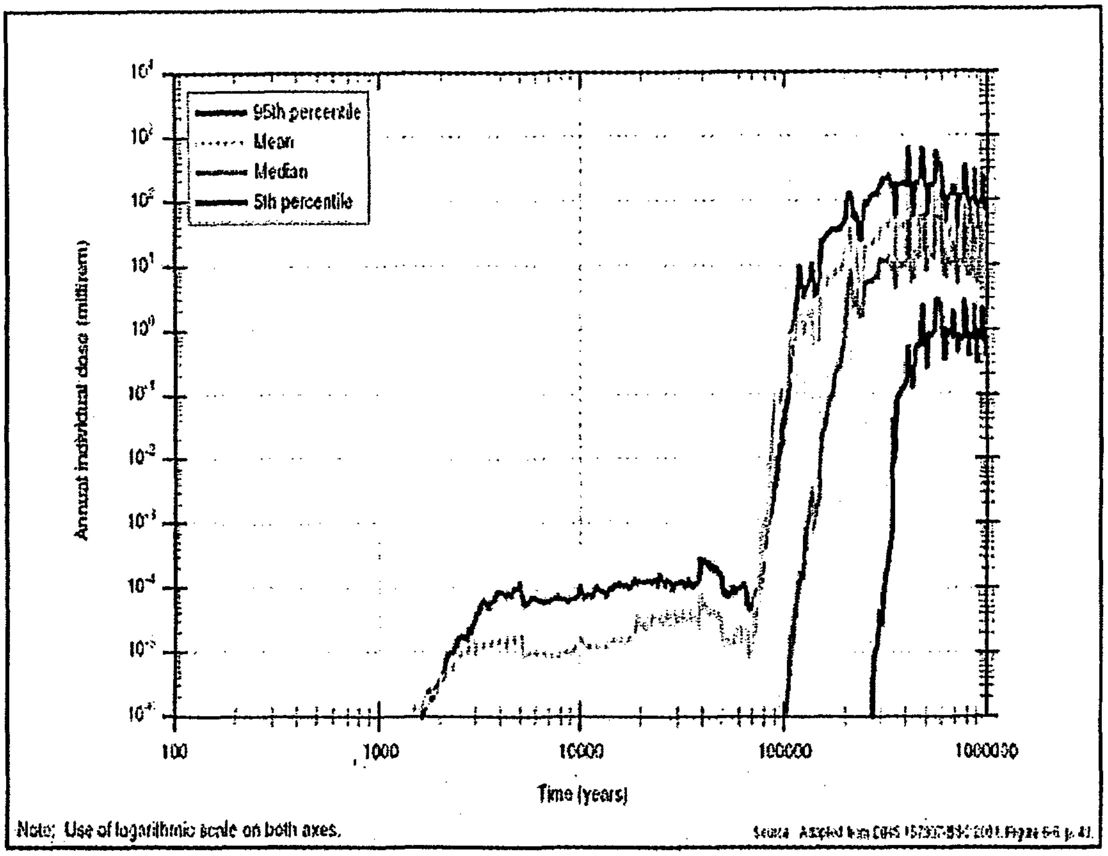


Figure I-13. Total annual individual dose at the RMEI location for 300 probabilistic simulations of the lower-temperature operating mode for the Proposed Action inventory, nominal scenario; the figure also displays the 5th-percentile, median, mean, and 95th-percentile values of these simulations.

Figure 12-3. Revised Supplemental TSPA One-Million-Year Dose Histories Based on the FEIS Lower-Temperature Operating Mode

Cohen essentially encouraged DOE not to make any further effort (relating to either natural or engineered barriers) to reduce the uncertainty level in its projections, telling EPA to expect no such action by DOE because it would adversely impact the repository's cost and schedule:

> The larger uncertainties in projected dose rates for long compliance time frames, in comparison with uncertainties for time frames on the order of 10,000 years, lead to consideration of two basic types of actions aimed at increasing confidence in dose rates submitted for licensing reviews. One is to increase the site characterization database, with the objective of increasing confidence in assessed performance of the *natural system*. The other is to augment the barrier features of the *engineered system*, with the

objective of increasing the resistance of the system to degradation as a result of water contacting the waste form. Both types of action would extend the time to readiness for licensing reviews, and both would incur major costs.

OAR-2005-0083-0085, at A-20, 21.

Cohen observed, "Because DOE is not expected to make changes, undertake significant site characterization, or drastically revise its performance approach or models as a result of EPA's revisions to the 2001 rulemaking, there are no costs directly attributable to EPA's rulemaking." *Id.* at 2-4. Thus, for the second time, EPA knowingly refrained from proposing a Yucca standard that might require DOE to spend an extra dollar.

C. <u>OMB's Role in EPA's New Proposal</u>

Presumably at the direction of DOE, the Office of Management and Budget ("OMB") instructed EPA to remove a provision from the draft proposed rule, circulated for comment to OMB, providing that "NRC may specify, in regulation, additional features, events, and processes ["FEPs," *see* Section XIX below] that DOE must consider because they may significantly affect the magnitude of the peak dose." EPA obliged, and that provision, which would have confirmed NRC's authority to apply traditional principles of performance assessment in its licensing review, was removed. As a result the rule is not risk informed. It arbitrarily eliminates factors that could significantly affect the calculation of the peak dose.

D. <u>The Nuclear Industry's Role in EPA's New Proposal</u>

The nuclear industry's research organization, the Electric Power Research Institute ("EPRI"), also weighed in with its proposals for ensuring that EPA promulgated a new standard that DOE could meet at the inferior geologic location of Yucca Mountain. Interestingly, the organization which prepared EPRI's "Yucca Mountain's Licensing Standard Options for Very Long Time Frames" (Apr. 2005) for submission to EPA was Monitor Scientific, LLC, whose website presently features EPRI, yet also brags that "Monitor's expertise has been used to support EPA in projects related to . . . the 2001 Yucca Mountain rulemaking." *See* http://www.monitorsci.com/projects.htm. The Monitor Scientific report delivered to EPA by EPRI also begged for an "implementable" standard. Among other things,

- EPRI recommended that future climate states be established by rulemaking; specifically, EPRI recommended that future climate be fixed to the present interglacial classification, despite the fact that it conceded, "It is improbable that, except for brief intervals, the earth's climate during the next 1,000, 10,000, 100,000, or 1,000,000 years will replicate that during human-recorded history." OAR-2005-0083-0079, at A-19.

- EPRI urged that EPA retain the 15 millirem/year standard for 10,000 years, but specify a different, higher dose limit to future generations after 10,000 years, as a separate stand-alone provision that would not alter the existing requirement for the first 10,000 years. This two-tiered standard for dose/time of compliance was critical "if the regulation . . . is to remain implementable," EPRI said. *Id.*

- EPRI recommended a different approach to establishing which FEPs were required to be included in DOE's compliance assessment and argued for no additional FEP screening for the time period beyond 10,000 years, a point evidently later also impressed upon OMB. *Id.*

EPRI delivered its report to EPA on April 11, 2005, urging that its proposals "would be 'reasonable' and implementable in a regulatory environment." 4/11/2005 Kessler Email, at 2. With DOE and nuclear industry parameters in hand, EPA proposed a rule which honored DOE's and the nuclear industry's essential requests by setting a dose standard beyond 10,000 years that should be high enough to be ensure implementability of the Yucca project, notwithstanding science and law to the contrary. Significantly, in selecting a 350 millirem/year long-term standard, and using the median as the measure of compliance, EPA went even further to accommodate DOE than the 100 millirem/year (mean equivalent) second-tier standard that even EPRI had found pushed the bounds of reasonableness.

X. <u>EPA's Proposed Standard Irrationally Abandons the Apportionment Principle</u>

EPA's proposed rule would abandon the well-established and universally accepted principle of apportionment. That abandonment departs, without any credible justification, from the consensus position embodied in the NAS's recommendations and in EPA's own prior statements and practice.

As the NAS report explained:

> [A] general consensus exists among national and international bodies on a framework for protecting the public health that provides a limit of 1 milliSievert (mSv) (100 millirem (mrem)) per year effective dose for continuous or frequent exposures from all anthropogenic sources of ionizing radiation other than medical exposures. A general consensus also appears to exist among national authorities in various countries to accept and use the principle of apportioning this total radiation dose limit among the respective anthropogenic sources of exposure, typically allocating to high-level waste disposal a range of 0.1 to 0.3 mSv (10 to 30 mrem) per year.

NAS Report at 4; *see also id.* at 40-41. Using this approach, each individual source is allocated not the entire amount of radiation that would reach the regulatory limit, but only a portion, based on the reasonable assumption that other sources will exist, and that people's health will depend upon the cumulative risks that all of those sources create.

Until releasing its proposed rule, EPA has consistently adhered to this internationally accepted apportionment principle. For example, in 1993, in its WIPP standards, EPA explained that its chosen 15 millirem/year standard

> is consistent with the ICRP approach of apportioning an overall dose limit from man-made radiation to particular activities, such as waste disposal. The ICRP suggests using an overall limit of one milliSievert CED (100 millirems CED) per year. While EPA has not established such an overall limit, the Agency finds that 15 millirem CED per year is today an appropriate and acceptable fraction of the 100-mrem ICRP recommendation because it is small enough to ensure that the total exposure of an individual who was exposed to a number of sources would stay below the overall limit.

58 Fed. Reg. 66398, 66402 (EPA, Dec. 20, 1993).

Likewise, in 1994, in proposed rules applicable to nuclear radiation exposures, EPA explained that

> there are many different categories of activities using radiation that can lead to exposure of members of the public. These currently include medical uses of radiation and their supporting activities; nuclear electric power facilities and their supporting fuel cycle facilities; research and industrial users; weapons production, storage, and disposal facilities; technologically-enhanced exposure to natural radiation sources; consumer products; space applications; disposal sites for radioactive wastes; and decommissioned sites at which radioactive materials were formerly used. It is therefore also necessary to ensure that total doses to individuals, who may be exposed not only to more than one source in a given category in a few cases, but more often to a number of different categories of sources at one time, are not likely to exceed the [total allowable dose].

59 Fed. Reg. 66414, 66423 (EPA, Dec. 23, 1994). Based on public health studies, EPA determined that "combined radiation doses incurred in any single year from all sources of exposure covered by these recommendations should not normally exceed a Radiation Protection Guide of 1 mSv (100 mrem) effective dose equivalent to an individual." *Id.* at 66420.

EPA adhered to, and relied upon, this guidance in the initial stages of developing the Yucca standard. In a report entitled "Environmental Radiation Protection Standards for Yucca Mountain: Considerations on Issues," EPA's Team Leader for developing the Yucca standards explained that

> the agency has proposed [a 100 millirem/year dose] as an acceptable level for members of the public exposed from all sources except background and medical exposures [citing EPA's December 1994 proposed standards]. The EPA, and international guidance, then requires that this overall dose be apportioned among actual and currently known potential sources and future exposures. In the vicinity of Yucca Mountain are several potential sources of exposure for a critical group, for example, the waste disposal site in Area 5 and the weapons testing areas on the Nevada Test Site, the commercial low-level radioactive waste disposal site near Beatty, Nevada, and a potential interim storage site for spent nuclear fuel.

See Raymond Clark, Environmental Radiation Protection Standards for Yucca Mountain: Considerations on Issues (1988), at 5 (a copy of which is submitted by Nevada with its comments).

EPA's final rule again adhered to this principle, setting the site-specific dose limit at 15% of the total allowable 100 millirem/year dose. EPA explained that

> [t]he apportionment of the total dose limit among different sources of radiation is used to ensure that the total of all included exposures is less than 1 mSv (100 mrem) CED/yr. Thus, ICRP recommends that national authorities apportion or allocate a fraction of the 1 mSv (100 mrem)-CED/yr limit to establish an exposure limit for SNF and HLW disposal facilities. Most other countries have endorsed the apportionment principle.

66 Fed. Reg. at 32089. EPA went on to explain that its 15 millirem/year standard "is 15% of the ICRP-recommended total dose limit. It falls within the range of standards used in other counties and the range recommended by NAS, and is also consistent with the individual protection standards in 40 CFR part 191." *Id.*

In its responses to comments on Part 197, EPA relied directly on this apportionment principle in rejecting a suggested 70 millirem/year standard. EPA explained that "70 mrem from one source is too high a proportion of the annual 100 mrem recommended by the NCRP and ICRP (excluding background, occupational, accidental and medical sources). The apportionment of the total dose limit among different sources of radiation is used to insure that the sum, or total, of all included exposures is less than 1 mSv (100 mrem)." EPA, Response to Comments, 4-5 to 4-6 (2001). EPA then reiterated that ICRP recommends national authorities allocate "a fraction" of the 100 millirem total to establish an exposure limit for spent fuel and high-level waste disposal facilities. *Ibid.*

Yucca Mountain presents (and EPA has provided) no reason to abandon this concept. The proposed repository cannot be the sole source of local radiation, for, as EPA itself has noted, the area surrounding Yucca Mountain already has borne more than its fair share of the nuclear era's impacts.

> There are multiple sources of potential radionuclide contamination on or near [the Nevada Test Site], one of which is the Yucca Mountain site. Portions of NTS have been subjected to both underground and aboveground weapons detonations. A substantial quantity of radionuclides was created by these tests. An estimated inventory of 300 million curies remains underground.... Elsewhere in the NTS, DOE is burying [low-level waste] in near surface trenches and TRU radioactive waste has been disposed of in the Greater Confinement Disposal facility. Finally, there is a commercial LLW disposal system located west of Yucca Mountain near Beatty, Nevada. Each of these facilities could have releases of radioactivity to the groundwater.

66 Fed. Reg. 32074, 32088 (citations omitted).

All these Nevada-specific exposures would occur *in addition* to the many other anthropogenic exposure sources. As EPA has noted, commercial nuclear power plants, university research and development, experimental reactors, government-controlled reactors, and foreign facilities, among other sources, all contribute radiation. *See* 66 Fed. Reg. at 32079; *see also* ICRP Publication 46, *Radiation Protection Principles for the Disposal of Solid Radioactive Waste* 2-3 (1985) (describing the generation of radiation throughout the fuel cycle). EPA has offered no basis to assume these other sources will cease to affect the Yucca Mountain area.

Nevertheless, EPA's proposed 350-millirem (1000-millirem mean equivalent) second-tier standard would completely abandon the principle of apportionment. EPA would allocate Yucca approximately 3.5 times—or over ten times, in mean-equivalent terms—that total dose standard to *one site*. EPA provides no coherent explanation for this shift. Instead, the proposed rule acknowledges that "in practice today, doses from any particular source of radiation are generally kept to a fraction of the 100 mrem overall limit, in recognition that a person may be exposed to more than one practice or source." 70 Fed. Reg. at 49040. But EPA then makes the remarkable claim that because the agency does not know what future sources will exist, it is appropriate to allocate all of the accepted 100 millirem/year total dose to one source. *Id.* at 49041.

In multiple ways, this statement turns the principle of apportionment on its head. First, the principle always has been applied, in the past, to sites at which other future exposure sources were unknown and unknowable. It would require "immense speculation," for example, to guess what specific sources will be near the WIPP site, but EPA relied on the apportionment principle to establish the WIPP standard. *See* 58 Fed. Reg. at 66402. It would similarly require "immense speculation" to guess what specific sources will exist at Yucca Mountain over the next 10,000 years, yet in promulgating its original 10,000-year standard, EPA again applied the apportionment principle. 66 Fed. Reg. at 32089. The prerequisite for application of this principle has never been foreknowledge of particular future sources at the site in question; nuclear waste disposal systems are inherently long-lasting, and we never know exactly what other sources will exist.

Indeed, that very lack of knowledge is a core reason for utilizing apportionment, not a reason to abandon the principle. Since EPA does not know what will happen in the future, but does know that other sources are possible—indeed, they are inevitable if we continue our current practices of using nuclear materials—it must make accommodations for those potential sources. As the ICRP explained, in the publication that for two decades has formed the foundation of EPA's apportionment policy,

> [t]o allow for dose contributions from present practices *and to provide a margin for unforeseen future activities*, the Commission recommends that national authorities select a fraction of the dose limits as a source upper bound for each source of exposure, to ensure that the exposure of individuals will remain below the relevant dose limit.

ICRP Publication No. 46 at 11 (emphasis added). EPA's approach, by contrast, is the equivalent of assuming that other sources will never affect the vicinity of Yucca Mountain—despite EPA's own statement that it would involve "immense speculation" to predict such future events. *See* 70 Fed. Reg. at 49041. In the guise of avoiding speculation, EPA proposes to make an unprecedented, absurdly optimistic, and totally speculative assumption.

This rationale also ignores additional sources that *already exist*. EPA itself has repeatedly pointed out that "[t]here are multiple sources of potential radionuclide contamination on or near [the Nevada Test Site], one of which is the Yucca Mountain site." *See* 66 Fed. Reg. at 32088 (also quoted above). Specifically, NTS contains residual radiation from 1054 above-ground and underground nuclear weapons tests, the still-contaminated 1960s rocket test area (Area 25) adjacent to Yucca, the no-longer operating Greater Confinement Disposal Area, in which about 9.3 million Curies of the equivalent of Greater Than Class C waste are buried in vertical shafts, and areas of ongoing disposal of low-level waste, with about 500,000 Curies already buried. BID, Appendix II, Table II-1. The Beatty commercial low-level waste disposal facility is located in Amargosa Valley, also up-gradient from the valley population; when it was closed in 1992 the Beatty low-level waste shallow landfill contained 641,000 Curies of waste. EPA's blithe suggestion that Yucca Mountain will be the only source worth considering thus ignores present reality as well as the unpredictability of the future.

Further sources also are a foreseeable possibility. Given its past and current uses, other sources of radioactive contamination may be installed at the Nevada Test Site. For example, there is current discussion of reorganizing the entire U.S. nuclear weapons complex onto a single site in the future, and the Nevada Test Site has been considered by the government for such future use. All of the current weapons complex sites are in some stage of clean-up, suggesting that any new location of the complex would be subject to some level of contamination.

EPA supplies no other attempted justification for diverging from the NAS's recommended approach, its own past practice, and worldwide convention. Its abandonment of apportionment therefore is arbitrary, capricious, and inconsistent with the EnPA's mandate that EPA's rule be "based upon and consistent with" the NAS report's recommendations.

XI. The Proposed Rule Unlawfully Permits Calculations Based on the Median, Not the Mean, of Exposure Predictions

Appendices B and C to these comments contains a more detailed statistical and mathematical evaluation of this issue by Dr. B. Thomas Florence, Dr. Thomas Vasquez, and Dr. Thorne. *See* B. Thomas Florence and Thomas Vasquez, ARPC, *Some Comments on the Proposed Yucca Mountain Compliance Standards* (Oct. 15, 2005) ; Dr. M. C. Thorne, *The Role of Uncertainties in Defining the Proposed Standard* (Nov. 10, 2005), attached as Appendices B and C. The full text of Appendices B and C must be considered.

Departing from the recommendation of the NAS, its own past and present practice, and the past practice of the NRC, EPA's proposed rule would use the median,[1] rather than the arithmetic mean, of projected doses from its Yucca performance simulations to measure compliance during the post-10,000-year period. That is a highly significant shift; DOE's current modeling predicts that at peak dose, mean values will be approximately *three times higher* than median values, and a 350-millirem median standard is thus the equivalent of an approximately 1000-millirem mean standard. Because EPA proposes to continue using the mean, which it accurately describes as a "familiar and well-understood statistical concept," for its 15 millirem pre-10,000 year period, *see* 70 Fed. Reg. at 49042, its post 10,000-year standard will be almost *seventy* times higher than its pre-10,000 year standard. This shift may be (and appears calculated

[1] The arithmetic mean of a set of numbers is the average number. That is, it is the outcome produced by adding up each individual number and dividing by the total of the numbers. The median, by contrast, is merely the midpoint of all numbers. For some data sets, the mean and median may be close, or even equal. For example, if the numbers in set A are 1, 2, 3, 4, and 5, both the mean and median will be 3. Other sets, however, have radically divergent means and medians. If, for example, the numbers in set B are 1, 2, 3, 10, and 24, the median is 3, but the mean is 8—more than twice as high. Though sets A and B obviously are quite different, that difference is captured only by the mean; the median for both sets is exactly the same. The real-world implications of this distinction can be crucial. Imagine, for example, that the safety of a city's proposed levee system is assessed by modeling five anticipated storm scenarios, and model runs for the five different scenarios predict 0, 1, 4, 45, and 650 deaths. The median prediction would be four deaths—a number that engineers might decide was acceptable, or required only minimal changes to the proposed levee system. The mean, prediction, however, would be 140 deaths—a very different number. If the engineers consider only the median, they may allow an unreasonable level of risk.

to be) outcome-determinative; DOE's TSPA modeling suggests that Yucca could just barely meet a median-based standard, but would grossly fail a standard based on the mean.

For several reasons, this shift to the median is flawed. First, the NAS expressly recommended the use of the mean. Second, using the median is inconsistent with EPA's own past and present statements and practice, and EPA has offered no rational explanation for the shift. Third, EPA's approach is scientifically and statistically unsound. Finally, use of the median would allow a grossly unsafe site to be licensed; though DOE's current modeling projects that the median dose will be below 350 millirem/year, 42 percent of the modeling runs appear to exceed that number. *See* Appendix A, at 8. No site that has a 42 percent chance of failure can ever be considered adequate.

A. EPA's Abandonment of the Mean Departs from the NAS's Recommendation

In its Technical Bases Report, the NAS could not have been more clear: "We recommend that the *mean* values of calculations be the basis for comparison with our recommended standards." NAS Report at 123 (emphasis added). Since EPA's rule must be based upon and consistent with the NAS's findings and recommendations, that recommendation mandates the use of the mean.

Yet EPA has not only failed to implement that recommendation; it has pretended it doesn't exist. EPA falsely claims that "NAS in its recommendations did not speak explicitly to any particular performance measure to be used in determining compliance with regulatory standards." 70 Fed. Reg. at 49043. That obviously is not true.

B. EPA Departs from its Own Past and Present Use of the Mean

EPA's shift from the mean to the median also marks a dramatic departure from EPA's prior approach. In its prior rulemaking, EPA initially proposed to use the *higher* of the mean or median, and eventually settled on the mean as its chosen compliance measure.

In the 1999 proposed rule for Part 197, EPA stated that: "As a result of the performance assessment there will be a distribution of the highest potential doses incurred by the RMEI [Reasonably Maximally Exposed Individual]. We are proposing that the mean or median value (whichever is higher) of that distribution be used by NRC to determine compliance with the individual protection standard." 64 Fed. Reg. 46988.

> In the June 2001 Final Rule, EPA stated: "*We propose a compliance measure we believe is reasonable but still conservative: the mean of the distribution of projected doses from DOE's performance assessment.* The primary reason we propose this requirement is that it provides a necessary context for implementation of the standard.... We believe that a thorough

> assessment of repository performance expectations should examine the full range of reasonably foreseeable site conditions and relevant processes expected during the regulatory time frame...."

66 Fed. Reg. 32125 (emphasis added). EPA went on to consider many of the rationales it now offers for selecting the median, but it rejected them, concluding instead "that, in the case of Yucca Mountain, the mean is an appropriate measure." *Id.*

In its June 2001 Responses to Comments in its prior rulemaking on Part 197, EPA similarly made clear that it would employ the mean rather than the median (emphasis added in each):

> Page 4-11: "Note that while we proposed using the higher of the mean or median, *in our final rule we specify that the mean be used* (see Section 7 of this document for a full discussion of our decision on this point.)"
>
> Page 7-3: "In line with EPA's use of the term 'reasonable expectation,' *the fundamental compliance measure consistent with the literal interpretation of this term would be the mean value* of the distribution of calculated doses."
>
> Page 7-3: "Although we proposed using the higher of the mean or median, *after further consideration we believe that the mean alone will be an appropriate measure of compliance*. We believe this approach is sufficiently conservative in that it leans toward giving greater weight to calculations that result in higher exposures, without being overly influenced by 'worst-case' and possibly extreme low-probability situations."
>
> Page 7-4: "*We have specified only that the mean of the dose assessments must meet the exposure limit,* without specifying any statistical measures for the level of confidence necessary for compliance, such as 95 or 99% confidence level for the mean. We believe setting a confidence level is clearly an implementation function that should be left to NRC...."
>
> Page 7-5: "*...EPA believes that the mean will reflect the effects of high dose situations sufficiently* and we do not feel the alternatives proposed are compatible with our approach."
>
> Page 7-6: "Because it is possible to observe skewed parameter distributions, a non-uniform dose distribution is not unexpected. Nevertheless, *we believe that use of the mean alone will adequately address these questions.*"

In proposing to use the median rather than the mean, EPA also would deviate from the practice of the NRC, which in its prior Yucca Mountain rule also specified that the mean would be used. In responses to comments, the NRC explained why the mean was the appropriate measure. Initially, it explained that the mean was consistent with the recommendations of the NAS:

> NAS recommended a performance objective for Yucca Mountain based on risk to an individual. Proposed part 63 defined "risk" to an individual as being proportional to two factors: (1) The dose to the individual from exposure to ionizing radiation and (2) the probability of the individual receiving that dose. Analyses conducted by NRC staff demonstrate that the mean annual dose correctly expresses the risk from radioactive exposure to the individual.

66 Fed. Reg. at 55752 (November 2, 2001). Additionally, NRC explained the statistical justification for selecting the mean rather than the median:

> The Commission expects that performance assessments conducted by [DOE] in support of any potential license application will use probabilistic methods to simulate a wide range of possible future behaviors of the repository system. Each possible future behavior of the repository system is represented by a curve describing the annual dose to the RMEI as a function of time. Generally, but not necessarily, each of the possible curves is assumed to be equally likely. Because none of these possible futures can be demonstrated to describe the actual future behavior of the repository system, the Commission requires that the applicant calculate the mean of these dose versus time curves, properly weighted by their individual probabilities.

Id. In other words, because no model run outcome is assumed to be more likely than any other modeling run, the mean, which treats each run as equally important, is more appropriate than the median, which treats higher, more dangerous outcomes as less important outliers. In contrast, the median artificially discounts high dose realizations (the distributions tend to be positively skewed) simply because they are high, with no justification in sound science, and notwithstanding that the doses are already weighted by their associated probabilities. Put another way, use of the mean violates the principle that all realizations are presumed to be of equal weight, absent some actual investigation of particular outliers that would raise questions about their scientific validity.

C. <u>EPA Lacks Any Rational Basis for Abandoning the Mean</u>

EPA's proposed rule offers no reasonable basis for diverging from the NAS's recommendation and from its own past practice, or for using one compliance measure for the pre-10,000-year period and another for the post-10,000-year period. Primarily, EPA cites uncertainties about Yucca Mountain and perceived "over-conservatisms" in DOE's modeling. These uncertainties and supposed over-conservatisms, EPA claims, call into question the higher values in DOE's modeling, and suggest that a performance measure that devalues those higher values is appropriate. EPA suggests that these uncertainty and over-conservatism problems are greater in the post-10,000 year period, and therefore suggests that its switch from mean to median at 10,000 years is somehow justifiable.

These explanations lack any logic or rationality. First, none of these explanations can mask the blatant inconsistency with the NAS's recommendations. The NAS stated that EPA should measure compliance at the time of peak dose, that there was no scientific basis for distinguishing between the pre-and post-10,000-year periods, and that EPA should use the mean as its measure of compliance. Both in substance and supporting rationales, EPA's proposed rule ignores those recommendations, and thus repeats the EnPA violations that led to the Court's invalidation of its previous Yucca rule.

Second, as discussed in detail in Section XIII of these comments, uncertainty provides no reason for creating a more lax standard, whether that laxity is achieved through a higher numeric standard or a more permissive statistical measure. EPA's mantra-like references to "uncertainty" are inconsistent with its rationale for selecting the median. Also, the premise of EPA's selection of the median is that the median tends to disregard higher repository performance model-run outputs, which EPA says should be treated as less important simply because they are higher. This has no statistical or scientific basis.

Similarly, as discussed in section XIV of these comments, conservatism provides no reason for selecting the median rather than the mean, because conservatism, if it actually existed (the reverse is the case), would be a reason for DOE to fix its modeling, not for EPA to adjust its standard. In any event, as discussed *infra,* DOE's modeling to date suffers not from over-conservatism, but from a gross *lack* of conservatism.

EPA's selection of the median is based on a basic misunderstanding of statistics. EPA's entire premise for selecting the median is that some model runs—specifically, those with higher predicted outcomes—should be given less weight than others. EPA repeatedly states that the median avoids placing "undue" emphasis on extreme events. Yet, as the NRC pointed out in defending the *mean* as an appropriate measure, "[g]enerally, but not necessarily, each of the possible curves is assumed to be equally likely." 66 Fed. Reg. at 55752; *see* Appendix B. In other words, each model run's outcome is as likely as any of the others, and a statistical measure specifically designed to throw out the higher numbers introduces a pronounced, non-conservative, and irrational skewing effect. But the mean is not skewed, as EPA implies, by those higher outcomes; in the averaging process, the results are treated as equally likely and important. No other approach is rational.

The selection of the median is statistically inappropriate for another reason. By selecting the median, which considers only the number, but not the magnitude, of "bad" (i.e. above-the-median) outcomes, EPA has declined to consider the degree of harm threatened by each of those bad events. Use of the median will discourage any investigation of high dose calculations since those high doses will have little or no effect on compliance. Indeed, use of the median will permit a finding of compliance notwithstanding hundreds of dose calculations showing lethal doses of radiation, because the median is insensitive to the actual magnitude of the approximately 42% of the dose calculations above it. As a hypothetical example, if 149 realizations (calculations) showed Yucca Mountain would destroy all of the nearby Nevada residents, but 151 of the realizations showed a dose of less than 350 mrem, the EPA approach would pass the repository. The reality is that for any safety evaluation, the magnitude of any potential bad outcomes does matter, and the mean takes that magnitude into account whereas the median does not. In fact, as Dr. Thorne points out (see Appendix C), the median has no well defined relationship to health detriment, so that EPA's proposed use of the median effectively severs the dose standard from the actual harm it is supposed to prevent. Such a standard is not even health-based, as required by law.

EPA fails to explain why focusing on "bad" outcomes is inappropriate for a safety analysis. Indeed, the typical goal of nuclear safety analysis is to focus precisely on the potential bad outcomes. The core purpose of a health and safety analysis is to figure out what will happen if things go wrong. No one would ever criticize levee builders for focusing on performance during extreme weather events rather than on routine sunny days.

Finally, by discounting the effects of high dose calculations, use of the median also reduces the very uncertainty EPA relies on for its choice of 350 millirem.

For those additional reasons, EPA and NRC acted appropriately in previously selecting the mean as their performance measure, and EPA's proposed abandonment of the mean is irrational, unscientific, and blatantly inconsistent with the recommendation of the NAS.

XII. EPA Arbitrarily Terminates Its Groundwater Protection Standard

In a cursory section of the proposed rule, EPA explains, without any legal or scientific justification, that the proposed rule would abruptly remove any groundwater protection standard at all once 10,000 years have elapsed. That premature abandonment of groundwater protection, at a stage when peak doses may not have already arrived, is ironic and disturbing in light of EPA's vigorous support of its separate groundwater standard in its previous rulemaking and in *NEI v. EPA*, 373 F.3d at 1278-1285, where it successfully defended that standard against aggressive challenges brought by NEI. Moreover, EPA has announced in advance that it will *not even consider comments* regarding "any aspect of the groundwater protection standards." 70 Fed. Reg. at 49024. That rigid determination to terminate the groundwater protection standard without any public comment, which stems from a fundamental misunderstanding of the Court's ruling in *NEI*, is arbitrary and contrary to law.

EPA's principal explanation for its termination of the separate groundwater standard is that it does "not believe the Court's ruling regarding the 10,000-year compliance period applies to the ground-water protection standards which have the same compliance period." 70 Fed. Reg. at 49024. The proposed rule states, "we are not proposing to modify the ground-water protection standards either by extending the period of compliance or in any other respect." *Id.*

Contrary to that premise, the Court's ruling does govern the separate groundwater standard. The court "vacate[d] Part 197 to the extent that it requires DOE to show compliance for only 10,000 years following disposal." 373 F.3d at 1273. In its conclusion, the Court reiterated the same statement, saying "in sum, we vacate 40 C.F.R. Part 197 to the extent that it incorporates a 10,000 year compliance period because, contrary to EnPA section 801(a), that compliance period is not 'based on and consistent with' the recommendations of the National Academy of Sciences." *Id.* at 1315. The groundwater protection standard is a component of Part 197, and it "incorporates a 10,000 year compliance period" and "requires DOE to show compliance for only 10,000 years." The court therefore expressly vacated this portion of the rule, and EPA's conclusion that the decision did not apply to the groundwater standard rests upon clear error.

The reasoning underlying *NEI v. EPA* compels the same conclusion. As the Court held, EnPA requires EPA to avoid inconsistency with the NAS's recommendations in setting all standards. That requirement must extend to the groundwater standard, for the same sentence of section 801(a) that empowers EPA to set standards also requires consistency with the NAS's report. *See* NEI, 373 F.3d at 1315. EPA cannot invoke the half of that sentence that empowers it to set standards yet ignore the other half, which requires that those standards be based upon and consistent with the findings and recommendations of the NAS, and thus any standards it promulgated could not employ a 10,000-year compliance cutoff after the NAS expressly rejected that cutoff. The logic of the court's opinion therefore supports its literal meaning and indicates, contrary to EPA's current position, that the 10,000-year cutoff of the groundwater protection standard has been vacated. EPA therefore cannot re-adopt that cutoff, especially without allowing comment.

EPA is well aware of the history of agency experiences with groundwater protection standards preceding its present proposal, including the appellate ruling in *NRDC v. EPA*, 824 F.2d 1258, 1293 (1st Cir. 1987), in which the court set aside the original groundwater protection requirements in the generic Part 191 radiation rule because the agency failed to allow for "proper notice and comment as required by the Administrative Procedures Act, 5 U.S.C. § 553(c)." History would repeat itself if EPA were to take the outrageous step of finalizing its approach to groundwater in the proposed Yucca rule without allowing other agencies and members of the public a full and fair opportunity to comment on the agency's dubious approach. Yet, EPA has arbitrarily decided not to consider and respond to comments on this critical subject. That decision would effectively preclude the public participation in rulemaking that is "necessary to ensure informed agency decision-making." *NRDC*, 824 F.2d at 1286.

Moreover, the logic of the Court's opinion, and the NAS recommendation upon which it is based, clearly indicate that EPA could not readopt the 10,000-year cutoff even if it did accept comment. The NAS rejected a 10,000-year cutoff because (1) it saw no scientific basis for drawing lines at 10,000 years; and (2) it realized that a 10,000-year cutoff would terminate the standards before the time of peak risk. That reasoning is just as applicable to groundwater protection as it is to individual exposure. The NAS already has concluded that the physical systems at the site, including all those that influence groundwater flow, are sufficiently predictable that there is no reason for cutting off compliance assessments at 10,000 years. And it has similarly noted that there is no sense in cutting off compliance assessments while the risk is just beginning to increase. Indeed, given DOE's assumption that no releases to groundwater will occur prior to 10,000 years, and EPA's ratification (through its agreement with DOE's assumptions about container corrosion) of that assumption, a 10,000-year-only groundwater standard would be nothing more than a public relations maneuver. For that reason, the NAS's recommendations and the Court's holding compel extension of the groundwater standard through peak dose. Indeed, the opinion is devoid of any suggestion that EPA, once it has decided it is necessary to provide a separate groundwater standard, could then adopt a period of compliance that the Court and NAS had expressly rejected.

EPA also fails to articulate any credible ground for terminating the groundwater standard that can be reconciled with its prior explanations of its groundwater protection policy, or with its statutory responsibility to promulgate standards protective of public health and safety. In its 2001 Final Rule, EPA observed, "we consider ground water that is, or could be, drinking water to be the most valuable ground water resource. We believe that it deserves the highest level of protection." 66 Fed. Reg. at 32128. The groundwater protection rule "continues a longstanding Agency policy of protecting groundwater resources and the populations who may use such resources." 66 Fed. Reg. at 32106 (June 13, 2001); see also EPA, "Protecting the Nation's Groundwater: EPA's Strategy for the1990s," Part 197 Docket No. A-95-12, item V-A-13. The separate groundwater standard was designed to "protect the groundwater in the vicinity of Yucca Mountain to benefit the current and future residents of the area who could use this ground water as a resource for drinking water and other domestic, agricultural and commercial purposes." 66 Fed. Reg. at 32106.

To excuse its early termination of groundwater protection, EPA insists in the proposed rule that public health protection from groundwater releases will be accomplished by extending the *individual protection* standard through peak dose. 70 Fed. Reg. at 49024. But, as discussed above, EPA's post-10,000-year individual protection standard is grossly inadequate. Application of the proposed 350-millirem (1000-millirem mean equivalent) standard to protection of public health from releases to groundwater would create the *lowest* level of protection, by far, ever proposed by a regulator, and would be contrary to the Agency's overall pollution prevention policies.

EPA's explanation also cannot be reconciled with its responses to comments addressing earlier challenges to the separate groundwater standard. As EPA then explained, the individual protection standard is not a sufficient substitute for groundwater protection. EPA stated that the individual protection standard, which focuses specifically on human health,

> would address ground-water resources and the viability of ecological habitats less effectively than would separate groundwater protection standards. We believe that ground-water protection standards will confer greater protection to aquatic or biological communities by limiting the contamination of groundwater that would discharge to the surface, such as springs or seep areas.... We have a longstanding policy to encourage protection of groundwater resources in a consistent manner in our programs that may affect groundwater directly or indirectly.

Responses to Comment, 6-11, 6-12. As EPA counsel orally confirmed during the *NEI* litigation, EPA's separate groundwater standard "furthers the statutory goal of protecting public health and safety." January 14, 2004 Transcript at 59. And in *NEI*, as EPA correctly notes, the Court "concluded that [EPA's] reasoning for including such a standard as a means to protect the ground-water resource was sound and consistent with the Agency's overall pollution prevention policies." 70 Fed. Reg. at 49024.

In sum, EPA's refusal to entertain comment on its retention of the 10,000-year period for the groundwater standard is both unwise and unlawful. The 10,000-year termination period cannot be reconciled with the ruling in *NEI v. EPA*, and the arbitrary decision to abandon the standard at that stage is inconsistent with EPA's statutory and ethical obligations regarding environmental protection and public health.

Problems with EPA's Rationales for Its Standard

XIII. <u>EPA Misunderstands the Importance of Uncertainty</u>

The core justification EPA offers for numerous components of its proposed rule—its lax, two-tiered standard; its use of the median rather than the mean; and its attempts to pre-set modeling parameters, among others—is increased "uncertainty" after 10,000 years. But the EPA and DOE studies relied on by EPA show no qualitative increase in uncertainty after 10,000 years, and there is good reason to believe that the uncertainty after 10,000 years will in fact be less. Therefore, uncertainty provides no foundation for EPA's proposed rule. This contention is set forth in great detail in a report prepared for Nevada by Dr. M. C. Thorne, *The Role of Uncertainties in Defining the Proposed Standard* (Nov. 10, 2005), attached as Appendix C.

Moreover, it defies logic and common sense to use uncertainty about Yucca's future performance as a rationale for a *looser* standard. If DOE is highly uncertain about whether its chosen site and systems will be safe, that uncertainty provides more reason for retaining a conservative, protective standard through peak dose, not a looser one.

EPA's discussion of uncertainty is terminally vague, and fails to specify not only the logical link between uncertainty and a looser standard but also the types of uncertainty upon which EPA bases its logical leaps. Had EPA actually considered specific sources of uncertainty, it would have found that no source provides a basis for rationalizing a looser standard. Moreover, as the Court has already pointed out, EPA's uncertainty rationale is inconsistent with the NAS's findings and recommendations

Perhaps most importantly, there is no uncertainty about two key points: First, because DOE's containers will fail, and because the site geology allows water to flow through the repository, Yucca's radionuclides will eventually escape into the environment. Second, almost every projected scenario shows that when they do escape, the dose to the RMEI will sharply exceed 15 millirem/year. Thus, while EPA invokes uncertainty as a reason to escape a traditional 15 millirem standard, there is no real uncertainty about compliance with that standard; the site plainly flunks. EPA's uncertainty rationale therefore is nothing but a red herring. The reality is that EPA is seeking to escape from promulgating a standard it knows Yucca cannot meet. No public health rationale underlies its decision-making.

A. Illogic of EPA's Reliance on Generic "Uncertainty"

Even if EPA were correct that Yucca's long-term performance after 10,000 years is qualitatively more uncertain, its proposed rule fails to explain how that uncertainty justifies a more lax standard. Such an explanation would be extraordinarily difficult to provide, for the reasonable response to uncertainty about the safety of an engineered system would be to demand greater protection, or preclude that system from being deployed at all. Reasonable regulators never would evaluate the safety of bridges, for example, against less stringent safety standards simply because engineers were able to predict their performance only over the short-term. That uncertainty should only make regulators more conservative, not less.

Consistent with that principle, EPA (and other federal agencies) have until now reacted to anticipated uncertainty by adopting *conservative* assumptions and standards. In fact, Nevada has confirmed that, when faced with uncertainty, EPA uses conservative assumptions and adopts conservative standards in all areas of health-based regulation except, now, for Yucca. EPA does not explain why it departs from these sensible precedents.

For example, EPA adopted conservative values of parameters or standards when there were uncertainties when it regulated underground injection of hazardous materials under a regulatory regime (40 C.F.R .Part 148, especially 40 C.F.R. § 148.21(a)(5)) requiring that there be no migration of the wastes for so long as they remain hazardous, 69 Fed. Reg. 15328 (March 25, 2004); when it developed a methodology for deriving air quality criteria to protect health, 65 Fed. Reg. 66444 (November 3, 2000); when it regulated pesticides to protect health, 64 Fed. Reg. 37022 (July 8, 1999) ("the greater uncertainty in the data associated with the assumptions, the more conservative (i.e., unlikely to underestimate exposure) the assumptions should be"), and 68 Fed. Reg.

15945, April 2, 2003 ("uncertainty was addressed in the screening level assessments...with conservative assumptions for model inputs"); when it increased the cover standards to limit emissions from uranium mill tailings because of uncertainty in long-term (1000 year) projections, 48 Fed. Reg. 45926 (October 7, 1983); when it set water quality standards for toxic pollutants, 64 Fed. Reg. 61182 (November 9, 1999); when it developed a policy regarding persistent, bio-accumulation of new chemicals, 64 Fed. Reg. 60194 (November 4, 1999) ("given...the uncertainty...due to lack of data, the TSCA new chemicals program is and must be conservative by nature"); when it set emission standards for locomotives and locomotive engines, 63 Fed. Reg. 18978 (May 14, 1998); when it adopted principles for estimating neuro-toxicity in risk assessments, 59 Fed. Reg. 43260 (August 17, 1994); when it regulated hazardous wastes using the 90th percentile Monte Carlo risk curve, 63 Fed. Reg. 42110 (August 6, 1998); when it regulated food additives, 56 Fed. Reg. 7750 (February 25, 1991) ("in addressing uncertainties [in quantitative risk assessment] however, EPA generally uses conservative assumptions to ensure that risks are not underestimated."); when it protected drinking water, 56 Fed. Reg. 3526 (January 30, 1991); and when it listed hazardous wastes under RCRA, 55 Fed. Reg. 11798 (March 29, 1990).

Other federal agencies use similar approaches. For example, OSHA used the 95th percentile (as opposed to the central tendency) value in risk assessments used to derive safety standards for workers' exposure to toxic chemicals, 62 Fed. Reg. 1494 (January 10, 1997) (standards for methylene chloride). And HHS uses conservatisms in addressing health effects, 61 Fed. Reg. 33511 (June 27, 1996) ("a conservative (i.e., protective) approach to address these uncertainties in health effects").

In fact, EPA's abandonment of its longstanding approach to uncertainty has the effect of protecting humans in Nevada less than fish, for NOAA used conservative assumptions when confronted with uncertainty in protecting fish populations, 59 Fed. Reg. 7647 (February 16, 1994); 57 Fed. Reg. 3952 (February 3, 1992).

B. Unreasonably Vague Treatment of Uncertainty

While EPA repeatedly emphasizes "uncertainty" as a core justification for its proposed rule, its discussions of uncertainty are hopelessly vague. EPA uses the term "uncertainties" generically. It rarely specifies either the particular uncertainties with which it is actually concerned, or their likely effects, and it never coherently explains how it believes specific types of uncertainty might justify a more lax or a two-tiered standard. This is especially important when one considers that the most obvious source of potential uncertainty, climate change, as well as others, are eliminated from consideration.

This is a crucial failure. It precludes Nevada and others from knowing which uncertainty sources EPA considers important, and why EPA believes those sources might justify a higher standard. Indeed, EPA's failure to specify the relevant uncertainties suggests that EPA may not even know which uncertainties matter, or what the implications of particular sources of uncertainty actually are. Indeed, as noted earlier, premising a rule on uncertainties in the licensing analysis before the licensing analysis is even done is itself speculative to the point of being useless.

In lieu of specific discussion, EPA's proposed rule relies on inapposite analogies. EPA suggests that just as hurricane watchers cannot predict, several days in advance, where exactly a hurricane will strike and how damaging it will be, DOE will be unable to predict when peak dose will occur at Yucca Mountain. This analogy has some truth; because of major uncertainties about when its containers will fail, DOE does not know the timing of peak dose, and its projections that doses will increase only after 10,000 years are assumption-based modeling artifacts. But EPA misunderstands the relevance of its own analogy. Just as the Army Corps of Engineers should not measure levees against lax safety standards because it cannot predict exactly when Katrina-esque hurricanes will strike, Yucca Mountain should not be held to a looser standard simply because DOE cannot project when exactly the engineered barriers will fail. They will fail, and radionuclides will escape, at some time. EPA's standard must protect against that threat even if EPA and DOE are uncertain whether it will occur in 400 or 400,000 years.

The particular sources and types of uncertainty that exist at Yucca Mountain do have implications for regulatory decision-making. Some uncertainties imply that the site should be more carefully studied. Others imply the need for better engineering, or for a different site. *None* of these types of uncertainty provide any basis for a looser standard, or for taking a different approach to assessing post-10,000-year compliance. The report by Dr. Thorne establishes this fact. On a regulatory policy level, uncertainty about potential flaws in DOE's engineering barriers provides a reason for demanding better-engineered systems or, perhaps more realistically, for locating a site where geologic systems provide containment and thus mitigate the impact of the engineered barriers' inevitable failure, as is the case with DOE's WIPP repository site, for example. But it defies logic to suggest that DOE is entitled to a looser safety standard because it cannot say for certain whether its engineered systems will work.

The NAS was clear that reasonable predictions of the performance of the natural systems can be made within the period of geologic stability. But here too, DOE is not entitled to a looser safety standard simply because it is uncertain how its chosen site will behave because it stopped its site investigation program before all of the data were in. Also, some natural systems at the site will change in the future—for example, climate will vary, earthquakes may occur, and volcanic eruptions may disrupt the repository—and some uncertainties do exist with respect to such changes. The NAS considered possible uncertainties in natural system behavior and specifically concluded that they did not preclude assessments of performance at peak dose. It repeatedly rejected any suggestion that these parameters change and become more unpredictable at 10,000 years, noting that "earth scientists are accustomed to dealing with physical phenomena over long time scales." *Id.* at 71. But again, such uncertainties, even if they were more than NAS assessed, are no basis for setting a laxer standard. If Yucca were a better site, with much longer geologic containment, these uncertainties would matter much less or not at all. A poor site is no justification for a lax standard.

C. EPA's Uncertainty Rationale is Inconsistent with the NAS's Recommendations

EPA's reliance on "uncertainty" as justification for a two-tiered standard is also thoroughly inconsistent with the findings of the NAS. EPA's core rationale for its looser standard is that unspecified uncertainties render long-term compliance assessments less meaningful than those for shorter periods. In a typical statement, EPA writes that

> we also believe that over the very long periods leading up to the time of the peak dose, the uncertainties in projecting climatic and geologic conditions become extremely difficult to reliably predict and a technical consensus about their effects on projected performance in a licensing process would be difficult, or perhaps impossible, to achieve.

70 Fed. Reg. at 49029. Accordingly, EPA states that "in formulating an approach to compliance out to peak dose, we have established 10,000 years as an indicator for times when uncertainties in projecting performance are more manageable...." *Id.*

The NAS's findings, however, were to the contrary.[2] "Implicit in setting a Yucca Mountain standard," it concluded,

> is the assumption that EPA, USNRC, and DOE can, with some degree of confidence, assess the future performance of a repository system for time scales that are so long that experimental methods cannot be used to confirm directly predictions of the behavior of the system or even of its components. This premise raises the basic issue of whether scientifically justifiable analyses of repository behavior over many thousands of years in the future can be made. *We conclude that such analyses are possible,* within restrictions noted in this report.

NAS Report at 1 (emphasis added); *see also id.* at 55 (specifically rejecting increasing uncertainty as a reason for a different approach after 10,000 years); *id.* at 68. The NAS noted one specific restriction on that conclusion—its determination that future *human* scenarios were too uncertain to model—but otherwise adhered to the consistent conclusion that uncertainties did not preclude meaningful assessments of long-term compliance with a numeric standard. *Id.* And it expressly rejected any suggestion that 10,000 years represents a significant crossover point at which uncertainties render long-term compliance assessment less meaningful, finding that "there is no scientific basis for

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[2] In addition to being inconsistent with the findings and recommendations of the NAS, EPA's conclusions about steadily increasing uncertainty are wrong. Even if DOE is correct in its optimistic assumptions about short-term performance of the waste canisters, its current modeling graphs indicate that the range of modeling results rises initially but then *decreases* as time passes. *See* Appendix C. And if those engineering assumptions are acknowledged to be major sources of uncertainty, the highest levels of uncertainty are likely to occur even earlier.

limiting the time period of an individual-risk standard in this way." *Id.* at 6. The NAS report thus contains an unequivocal rejection of the notion that uncertainties are somehow more unmanageable in longer-term compliance projections.

Rather than acknowledging, let alone avoiding, this conflict, EPA attempts to mask it through disingenuous discussion of the NAS report. EPA quotes the NAS stating, "[b]ecause there is a continuing increase in uncertainty," and suggests that this carefully selected excerpt indicates that the NAS clearly agrees with EPA's view that "uncertainties generally increase with time, at least to the time of peak dose." 70 Fed. Reg. at 49025. But the entire NAS quote states: "Because there is a continuing increase in uncertainty about most of the parameters describing the repository system farther in the distant future, it might be expected that compliance of the repository in the near term could be assessed with more confidence. *This is not necessarily true.*" NAS Report at 72 (emphasis added). The NAS then explained why "this is not necessarily true," pointing out that many site parameters (like geologic parameters) do not change with time, and that others are more significant during the short term. *Id.*

EPA also attempts to mask its continued disagreement with the NAS by labeling its uncertainty rationale a mere matter of "policy," and by citing exceedingly general statements from the publications of other nuclear regulatory authorities. But the NAS's uncertainty-related determinations quite clearly were not policy determinations. The NAS instead considered those determinations, all of which relate to specific scientific issues like present and future geology, climate, and hydrology, to be well within the bounds of its scientific authority. EPA may disagree with those conclusions, but it may not escape the EnPA's mandate simply by attempting to characterize its technical disagreement with NAS as a "policy" dispute.

D. Prior Judicial Rejection of Uncertainty Rationale

In employing an uncertainty-based rationale directly at odds with the NAS's findings and recommendations, EPA has not only abrogated EnPA's mandate; it also has attempted to resurrect an approach already rejected by the Court. That attempt suggests that EPA does not realize, or is choosing not to acknowledge, that it is bound by a judicial decision.

Uncertainty was a key rationale for the portion of 40 C.F.R. Part 197 that the Court has already set aside. In attempting to justify its previous 10,000-year cutoff, EPA asserted, just as it asserts today, that "we have concerns regarding the uncertainties associated with such projections, and whether very long-term projections can be considered meaningful." 66 Fed. Reg. at 32096. It similarly stated that "[d]espite NAS's recommendation, we conclude that there is still considerable uncertainty as to whether current modeling capability allows development of computer models that will provide sufficiently meaningful and reliable projections over a time frame up to tens-of-thousands to hundreds-of-thousands of years." *Id.* at 32098. And it sought to cast a gloss of "policymaking" over those statements, asserting that "the selection of a compliance period for the individual protection standard involves both technical and policy considerations." *Id.*

EPA heavily relied on that "uncertainty" rationale in its arguments before the Court. It claimed that the 10,000-year cutoff was justified partly by "the large uncertainties inherent in attempting to project human exposures to releases from the repository for time periods over 10,000 years...." EPA Brief at 14, 19. And it provided a detailed discussion of these uncertainties, suggesting, in terms highly similar to those of the current proposed rule, that increasing uncertainties made long-term compliance projections untenable. *Id.* at 44-45. At oral argument, EPA's counsel clearly repeated EPA's attempt to cast this uncertainty rationale as a key policy judgment, arguing, in response to a question about the "policy aspects" of EPA's decision, that uncertainty was "one of the most significant" policy rationales for treating the post-10,000-year compliance assessment differently. Oral Argument Transcript, *NEI v. EPA*, at 25. EPA's current argument—that uncertainty justifies a different post-10,000 year standard—thus has already been considered and rejected by the Court.

The Court rejected EPA's 10,000-year cutoff and the uncertainty rationale upon which it purported to rest. 373 F.3d at 1270-73. Indeed, at oral argument, Judges Tatel and Edwards repeatedly indicated that they were well aware that EPA was trying to use uncertainty to justify its differing treatment of the post-10,000-year period and questioned EPA's discretion to employ that rationale. In a typical statement, Judge Tatel, responding to EPA's attempt to cast its uncertainty disagreement as a policy disagreement justifying its 10,000-year cutoff, said, "but that's the scientific judgment that Congress wanted the EPA to defer to." Transcript at 25. That transcript, the former rule, EPA's briefing, and the decision itself all indicate that EPA has already litigated its uncertainty rationale and lost. Accordingly, EPA is legally prohibited from resurrecting "uncertainty" as the core rationale for a permissive post-10,000-year standard.

XIV. EPA Misunderstands the Need for, and Absence of, Conservatism

The other core pillar of EPA's rationale for its proposed rule is its suggestion that analysis of the future performance of Yucca by DOE will be "overly conservative." EPA posits that DOE's models will be overly negative in their predictions of repository performance, and that EPA must therefore create a lax rule to accommodate or balance out that negativity.

Elsewhere in these comments, Nevada will explain that judgments about the conservatism of DOE's modeling—which has not yet been completed—are not EPA's to make. Here, Nevada focuses solely on the irrationality of relying on perceived over-conservatism as a rationale for a lax standard, explaining why EPA's reasoning is both flawed and lacking in empirical basis.

A. EPA's Failure to Explain Its "Over-Conservatism" Rationale

The first major problem with EPA's over-conservatism rationale is that EPA never explains it. EPA never describes the logical link between an overly conservative analysis and a more lax, second-tier standard. Nevada infers that EPA believes the standard must be lax to accommodate perceived weaknesses in the modeling, but EPA itself has never specified this or any other rationale. But even this rationale, if expressed, would be unreasonable, for the proper remedy for flawed modeling is to fix the modeling, not to weaken the standard. If EPA intended to say that, because of inevitable increased conservatisms after 10,000 years, a 350 millirem/year standard is the equivalent of 15 millirem/year, it has failed to support its premise. In fact, the opposite premise is the more supportable one. The report by Dr. Thorne in Appendix C confirms this.

In support of its statements about conservatism, EPA does cite a 2005 report prepared by its contractor, Cohen and Associates. But that report cannot support any proposition about the degree of conservatism in DOE's analysis. To evaluate whether DOE's past modeling was overly conservative, the report would have needed to determine which assumptions were conservative and which were optimistic. It would then have needed to quantitatively assess the relative importance of those assumptions to determine whether the overall results were shifted toward conservatism or optimism. Because some degree of conservatism normally is considered desirable in a risk projection—particularly where, as EPA repeatedly states is the case here, there is some uncertainty about the projections—EPA would also need to determine whether any resultant shifting of the projections was excessive.

The Cohen report contains no such analysis. Instead, it provides a qualitative and almost totally one-sided discussion. It summarizes almost every assumption that could conceivably be characterized as conservative, sometimes even double-counting the same assumptions. With the exception of a handful of pages (discussed in detail below) in chapter 5, however, the report does not even consider whether optimistic assumptions have been made. Moreover, nowhere does the report perform any quantitative analysis of the effects of the assumptions it identifies, let alone quantitatively address the effects of the optimistic assumptions it ignores. The report is thus like a legal analysis that addresses only one side of an argument; it is completely unbalanced and provides no basis for EPA to conclude that DOE's modeling is overly conservative. Moreover, the Cohen report fails to support the actual rule proposed by EPA which, as noted above, eliminates many uncertainties and potential conservatisms from the analysis.

B. A Bounding Approach is the Only Appropriate Approach

EPA's conservatism rationale founders for a second reason: EPA fails to explain why conservatism is inappropriate. To the extent conservatisms are unnecessary, and can be replaced by more realistic analyses, this is the appropriate solution – not weakening the standard. Indeed, by premising the rule on alleged conservatisms after 10,000 years, the rule has the perverse effect of discouraging DOE and NRC from doing more realistic analyses, lest the premise for application of EPA's rule be found lacking and the licensing process be thrown into confusion.

To the extent the state of scientific knowledge does not permit realistic analyses, then bounding assumptions and analyses are inevitable, but we have no way of knowing how such bounding assumptions and analyses are conservative. It defies scientific logic to give credit for "conservatisms" when it cannot be established whether the conservatisms actually exist. In fact, as discussed above, EPA traditionally considers conservatism an important and necessary response to this kind of uncertainty.

Such conservatism is particularly important for Yucca Mountain, because EPA's standard and NRC's licensing process will likely be the only opportunities to "test" the safety of the repository design. If DOE, EPA, and NRC eschew conservatism in their approval process and allow the construction of a repository with only a moderate probability of success, they will create a major risk for future generations—without giving those future generations any tools to manage that risk. Those future generations may not have any ability to undo repository failures, or even to know that the repository exists. A conservative standard now will be the primary protector of their safety.

C. DOE's Analysis Will Not Be Conservative

As noted above, the greatest uncertainty in the performance of the repository relates to the timing of the peak dose, which is itself entirely dependent on the lifetime of man-made waste packages. If DOE's optimistic assumptions about container life are wrong, then DOE's entire performance evaluation becomes extremely non-conservative. EPA itself has noted the importance of this issue, which, if DOE's assumption is wrong, has led modelers to vastly overestimate the ability of the repository to contain waste.

There is no disagreement that DOE's waste containers eventually will inevitably fail, and that Yucca's porous geology will permit leaking radionuclides to reach the accessible environment. The timing of that failure is uncertain, for DOE is proposing to employ engineered systems that have never been tested on anything approaching the time scales over which DOE hopes they will provide protection. Finally, there is no genuine dispute that the resistance—or lack thereof—of the containers to corrosion is the crucially important determinant of the timing of peak dose.

In its recent report, EPA's contractor provided a detailed discussion of DOE's lack of knowledge about when its containers will fail. Initially, the Cohen report noted that DOE's proposed system is unique. "Unlike most concepts adopted by other nations," it stated, "the proposed Yucca Mountain repository exposes the metallic waste packages and drip shields to sustained oxidizing conditions." Cohen at 5-1. It then noted that the performance of that unique system was difficult to predict. "Engineering experience," the report stated, "with passive metals is extremely short (i.e., approximately 100-150 years) compared with the timeframe of repository performance projections. Extrapolation of present knowledge to the longer timeframe is thus highly uncertain." *Id.* at 5-13 (parentheses in original). It later added that "[t]he failure, to date, to identify clear natural or archeological analogs for long-term passive metallic behavior seriously limits confidence regarding the stability of passive films in providing extremely long-term corrosion resistance." *Id.* at 5-15.

In drawing these conclusions, the Cohen report cited, and followed, the conclusions of leading corrosion experts. In 2001, an expert panel considered corrosion risks to the Yucca Mountain containers. That panel "called attention to how little is presently known about the nature of passive film on Alloy 22," the alloy to be used to provide corrosion resistance for containers at Yucca Mountain, and it considered a series of ways in which the containers might fail. *See id.* at 5-15 to 5-16 (quoting Sagues, 2002).

The Cohen report also emphasized the threat of unanticipated modes of corrosion. "[U]nexpected modes of alloy deterioration often emerge when service conditions deviate (even on a microscopic scale) from anticipated regimes," it wrote, and it concluded that "the possibility of other unexpected but potentially severe deterioration mechanisms developing into the far future cannot be dismissed easily." *Id.* at 5-13 (parentheses in original). The expert review on which the Cohen report relied similarly identified a series of potential failure modes that would merit further study.

In addition to being highly uncertain, the corrosion resistance of the casks is critically important. The Cohen report notes that "the choice of corrosion rates for the performance projections is a major factor in both estimating the magnitude and time of peak dose projections." Cohen at A-20. EPA similarly emphasizes that corrosion is "exactly the critical element in estimating the timing and magnitude of peak dose." 70 Fed. Reg. at 49026. This importance exists for an obvious reason; because water always is percolating through Yucca Mountain, radionuclide transport will begin as soon as radionuclides are released, and corrosion rates therefore will determine when releases take place. Indeed, the effect of those corrosion rates on repository performance is so great that EPA's own economic impact analysis suggests that there is little value in attempting to reduce any other sources of uncertainty. Cohen at A-20.

EPA's own documents thus indicate (1) that the rate of corrosion is of enormous importance; and (2) that EPA and DOE have very little certainty about how quickly corrosion will occur. Nevertheless, DOE's models, to date, consistently have assumed that no corrosion-related failure will occur during the first 10,000 years of the repository lifetime, and, indeed, that robust corrosion resistance will continue for additional thousands of years. *DOE thus has assumed the certain performance of one of the most uncertain aspects of the repository system.*

This assumption undermines EPA's speculative theory that DOE's modeling will be "overly conservative." DOE has made highly optimistic assumptions about the single most critical variable affecting repository performance, notwithstanding the "various sources of worse-than-anticipated performance of the WP that have not been sufficiently investigated, or, in some instances, would be very difficult to evaluate in a short research period." Cohen at 5-16. That assumption leaves DOE's analysis as optimistic as a safety assessment of the Titanic that assumed the ship certainly would not collide with icebergs, or an analysis of the Hindenburg's safety that ignored the potential proximity of sparks.

Moreover, corrosion assumptions are just one of many potential sources of optimism in DOE's proposed modeling. Neither DOE nor EPA has done a comprehensive analysis of optimistic assumptions and their potential consequences, but, as discussed in detail elsewhere in these comments, several other assumptions and modeling techniques could similarly skew the analysis. For example, EPA's proposed exclusions of criticality events, EPA's ratification of DOE's assumption of the non-existence of manufacturing defects, EPA's exclusion of natural events it considers "unlikely," and EPA's exclusion of localized corrosion and other potential engineering problems all would skew DOE's modeling toward potentially excessive optimism. *See* discussion *infra* on FEPs. That excessive optimism vitiates any attempt by EPA to rely on supposed "over-conservatism" as a justification for a lax second-tier standard.

XV. <u>EPA Misuses Natural Background</u>

EPA's proposed rule offers a convoluted and arbitrary rationale for what its second-tier standard should be. EPA suggests that "given the large uncertainties surrounding the outcomes at these unprecedented time frames," it is reasonable to set a standard based on natural background radiation levels in one of the nation's more radioactive states: not Nevada, where Yucca Mountain actually is, but Colorado. On this rationale, EPA concludes that allowing 350 millirem/year of anthropogenic exposures to Nevada's citizens is appropriate. But for a series of reasons, EPA's background rationale is fatally flawed.

A. <u>EPA's Natural Background Rationale is Inconsistent with EPA's Own Past Conclusions and NAS's Recommendations</u>

First and foremost, EPA's Colorado rationale is flatly inconsistent with EPA's past standards and conclusions, and with the NAS's recommendations. Although EPA has been regulating anthropogenic radiation exposures for decades, it has never used this type of standard or invoked this natural background rationale before. Instead, its consistent past practice has been to follow the international consensus and allow a maximum of 100 millirem/year of anthropogenic exposures *from all sources combined*, and to allow individual sources to contribute no more than 15 millirem/year of exposure, a level it noted was consistent with the NAS's recommendations (a range of 2 to 20), and that EPA continues to assert is appropriate for Yucca Mountain in the pre-10,000-year period. 66 Fed. Reg. at 32088 (15 millirem/year is "within the NAS-recommended range"); *see* NAS Report at 41 (describing the international consensus supporting this level). EPA has viewed the 15 millirem/year level of protection as consistent with the specific recommendations of the NAS report.

In soundly rejecting suggested 25 millirem, 70 millirem, and 150 millirem standards, EPA never even hinted that existing natural background levels in other places somehow would have made those higher levels appropriate. *See* EPA Response to

Comments at 4-5 to 4-6. Instead, EPA has taken the consistent position that 15 millirems is the reasonable limit on anthropogenic exposure from one source. Likewise, where the NAS spoke of natural background as a benchmark for acceptable exposures, it referred only to the "concept of negligible incremental dose (above background levels)," a concept that suggests that repositories should cause negligible incremental changes—not a doubling—of existing background levels. *See* NAS Report at 8-9 (parentheses in original).

EPA's proposed rule never comes to terms with this sharp divergence from its past practice. At most, EPA insinuates that international bodies support its new notion that anthropogenic sources should be able to double existing natural background levels. But in fact they do not. EPA's citations are misleading and out of context. See Appendix A. As EPA itself noted, "[n]o regulatory body that we are aware of considers doses of 150 mrem to be acceptable," and those international bodies have never suggested that natural background levels should create an exception to the more stringent limits they have created. EPA, Response to Comments at 3-8.

There is good reason for EPA's (and other standard setting agencies') past reluctance to use natural background or variations in natural background as a basis to establishing acceptable levels of risk. A risk is not acceptable just because it is "natural." Societies undertake extraordinary measures to eliminate or mitigate such natural hazards as hurricanes, tornados, and toxic substances found in nature like botulism. Moreover, the concept that variations in natural background pose acceptable risks is based on the highly doubtful premise that people are knowledgeable about these radiation levels, and the associated health effects of radiation, when they choose where to live or work. Finally, even if these comparisons were relevant, EPA cannot explain how they are uniquely relevant to the period after 10,000 years.

B. EPA's Colorado Rationale is Irrational and Inconsistent with Past Practice and NAS's Recommendations

Discerning how the Colorado rationale is actually supposed to justify EPA's proposed standard is not easy, for EPA's explanation of the rationale is far from clear. EPA never performs any kind of risk assessment that concludes that a 700 millirem total exposure is safe. Nor does it ever suggest that the fact that people's choices to live in Colorado reflect a societal judgment that such exposure levels are safe; EPA specifically states that "[i]t should be clear that we are not arguing that most people take into account levels of background radiation when deciding where to live or work, or that it in any way plays a major role in their decision-making." 70 Fed. Reg. at 49038. Instead, EPA reasons that since levels of exposure near 700 millirem/year occur naturally in a few isolated places, and people live in those areas without obviously dying in droves, a standard that allows 350 millirem/year anthropogenic exposure on top of the already occurring 350 millirem/year of natural exposures in the Amargosa Valley must suffice. As EPA puts it, risk levels apparently are fine so long as "in EPA's view" those levels "do not 'pose a realistic threat of irreversible harm or catastrophic consequences.'" *Id.*

EPA does not explain why it holds this view. But the rationale is in any event arbitrary. EPA's role is to establish a standard protective of public health and safety, and never in the past has it considered that role to be fulfilled merely through avoidance of "a realistic threat of irreversible harm or catastrophic consequences." Instead, it has set standards, both to protect people from radiation and in other regulatory contexts, designed to allow only the most minimal of increases in the levels of cancer and other illnesses already induced by background levels of radiation.

Moreover, EPA itself has acknowledged, as has the NAS, the general consensus views that natural background radiation levels are not "safe." The NAS noted that "[i]nternational scientific bodies currently accept what is called the linear, or no-threshold hypothesis for the dose-response relationship.... The no-threshold hypothesis holds that there is no dose, no matter how small, that does not have the potential for causing health effects." In its original 40 C.F.R. Part 197 rule, EPA, after discussing research on the health risks of radiation exposures, similarly noted that even natural background levels cause human harm. "We believe," EPA stated, "that the best approach is to assume that the risk of cancer increases linearly *starting at zero dose*. In other words, any increase in exposure to ionizing radiation results in a constant and proportionate risk in the potential for developing cancer." 66 Fed. Reg. at 32080-81 (emphasis added). EPA specifically noted that the risk of anthropogenic radiation could not be considered in isolation, but instead must be considered in addition to the pre-existing risks created by background conditions. "The risk of interest," EPA stated, "is not at or near zero dose, but that due to small increments of dose above the pre-existing background level." *Id.* at 32080 n.6. It is for this reason that EPA in the past has always sought to keep anthropogenic exposures at levels well below background levels; it has respected the scientific consensus that even background levels kill. *See also* EPA, *A Citizen's guide to Radon*, OAR-2005-0083-0058, at 2 (noting that background levels of radon kill an estimated 21,000 Americans every year, and that radon is a larger source of death than drunk driving).

Similarly, EPA's implication that it can safely create Colorado-like levels of exposure in Nevada because people live in Colorado is untenable.[3] Simply because a risk exists naturally in one location does not mean that it is acceptable or "safe" for humans to create it somewhere else. We would never accept as "safe" a human project that creates San-Francisco-like levels of earthquake risk in Chicago, or that subjects Washington D.C. to the risks of hurricane damage that Miami naturally faces, even though millions of people live in the at-risk areas. Similarly, EPA has no basis in implying that because people live in Colorado now, the radiation levels they may face may acceptably be created elsewhere.

In setting other health and safety standards, EPA has frequently rejected

[3] This also is only an implication; EPA is never brazen enough to expressly state this rationale. But its invocation of the Colorado rationale clearly appears designed to foster the impression, even if EPA attempts to disclaim this rationale, that future Nevadans will be safe because they will face risks already allegedly borne by some Coloradans.

comparisons with natural background. Earlier this year, EPA rejected the concept that emissions of hazardous materials should not be regulated if the resulting levels in the environment are within the bands of variation in ambient background levels. 70 Fed. Reg. 19992, April 15, 2005 (rule limiting emissions from coke oven batteries), citing with approval 54 Fed. Reg. 38044, September 14, 1989 (rule limiting emissions of benzene and other hazardous materials). EPA also rejected a natural background radiation rationale when it set health-based emission standards for radioactive materials under a statutory regime (the Clean Air Act) identical to the Atomic Energy Act, 54 Fed. Reg. 51654, December 15, 1989, and when it set standards limiting radioactive emissions from uranium mills, 51 Fed. Reg. 42573, November 2, 1986. Notably, EPA rejected comparisons with natural background when it proposed changes in guidance to all federal agencies on the formulation of radiation protection standards. 66 Fed. Reg. 66414, December 23, 1994 ("although the average level of exposure to natural background provides perspective, it does not, however, provide justification for the RPG [Radiation Protection Guidance], since it represents an uncontrollable source of risk, and the RPG applies to controllable sources").[4]

Additionally, EPA's rationale misunderstands the role of radon in creating natural exposures in Colorado and elsewhere. As EPA acknowledges, most natural exposures, in Colorado and elsewhere, result from radon. Indeed, in Colorado radon accounts for approximately 87% of total radiation exposure. S. Cohen and Associates, *Assessment of Variations of Radiation Exposure in the United States* (2005), OAR-2005-0083-0077, at 4. But radon exposures are locally variable, site-specific, and amenable to mitigation; a person lives with radon risk because either they are ignorant of that risk or they have made a conscious choice not to deal with it.

C. EPA's Selection of Colorado as Its Benchmark is Arbitrary

Independently of the errors discussed above, EPA's method of choosing its natural background benchmark is irrational. If EPA were to utilize a natural background standard, the most logical benchmark for that standard would be natural levels in the Yucca Mountain area or, perhaps, in the nation as a whole, which has average radiation levels significantly lower than those that already exist in the Amargosa Valley.[5] But EPA has deliberately rejected both possibilities, and has chosen Colorado for two simple reasons: first, because Colorado has substantially higher natural background radiation

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[4] In its proposed rule, EPA concedes that "meaningful distinctions are made today between natural background radiation and additional incremental (and involuntary) exposures caused by human activity." 70 Fed. Reg. at 49039. Without offering any explanation, EPA asserts that those distinctions somehow become irrelevant over longer time frames.

[5] If EPA believes natural background levels provide an appropriate benchmark for the total level of risk from all sources of radiation, the repository should not be located in Nevada *at all*, for Nevada already has higher-than-the-national-average risk levels.

than the Amargosa Valley or the country as a whole; and second, because Colorado also is in the western United States.

EPA's reliance on the former reason is completely circular. In effect, EPA has determined that increased radiation is appropriate by comparing conditions in the Amargosa Valley to a subset of other states, all of which it selected specifically because they have higher exposure levels, and within that subset has chosen Colorado over Idaho apparently just because Colorado is more radioactive. EPA thus based its conclusion that higher exposure levels are allowable on the premise that its analysis must produce a conclusion that higher exposure levels are allowable. Put differently, EPA has proposed that Nevada can have substantially higher exposure levels because Colorado does, and has said that Colorado is an appropriate comparison because it has substantially higher exposure levels. This reasoning lacks any logic. Comparing Nevada to Colorado because both are in the West, and therefore determining that Colorado's natural background levels are appropriate for Nevada, is as reasonable as suggesting that humans could appropriately recreate New Orleans' flood risk in Atlanta because both are in the South.

EPA has provided no other reason for its selection of Colorado. That selection therefore appears to represent an obvious effort by EPA to rig its analysis, and to justify its predetermined conclusion that an unprecedentedly high standard should be employed.

D. EPA Use of Natural Background Wrongly Assumes Natural Risks are Acceptable

As the report by Dr. Fleming in Appendix D establishes, EPA cannot assume that natural background or variations in natural background are acceptable risks. Yet this appears to the basis for EPA's proposal.

XVI. EPA Abandons Intergenerational Equity

Having incorrectly determined that "uncertainty" renders impossible a traditional, apportioned standard, EPA proposes that it needs an alternative, and that 350 millirem/year is acceptable as a putative "policy" choice. But EPA offers no real explanation of why 350 millirem/year, which EPA does not consider acceptable today or 10,000 years from now, should be considered acceptable after 10,000 years. EPA hints that principles of intergenerational equity somehow support its proposed rule, but for a series of reasons, that implication is illogical, unjustified, and ethically wrong.

These flaws are explained in detail in Appendix D, a white paper prepared by Professor Patricia Ann Fleming, Ph.D. Dr. Fleming's full report must be considered. She considers the ethical implications of EPA's proposed action and the ethical rationales EPA has stated, or implied, in support of that rule, and concludes that EPA misconstrues accepted principles of intergenerational ethics, mischaracterizes the sources upon which it relies, and has offered an incomplete and internally inconsistent ethical rationale. Nevada incorporates Dr. Fleming's paper, in its entirety, by reference into these comments.

A. Vagueness

Initially, EPA's discussion of intergenerational equity is fatally vague. EPA never actually states what equitable principle it is adopting. Instead, EPA's proposed rule provides a cursory, selective, and inaccurate survey discussion of a few intergenerational equity theories, none of which EPA itself has ever adopted in the past. *See* Appendix D (discussing EPA's selective use of sources and its mischaracterization of the limited set of sources it does cite). EPA then hints at the notion that an action is equitable so long as it does not impose catastrophic burdens upon future generations. EPA never clearly articulates the principle it is endorsing, let alone explains why EPA considers that particular principle to be just, equitable, or appropriate. That failure of explanation leaves intergenerational equity as an improper basis for EPA's rule, for EPA cannot merely hint that a policy justification for its proposed action *might* exist; it must actually articulate and support its purported policy rationale.

B. Inconsistency with Past Statements and Policies and Relevant Law

EPA's failure of explanation stands in sharp contrast to its prior Yucca rule, in which EPA clearly articulated the "fundamental principle of intergenerational equity" that "we should not knowingly impose burdens on future generations we ourselves are not willing to assume." 66 Fed. Reg. at 32107. EPA does not explain whether it is abandoning this "fundamental principle" now, or how its proposed rule, which quite clearly does impose additional burdens on future generations, could possibly be reconciled with this "fundamental principle."

EPA's proposed rule is similarly suspect in light of the NWPA, which requires protection for future generations. In the NWPA, Congress stated that "appropriate precautions must be taken to ensure that such waste and spent fuel do not adversely affect the public health and safety and the environment for this or future generations." NWPA § 111(a)(7). This Congressional statement supports EPA's erstwhile "fundamental principle" that "we should not knowingly impose burdens on future generations that we ourselves are not willing to assume." 66 Fed. Reg. at 32107. But it is irreconcilable with EPA's current proposal to subject future generations to burdens that current generations have never deemed acceptable. Congress's statement is similarly inconsistent with any implication that future generations need not be accorded protection and ethical standing.

EPA's proposed rule also violated the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, to which the United States has agreed. That convention provides that contracting parties shall take appropriate steps to "strive to avoid actions that impose reasonably predictable impacts on future generations greater than those permitted for the current generation."[6] Section 101 of the National Environmental Policy Act has similar language in its declaration of a

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[6] *See* http://www.iaea.org/Publications/Documents/Conventions/jointconv.html (last checked November 7, 2005).

national environmental policy. The EPA rule reflects no such effort. It instead is predicated on an unlawful repudiation of this principle, for it would *purposefully* "impose reasonably predictable impacts on future generations greater than those permitted for the current generation."

The EPA rule is also contrary to one of the key IAEA "Principles of Radioactive Waste Management" (IAEA 1995), agreed to by the United States, that "radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today." EPA offers no reason why the United States should change its policy now with respect to Yucca and Nevadans. Nor does it have the authority to set or change U.S. policy in this regard; its sole duty here was to set a health-based standard that would protect this *and* future generations.

C. EPA's Implied Principle Misunderstands Intergenerational Equity

EPA's proposed rule also reflects a basic philosophical misunderstanding of intergenerational equity. Principles of intergenerational equity traditionally have been designed to *protect* future generations from unfairly bearing the burdens of current generations' activities. For example, EPA stated that "we should not knowingly impose burdens on future generations that we ourselves are not willing to assume." 66 Fed. Reg. at 32107; *see also* Appendix D. Yet EPA apparently would turn that notion on its head, implying that intergenerational equity is a *justification for*, rather than a bar to, subjecting future generations to burdens that our generation has never been willing to impose upon itself. In the name of intergenerational equity, EPA suggests that it may appropriately impose contamination levels beyond anything our generation accepts for itself, and to do so for a period that is orders of magnitude longer than the entire history of human civilization. *See* Figure 1, *supra* (graph showing the duration of the period of *median* doses close to 350 millirem/year); *compare* EPA, Response to Comments at 3-8 (2001) ("no regulatory body we are aware of considers doses of 150 mrem to be acceptable") (emphasis added). This is as rational as invoking the Christian Golden Rule to justify theft.

Indeed, as discussed in detail by Professor Fleming, the traditional premise of nuclear waste regulation has been that current generations do owe duties to future generations, and that those future generations should not suffer harms greater than those risked by the generations that actually derive the benefits from nuclear activities. Intergenerational equity is a constraint, not a license for current regulators to do whatever they please.

Even the obscure sources[7] EPA selectively cites cannot sustain its implied contrary theory. *See* Appendix D (characterizing EPA's choice of sources as "cherry-

[7] Notably, EPA never explains why it needs to rely on these sources when past U.S. and EPA policy is clearly contrary to these sources—or, at least, is contrary to EPA's crabbed interpretation of these sources.

picking"). First, the National Academy of Public Administration ("NAPA") report does not support EPA. That report recommends a "sustainability principle" that "no generation should deprive future generations of the opportunity for a quality of life comparable to its own." While the report also recommends that "each generation's primary obligation is to provide for the needs of the living and next succeeding generations" and that "near-term hazards have priority over long term hypothetical hazards," these recommendations are premised on the need to avoid trade-offs where present generations suffer an injustice, and on the concept of a "rolling present" which requires each generation to provide the next with the opportunity to reevaluate decisions and make changes. EPA never explains how its proposed two-tiered standard can be reconciled with those principles, and indeed it could not. EPA has identified no injustice the present generation would suffer were EPA's standard consistent, and thus NAPA's former premise for favoring current generations does not exist. Nor can EPA provide any opportunity for future generations to revisit the burdens EPA now proposes to impose, and thus the ability to create a "rolling present" does not exist.

EPA's other key source—a 1998 document by the Swedish National Council for Nuclear Waste ("KASAM")—contains none of the propositions for which it is cited. Indeed, in response to questions from Nevada regarding where in KASAM's report any of these statements existed, EPA conceded that they did not exist, and advised that the relevant comments instead came from another Swedish paper published in 2004 that is not yet publicly available in English. EPA then provided Nevada with an English-language translation of only one chapter of that document (chapter 9), which EPA claims supports its position.

Read in context, neither Chapter 9 nor the full 2004 Swedish document[8] even remotely supports EPA's proposed action.[9] Chapter 9 does describe a "minimal principle of justice"—as Appendix D points out, it is apparently the only discussion of that

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[8] Nevada subsequently itself located the entire document, translated into English, at http://www.sweden.gov.se/sb/d/574/a/52563.

[9] Moreover, key reference sources relied upon in KASAM's 2004 paper offer analyses that are fundamentally incompatible with EPA's approach to intergenerational responsibility in its proposed rule. For example, John Rawls' *A Theory of Justice* (1971) rejects any time preference that would dilute the moral responsibility to future generations; his discussion of justice between generations posits that "[n]o generation has stronger claims than any other." *Id.* at 289. *See also* Appendix D; KASAM 2004 document at 441-445 (discussing Rawls' work). KASAM also draws from works by Kristin Shrader-Frechette that have emphasized the present duty to avoid harm in the future. *Id.* at 449. In her most recent article, Dr. Shrader-Frechette expressly criticized EPA's new Yucca rule due to its failure to protect the life and health of future generations. Kristin Schrader-Frechette, *Mortgaging the Future: Dumping Ethics with Nuclear Waste*, 11 Science and Engineering Ethics (2005, Issue 4), at 3.

purported minimal principle—but the principle, as stated, does not support EPA's theory at all. Instead, the authors state that

> If we accept the minimal principle of justice as a reasonable principle for environmental ethics, it will have clear consequences for the nuclear waste issue. Thus, we are obliged to use nuclear power today in a manner that does not harm future generations—even if those generations are very distant. We cannot escape from our obligations just because they have to do with the very long-term consequences of our actions.

OAR-2005-0083-0197, at 429.

> The Principle of Minimal Justice applies for an unforeseeable period of time in the future and, quite simply, means that as long as living creatures exist on this planet, we have an obligation to not do anything that today that could jeopardise their life and health in the future.

Id. at 445.

> ...Therefore, on the basis of this principle, the specification for the repository should be completely clear: We must build a repository that can protection [sic] human beings and other living organisms for hundreds of thousands of years into the future – or for as long as we can anticipate that the waste is hazardous.

Id. at 446.

> Paradoxically, uncertainty concerning the future state of society, technology and knowledge clearly provides us with clear guidance for how we, today, must design a repository in a morally responsible manner. *It must be designed so that, without controls and corrective measures, it can protect the human beings who will live in its vicinity from about the year 2050 and a couple of hundred of thousand years in the future.*

Id. at 447 (italics in original.)

> The Principle of Minimal Justice requires that, with our technology, we do not jeopardise future generations' possibilities for life. *First and foremost: Do no harm. This means that we should only construct a repository if we know that it is safe enough to protect future generations.*

Id. at 449.

This discussion is impossible to reconcile with the principle EPA purports to extract from this document. The authors quite clearly do not believe that current regulators have license to do whatever they please so long as they do not compromise future generations' prospect for survival. Instead, they state that any repository must "do no harm" "for as long as we can anticipate that the waste is hazardous." *Id.*

The remaining sources EPA cites also provide no support for its implied but unarticulated intergenerational equity position. For example, EPA cites several sources for the principle that long-term numeric projections are of less value, and implies that these somehow bolster its suggested theories of intergenerational equity.[10] Those general statements, however, do not rebut the clear findings of the NAS that long-term numeric projections for Yucca Mountain will have value and should be the proper basis for a compliance assessment. Indeed, several of the sources EPA cites suggest that numeric assessment is inappropriate only in post-*million*-year time periods—a proposition irrelevant to EPA's current decisions about assessing compliance in the post-10,000-year period. And even the 2004 KASAM report Chapter 9, from which EPA purports to extract a highly permissive principle of intergenerational ethics, is clear: "To refrain from long-term assessments on account of the difficulty of making them can never be considered to be a reasonable level of ambition." *Id.* at 446 (quoting KASAM, Nuclear Waste – Research and Technique Development 32 (2002).

D. EPA Never Explains Why Its Implied Principle Applies to Yucca

EPA's intergenerational equity rationale, to the extent that it exists, fails for an important additional reason: EPA has never explained how a lax second-tier standard benefits anyone. While EPA's entire theory appears to be that providing future generations with the same protection we provide ourselves today would impose burdens upon present generations, EPA has not stated what those burdens are. Indeed, it has identified *no* possible trade-off that will result in any present harm if current levels of acceptable risk are sustained after 10,000 years.

If EPA is implicitly suggesting that the benefit to this generation from the lax future standard is the present success of Yucca Mountain, it strays into impermissible territory, for EPA has no authority to pre-determine that the Yucca Mountain repository

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[10] EPA selectively quotes from a recent book that borrows from economics to suggest that future interests may be discounted in favor of present interests. N. CHAPMAN AND C. MCCOMBIE, PRINCIPLES AND STANDARDS FOR THE DISPOSAL OF LONG-LIVED RADIOACTIVE WASTES (2003). That discussion neglects the strong agreement among environmental economists and ethicists, as well as KASAM and the NAPA panel, that it is unacceptable to discount future generations' interests simply because they will live at a different time. *See* Appendix D. Moreover, read in context, Chapman and McCombie's analysis provides no real support for the proposed rule. Much like the NAS Report, they suggest that "[t[here are no real scientific grounds for specifying any specific time cut-off for either safety assessments or regulations, beyond which there is no requirement to consider the fate of the repository. In particular, *any cut-off imposed whilst calculated releases are increasing has no credibility.*" Chapman and McCombie, *op cit.*, at 79 (emphasis added), OAR-2005-0083-0061.

should be built regardless of health and safety threats. With the NWPA and EnPA, Congress gave EPA one duty—to set the health-based radiation standard for Yucca. It did not call upon EPA to evaluate whether the success of the nation's repository program at Yucca today can justify a weaker standard of care for future generations. EnPA section 801(a)(1) requires EPA to promulgate a "public health and safety standard for protection of the public from releases [from Yucca]." Section 801(a)(2) refers to this standard as "health-based." A "public health and safety" or "health based" standard must be based on a consideration of what is an acceptable level of risk; it may not be based on economic costs or a balancing of costs and benefits. *National Cottonseed Products Ass'n v. Brock*, 825 F.2d 482 (D.C. Cir. 1987) (citing *American Textile Manufacturers Ins't v. Donovan*, 452 U.S. 490 (1981)); *NRDC v. EPA*, 824 F.2d 1146 (D.C. Cir. 1987); *Union of Concerned Scientists v. NRC*, 824 F.2d 108 (D.C. Cir. 1987).

Moreover, Nevada disputes whether Yucca Mountain would actually provide any benefit to present generations. As Nevada has pointed out in detailed past comments, both the site itself and, potentially more importantly, the massive project of transporting 70,000 tons of nuclear waste across the country to the site pose enormous risks to present generations. *See* Nevada, *Comments on Department of Energy's Draft EIS.*

Similarly, a lax second-tier standard provides significantly reduced protection to generations living within the 10,000-year period. If the repository is licensed on the *assumption* that peak dose will occur after 10,000 years, and that assumption proves wrong, the first-tier standard will provide no protection to the people who bear the brunt of the repository's impacts. Instead, those generations, whom EPA has never suggested should receive the same minimal protection it would accord to generations in the post-10,000-year period, would be put at greater risk by EPA's decision to rationalize a lax-second-tier standard on the theory that later harms are somehow more permissible.

XVII. EPA Wrongly Defines and Applies "Implementability"

EPA's final justification for its rule is the euphemistic concept, originated by DOE, of so-called "implementability." EPA believes, reasonably enough, that the standard it selects should be usable by the NRC to distinguish an adequate repository design and site proposal from an inadequate one. But EPA offers no proof that its proposal will accomplish this result.

A standard must be "implementable" in the sense that the application of the principles of sound science should enable a regulator to decide whether or not compliance is achieved. But EPA's conclusion that only a lax standard is "implementable" in this sense is inconsistent with the findings and recommendations of the NAS. The NAS clearly determined that EPA's standard should apply at peak dose, and that physical processes affecting the site were sufficiently predictable to allow such a peak-dose compliance assessment. As EPA itself previously recognized, NAS recommended a methodology for setting the standard, and that methodology would produce dose limits in the 15 millirem/year range. *See* EPA, Response to Comments at 4-5 to 4-6 (rejecting a 70 millirem/year standard because it would be "well above the

NAS-recommended level"). Those determinations clearly indicate that, in the NAS's view, a 15 millirem/year standard is "implementable."

Moreover, EPA has produced nothing but speculation to suggest that only a higher standard is "implementable." Nor could it, for DOE's current modeling results show a clear and certain *failure*, by almost any statistical measure, when compliance is measured against a consistent 15 millirem standard. *See* TSPA graph reproduced in Appendix C) (showing that at peak dose, almost 100% of the model runs predict doses exceeding 15 millirem/year). Any test that shows such certain failure obviously would be implementable; NRC quite clearly can determine what the outcome would be.

To escape this obvious problem with its implementability rationale, EPA vaguely implies, notwithstanding the NAS's clear determinations, that inherent uncertainties would make compliance with a 15 millirem/year standard difficult at any site, and that a 15 millirem standard therefore is not "implementable" because it cannot distinguish good sites from bad. Yet EPA supplies absolutely no empirical support for this speculative statement.

EPA's "implementability" rationale is suspect for another reason: it already has been rejected by the Court. As the court noted, EPA's core rationale for its prior 10,000-year cutoff was that post-10,000-year analyses were "not practical for regulatory decisionmaking." *NEI*, 373 F.3d at 1268 (quoting 66 Fed. Reg. at 32097). EPA had reached this conclusion after considering "comment on whether it is possible to implement the NAS-recommended compliance period...." EPA's conclusion was that it was not. The Court specifically rejected this rationale, concluding that it was inconsistent with the NAS report. As the court noted, NAS specifically warned against calculational approaches that make "compliance rather easy" and "simplify licensing," but fail to uphold the core duty to ensure "no unreasonable risk to the health and safety of the public." 373 F.3d at 1271. Yet, EPA now proposes to resurrect a similar rationale to severely loosen its peak dose standard.

As discussed *infra*, what EPA really means by "implementability" is that DOE is entitled to a standard that Yucca can pass. But that determination is not EPA's to make. It is charged with promulgating a standard that protects public health and safety, and must do so consistent with the findings and recommendations of the NAS. It may not flout those recommendations and deviate from thirty years of practice by invoking "implementability" as an excuse to promulgate what is, in effect, a best available or best practicable technology standard, rather than a health-based standard, so as to grant Yucca an easy pass.

Problems with the Rule Other than the Standard

Like any administrative agency, EPA may not exceed the authority Congress has delegated to it. Here, EPA's authority is limited; it may only set health and safety standards for Yucca Mountain. Yet, EPA's proposed rule does far more than just set a standard. In numerous ways, those extra components of EPA's proposed rule would usurp the NRC's Congressionally defined role of resolving adjudicatory facts and making a licensing decision.

In addition to these usurpations of authority, EPA also proposes, without any Congressional authorization, to delegate part of its own rulemaking authority to the NRC.

XVIII. EPA's Effort to Legislate FEPs is Technically and Legally Flawed

EPA's proposed rule specifies several features, events, and processes (FEPs) that DOE is to model, or is to specifically avoid modeling, in preparing its license application. In setting those FEPs, the proposed rule exceeds EPA's statutory authority and is arbitrary and capricious in several ways. First, specific FEPs, as well as EPA's attempts to define and develop them, are in key respects fundamentally inconsistent with the NAS report's findings and recommendations. Second, in setting some of the FEPs, EPA's proposed rule exceeds the bounds of EPA's rulemaking function. Third, EPA's rationales for certain FEPs are arbitrary and capricious, flouting basic mathematics and containing unexplained categorical exclusions. Finally, even if EPA's specific uses of FEPs could otherwise survive scrutiny, they vitiate EPA's rationale for setting a higher numerical standard for evaluating post-10,000 year compliance.

A. The Importance of FEPs

To assess the future performance of its proposed repository, DOE will choose a set of scenarios to model. That set will not include all imaginable variations; instead, DOE will choose a subset of actual scientific possibilities, limited by a specification that certain features, events and processes with a probability of less than 10^{-8}/yr may be screened out as presumptive non-contributors to a probability-weighted dose calculation. These "features, events, and processes" are referred to as "FEPs."

FEP selection obviously has important implications, for it determines which possible scenarios the modelers will and will not consider. While excluding adverse scenarios simplifies the modelers' task, it also decreases the realism of the modeling process. If the scenarios excluded are generally adverse, their exclusion also will skew the modeling toward excessive optimism, making the repository more likely to pass the standard based on an artificial overestimation of its safety.

B. EPA's Approach to FEPs in the Proposed Rule

In its proposed rule, EPA has taken an active role in defining the FEPs that DOE must model. EPA proposes that DOE exclude numerous adverse scenarios from the modeling process, sometimes without specifying what those scenarios are or delineating the standard being used to exclude them. An entirely sensible initial EPA proposal that NRC would have authority to add additional FEPs for the 10,000-year period was unaccountably deleted (apparently at DOE's insistence), and replaced by a series of artificial and unfounded limitations that can have no purpose other than to make it easier for DOE to comply.

First, EPA proposes that DOE should evaluate only those FEPs that have a greater-than 1-in-10,000 chance of occurring over the next 10,000 years. EPA used this screening threshold when it set its original 10,000-year-only standard, and is proposing to retain it despite the now-increased compliance period.

Second, EPA proposes that FEPs not likely to have "significant" effects may be excluded even if those FEPs' probability of occurrence is greater than the numerical threshold described above. EPA has not defined, however, what level of effect would not be considered significant.

Third, EPA has delineated FEPs that DOE should model when considering engineered barrier failures and several natural phenomena. Specifically, EPA's rule would require consideration of a certain subset (and only that subset) of igneous and seismic risks, would require DOE to model constant climate conditions beyond 10,000 years, rather than a range of conditions, and would require DOE to exclude from consideration many potential engineering problems. EPA has stated that numerous other FEPs need not be considered, often without specifying what it is excluding.

As its underlying rationale for its FEP-setting process, EPA relies on the perceived need to manage uncertainty, to make realistic assumptions, and to rule out "extremely speculative" or "fantastical" events. 70 Fed. Reg. at 49048. EPA also bases its rationale on the "systematic conservatism" that it alleges would otherwise infect the modeling process and produce inconsistencies with EPA's own "reasonable expectation" concept. *Id.* Throughout the rule, EPA suggests that this approach is consistent with the NAS's recommendations.

C. Inconsistency with NAS's Recommendations

In several ways, EPA's FEP-setting process violates EnPA's mandate, and the core holding of the Court, for EPA's FEPs and the rationales EPA has employed to support them are inconsistent with NAS findings and recommendations.

1. Reliance on Rationales Rejected by NAS

EPA repeatedly cites a perceived need to avoid uncertainties and over-conservatism as a reason for limiting the FEP-setting process. EPA posits that including all possible scenarios, even if highly unlikely, would prejudice the analysis towards excessive pessimism. Indeed, EPA even claims that its decision to include only scenarios that have at least a 1-in-10,000 chance of occurring over the 10,000 period, *and* that are likely to have "significant effects" (a term EPA never defines) is "extremely conservative." 70 Fed. Reg. at 49049.

But NAS's conclusions were to the contrary. Describing the basic approach involved in performing a probabilistic risk analysis, NAS wrote:

> [t]]o judge compliance against a risk-based standard of the type proposed, a risk analysis including treatment of **all** scenarios that might lead to releases from the repository and to radiation exposures is, in principle, required. To include them in a standard risk analysis, **all these scenarios** need to be quantified with respect to the probabilities of *scenario occurrence and* the probability of their *consequences* to humans, such as health effects of radiation doses.

NAS Report at 72 (italics in original; bold text added). In other words, NAS recommended including a broad range of scenarios and accounting for the remoteness of the more unlikely scenarios by multiplying a scenario's impacts by its low probability of occurrence. Nothing in this passage, or anywhere else in the NAS report, suggests that such an approach would be excessively conservative.

A simplified mathematical example indicates why the NAS was correct that an inclusive analysis is, "in principle," appropriate rather than over-conservative, and why EPA's FEP approach is inherently *unrealistic* and *optimistic.*

> Suppose that events A, B, C, D, and E have probabilities of occurrence of 1%, 3%, 7%, 10%, and 12%, respectively, over the next year.[11] Next, suppose that each event has a likelihood of producing 10 units of exposure if it occurs.

[11] This example assumes that events A, B, C, D, and E are independent, so that the occurrence or non-occurrence of one event does not affect the likelihood of any of the others, or the extent of their effects. A similar assumption is appropriate for many scenarios that may affect Yucca Mountain. For example, nothing about seismic activity is likely to affect the occurrence of climate change, and vice versa. Even where specific variables are weakly or even strongly interrelated, the same general principle holds, though the mathematics becomes more complex: any exclusion of an adverse scenario skews the analysis toward optimism.

The probable degree of exposures per year thus would be ((probability of A)(exposures per occurrence of A) + (probability of B)(exposures per occurrence of B).... + (probability of E)(exposures per occurrence of E). Plugging the overall numbers into the equation produces an expectation of 3.3 units of exposure per year.

There is nothing inherently conservative about this prediction; the inclusion of "unlikely" events A and B is compensated by discounting their effect by their likelihood of occurrence. The inclusion of unlikely scenarios thus does not bias the analysis because the unlikelihood of those scenarios is accounted for mathematically.

Now suppose, however, that the regulator has attempted to simplify the modeling by excluding from consideration all events with a less-than-5% chance of occurring. The modeler would then not consider events A and B at all—even though they do have a real-world possibility of occurrence—and would produce a prediction of 2.9 units of exposure per year.[12] Although the change is not huge, defining FEPs to exclude certain scenarios has skewed the prediction toward excessive optimism. And the skewing will increase if, as EPA proposes, probable events with slight effects—for example, an event F which has a probability of 40% but a likely impact of only one unit of exposure—also are excluded.[13]

This example illustrates the fallacy of EPA's assertion that its prescribed FEP approach corrects supposed over-conservatism. In fact, unless compensating mechanisms are introduced, every exclusion of scenarios decreases the *realism* of the calculation, and skews the result toward optimism. The NAS report provides no support

[12] The problem can be stated somewhat differently. In mathematical terms, excluding an event from consideration is the equivalent of rounding its probability off to 0%—which is the same as assuming it certainly will *not* happen. Of course, any calculation in which all the numbers are rounded off in the same direction will necessarily produce a skewed outcome.

[13] In addition, the modelers will start from a skewed beginning point. Even before the modelers begin purposefully excluding "unlikely" scenarios, they inevitably will have excluded other scenarios simply by failing to think of them. Neither EPA nor the modelers can realistically expect to think of all the things that could go wrong in the next several hundred thousand years—it is axiomatic that engineering and natural systems sometimes behave in unanticipated ways—and some of those oversights could prove highly significant. Yet by not thinking of those scenarios, the modelers will have done the mathematical equivalent of assuming that their probability of occurrence is 0%, and the modeling therefore will be skewed toward optimism even before the process of excluding FEPs begins.

for such skewing, and instead endorses a methodology that provides more realism than that selected by EPA.

2. Excessive Exclusion of FEPs

The NAS report recommends that, in principle, "all" scenarios should be addressed that "might lead to releases from the repository and radiation exposure." NAS Report at 72. Nevada understands that direction not to prescribe an infinite number of runs, but to ensure that EPA's methodology fully accounts for potential releases from the repository and radiation exposure. This NAS recommendation reflects EnPA's underlying statutory mandate for EPA to develop standards for the protection of the public health and safety. As noted below, key exclusions proposed by EPA appear to be inconsistent with the NAS-recommended approach.

EPA has excluded a series of events—many of them entirely unspecified—on the mostly unexplained rationale that their effects would be "insignificant." For example, EPA suggests that if criticality events are not addressed during the first 10,000 years (which DOE had proposed it would not do because it assumes that such failure is unlikely), they also need not be addressed in the post-10,000 year period because, oddly enough, criticality events at such later times would likely have lesser effects than the earlier criticality events EPA already has excused DOE from analyzing. 70 Fed. Reg. at 49051 (stating, without explanation, that "we do not believe such scenarios are either very likely or very important to performance"). As a consequence, EPA's proposed rule would completely excuse DOE from analyzing one of the most worrisome threats posed by the repository, at the very time when waste packages will begin to fail, emptying their fissile contents into pools and piles of unknown (but perhaps critical) geometries. EPA has also excluded engineering failures, such as localized corrosion, on the theory that their post-10,000 year effects would be insignificant. *Id.* Similarly, EPA apparently acquiesces in DOE's assumption that no manufacturing defects will exist, without ever considering whether this assumption is reasonable, let alone sufficiently certain to totally exclude such scenarios from analysis. Indeed, EPA never defines what its standard of significance is, or itemizes all of the FEPs that are being excluded, with the consequence that the rule never explains what events are being left out or how important they might actually be.

On similar grounds, EPA has excluded from consideration several other FEPs on the rationale that their effects will be, in EPA's words, "overwhelmed" by the influence of more important variables. 70 Fed. Reg. at 49053; *see id.* at 49054. Again, EPA is inconsistent at best in defining what FEPs are being excluded on these grounds; while some, like seismic effects on hydrology, are specified, others are left unnamed.[14]

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[14] EPA's general approach is to specify a few engineering, igneous, seismic, or climatic scenarios as the only scenarios that require analysis, expressly or impliedly excluding numerous other scenarios without actually naming them. This methodology creates ambiguity about whether DOE will be responsible for the inclusion or exclusion of those specific FEPs or whether they are excluded by virtue of EPA's rule. It also creates,

Moreover, EPA never addresses the possibility that the comparatively minor FEPs' effects would occur *in addition* to those ostensibly more important ones represented in the scenarios that will be considered, and thus does not consider that this exclusion may well understate direct and cumulative effects. This approach is as irrational as a business declining to account for its smaller expenses on the rationale that they are "overwhelmed" by the larger ones. In reality, all of the expenses, large and small, influence the bottom line, and a failure to account for the small ones leaves any budget projection overly optimistic.

Finally, with only a few exceptions, EPA excludes from consideration FEPs that might be increasingly significant with the passage of time. Some FEPs, like general corrosion, may be of lesser importance during the first 10,000 years if DOE's sanguine predictions are realized, but could become increasingly important in the post-10,000 year period. EPA acknowledges this risk with general corrosion, and requires it to be addressed, but dismisses all other such time-sensitive effects (without even beginning to specify what they are) on the conclusory rationale that "the relevant FEPs are already captured within the 10,000 year screening process, and that any others would be overshadowed by other aspects of the longer-term modeling." 70 Fed. Reg. at 49055.

As a consequence, EPA's rule proposes considering only the limited subset of FEPs that EPA believes, for largely unspecified reasons, to be worth modeling. Even if EPA were correct, and the FEPs DOE will consider turn out to be the most important ones, the collective impact of all the excluded FEPs could have a significant impact on the performance assessment. By categorically excluding those effects from consideration, EPA has departed from the NAS recommendation and introduced a potentially significant level of over-optimism into the assessment.

Those exclusions also exceed EPA's expertise. It would be one thing if EPA's cavalier exclusion of potentially key technical issues were in an area for which the agency has known and Congressionally delegated expertise, such as the health effects of radiation. It is another altogether when the issues concern metallurgy, nuclear physics, seismicity, and climatology.

3. Specific FEP Designations

In addition to inconsistencies between the NAS report and EPA's general approach to using and justifying FEPs, there are also stark inconsistencies between specific FEPs and the findings and recommendations in the NAS report.

a. Seismic FEPs

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perhaps intentionally, the possibility that EPA will claim it has left the decision to DOE, and that DOE will later claim that its exclusions were determined by EPA's rule.

EPA proposes that only seismic effects on the engineered barriers should be considered. While conceding that seismic events also could affect the natural system—particularly by affecting fluid transport pathways—EPA is "proposing that DOE's analysis for seismic events may exclude the effects of seismicity on the hydrology of the Yucca Mountain disposal site." 70 Fed. Reg. at 49056.[15] EPA based this exclusion on two rationales: first, that predicting alterations in flow would be "highly speculative," and second, that any effects of seismic events would be overshadowed by the effects of climate change. *Id.*

These rationales are wholly inconsistent with the NAS's determinations. Rather than suggesting that seismic effects on hydrology could be excluded from analysis, NAS wrote that "[w]ith respect to the effects of seismicity on the hydrologic regime, the possibility of adverse effects due to displacements along existing fractures *cannot be overlooked.*" NAS Report at 93 (emphasis added). NAS did also state, as EPA selectively notes, that favorable alterations in the hydrologic regime were possible, but then went on to conclude that "the consequences of these events are boundable for the purpose of assessing repository performance." *Id.* But NAS never qualified its admonition that seismic effects on hydrology "cannot be overlooked" by suggesting, as EPA does now, that climate change might have similar but larger effects. That rationale is patently flawed, for it overlooks the realistic possibility that adverse hydrologic effects arising from seismic events would compound the adverse effects of climate change; there is no reason to assume that adverse climate change effects would preclude adverse seismic effects from occurring.

b. Climate

EPA does know that wetter periods will occur at some future time, and we can analyze how the repository will perform when those periods do occur. EPA suggests that because the site geology will have a dampening effect on climate changes, masking the effects of changes several hundred years or less in duration, changes of longer-lasting duration also need not be analyzed. This also is inapposite. As indicated by the NAS language that EPA cited, this dampening effect should transfer the focus to longer-term climate changes (for example, glacial states that might last for thousands rather than hundreds of years). NAS Report at 93. The short-term dampening effect provides no reason for ignoring long-term changes.

As the NAS report and EPA's own past statements indicate, significantly wetter climates will occur and will adversely impact repository performance. In mandating that those conditions be assumed out of existence, EPA's proposed rule would ignore the NAS's clear recommendation.

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[15] At 70 Fed. Reg. 49056, EPA gives DOE a blanket license to exclude from consideration any seismic effects other than the "key aspects of seismicity discussed above." EPA never specifies which effects it is excluding from consideration, or why "they can reasonably be excluded from analysis over the period of geologic stability," so this blanket exclusion lacks any reasoned basis.

Moreover, as the report of Dr. Thorne indicates (Appendix E), EPA's specification that only constant climate conditions may be considered ignores the possibility that other factors influenced by global warming will have a substantial effect on deep percolation of water into the repository.

c. Volcanism and Igneous Events

EPA states that DOE need only consider as FEPs volcanic events that have occurred, or may reasonably be inferred to have occurred, during the Quaternary Period, which includes approximately the last 1.6 million years. 70 Fed. Reg. at 49052. The rationale, apparently, is that if events haven't occurred during the last 1.6 million years, the probability of their occurrence within the next million years is negligible.

For events likely to occur on a shorter time cycle (e.g. climate shifts), this might be a reasonable assumption, since a 1.6 million-year period is long enough to encompass numerous climate cycles and provide a sense of the full range of possibilities. Volcanic eruptions in the Yucca Mountain area, however, occur infrequently and irregularly, and the activity in one 1.6-million year period—a long period by human standards, but a short one for many geologic processes—may not be an accurate preview of future activity. To assume that the volcanic events of the next million years are bounded by the events of the previous 1.6 million years is somewhat like assuming that Chicago's weather tomorrow can be predicted, with certainty, by reviewing the weather reports from the previous two days.

Indeed, EPA's own consultant's report concedes that during the Pliocene Epoch (5.2 million years before present to 1.6 million years before present), several larger-scale eruptions occurred at the site. Cohen Report at 10-1 to 10-2. Moreover, EPA's own rule acknowledges that the type of eruptions that formed the tuffs at Yucca Mountain is not the same as the type of eruptions that are known to have occurred more recently. EPA at 70 Fed. Reg. at 49058. The difference is important; in comparison to most basaltic eruptions, the eruptions that produce welded tuffs generally are gigantic.

Thus, in requiring that DOE model only events that occurred during the Quaternary period, EPA is excluding possible volcanic events from analysis. Moreover, it isn't excluding just any events, but instead is selectively leaving out larger events. While such events have low probabilities, since volcanic events in the region are infrequent, their effects, if they do occur, could be major, and there is no foundation for EPA's rationale for screening them out entirely.

D. <u>EPA's FEP-Setting Exceeds EPA's Authority and Expertise</u>

In setting FEPs for certain physical parameters of the Yucca Mountain analysis, EPA proposes to use the rulemaking process to pre-determine adjudicative facts, and to do so in areas well outside its expertise. In so doing, EPA would exceed the limited authority Congress conferred upon it, both by exceeding its rulemaking function and by undertaking tasks that Congress delegated elsewhere.

In the NWPA and EnPA, Congress specified a clear division of authority—one which built upon EPA's traditional role (incorporated in section 121 of the NWPA and the 1970 Reorganization Plan that established EPA). EPA's one and only duty is to promulgate, by rulemaking, a health-based standard "based upon and consistent with the NAS's findings and recommendations." EnPA § 801. DOE, not EPA, is to select a site and write an application for a license. The NRC, not EPA, is to judge, through an adjudicatory proceeding, whether that license application satisfies EPA's health-based standard, and whether the license should be granted. Like any administrative agency, EPA has no power beyond that delegated to it by law, and may not assume the functions delegated to its sister agencies.

The significance of Congress's division of authority is underscored by its concordance with the fundamental separation of powers that underlies our entire system of governance. Our Constitution itself has as its core principle the separation of powers between legislative, executive, and judicial entities; it does not contemplate the same entity simultaneously functioning as advocate, rulemaker, and judge. Likewise, "the entire (Administrative Procedure) Act is based upon a dichotomy between rule making and adjudication." ATTORNEY GENERAL'S MANUAL ON THE ADMINISTRATIVE PROCEDURE ACT (1947). In dividing authority among EPA, DOE, and the NRC, Congress utilized those core separation-of-powers principles, granting EPA only a limited rulemaking role, and EPA has no power to blur those distinctions. Indeed, the gravity of the Yucca Mountain decisions accentuates the importance of Congress's mandate; if government agencies are to decide that part of Nevada will be contaminated for a million years, that decision ought at the very least to be made through a process of checks and balances, and the agencies involved must respect the limits Congress placed upon their roles. EPA therefore is required, in promulgating this standard, to limit itself to the narrow and constrained rulemaking task Congress delegated to it.

Yet many of the specific FEP determinations EPA's proposed rule would make are not properly within the scope of EPA's rulemaking task, and are certainly far outside its traditional expertise. The grant of rulemaking authority in the EnPA is based on the prior grant of rulemaking authority in the NWPA. Both statutes are based on the original grant of radiation standard setting authority in Reorganization Plan No. 3 of 1970. That grant (and therefore the grant in the EnPA) is expressly limited to the setting of standards defined as "limits on radiation exposures or levels, or concentrations or quantities of radioactive material" in the environment. The rest was reserved exclusively to NRC as the agency responsible for implementing the EPA standards through the licensing process.

Here, EPA has used rulemaking to pre-set the highly technical assumptions that DOE's modelers will make, and to pre-judge the resolution of site-specific licensing issues that are the exclusive province of NRC. Such things as specification of FEPs do not remotely qualify as the setting of limits on exposures, levels, or concentrations of radiation. Indeed, in the past, NRC has vigorously opposed EPA intrusions into its repository licensing functions very much like the ones EPA now proposes. *See* NRC letters to EPA and NRC memoranda found on NRC's Licensing Support Network at NRC 000024406 and NRC 000024461.

Scientific determinations such as this are more properly made in the NRC licensing review where there is the flexibility to account for more recent scientific advances and to adjust to specifics of the performance assessment actually proposed as the basis for licensing. EPA itself has no power, in its rulemaking process, to review DOE's current draft applications and preliminary modeling work and utilize that work to screen certain scenarios out of the site evaluation process. By constraining the modeling assumptions, EPA has gone far beyond its limited rule-writing role and instead has injected itself into NRC's licensing function.

EPA's own past statements acknowledge that these determinations are not EPA's to make. In promulgating 40 C.F.R. Part 197's standard, EPA did not purport to specify FEPs that DOE would or would not model. Instead, EPA noted that "[t]hese considerations and decisions properly belong to the implementing authority." 66 Fed. Reg. 32074, 32126 (July 13, 2001). EPA specifically explained that in the WIPP process, "where [EPA] had both the standard-setting and implementing authority," it had specified "requirements for modeling techniques and assumptions." *Id.* But it concluded that in the Yucca Mountain rulemaking, where such implementing authority did not repose in EPA, such "requirements go well beyond the simple statement of a compliance measure," and, with the exception of the FEP discussed below, it did not establish them. *Id.* Likewise, EPA specifically noted that it declined "to specify that DOE must use a particular modeling approach to demonstrate compliance with the standards," and instead stated that "DOE (the organization responsible for developing the license application) and NRC (the authority responsible for the approval of the disposal facility) should make these decisions." *Id.* at 32127 (parentheses in original).

E. EPA's FEPs Vitiate EPA's Rationale for a Higher Standard and for Use of the Median

EPA's FEPs also undermine the key rationales for EPA's creation of a higher numeric standard in the post-10,000 year period, and for EPA's position shift to require use of the median, rather than the mean, for projecting compliance.

EPA proposes to justify both its 350 millirem/year standard and its use of the median primarily on the rationale that both are necessary to manage long-term uncertainties in performance assessment. EPA's theory appears to be that a combination of uncertainty and compounding conservative assumptions will unavoidably skew DOE's modeling, and that, rather than expecting DOE to fix those perceived modeling problems, EPA must for some reason compensate for that skewing by using a commensurately skewed higher standard and a less conservative statistical compliance measure.[16]

[16] Nevada has addressed the many other problems with this theory elsewhere herein.

The use of predetermined FEPs undercuts EPA's uncertainty rationale. By specifically defining future states for crucial FEPs, such future climate states, EPA manages uncertainty out of the modeling process. Having taken that step, it is inconsistent to *optimistically* adjust the end-goal to account for negative uncertainties that the modelers have been required to remove. Essentially, this methodology double-counts the perceived uncertainty.

The use of FEPs also thoroughly undercuts EPA's predetermination that DOE's modeling process will be overly conservative. As shown in the mathematical example above, arbitrary exclusion of FEPs can inherently skew the modeling process toward optimistic outcomes.

XIX. EPA Impermissibly Legislates Other Adjudicative Facts

The proposed EPA rule includes various "findings" of adjudicatory fact—that is, findings of fact that are applicable only to Yucca Mountain and that should be the subject of NRC review of the DOE license application in the NRC licensing hearing. Those "findings" also are made without any significant factual inquiry on controversial and critical subjects over which EPA has no particular expertise.

For example, EPA's entire "over-conservatism" and "uncertainty" theories rest on pre-determination of adjudicative facts. As Dr. Thorne points out in Appendix C, variations in uncertainty and conservatism with time are matters to be derived by detailed assessment modeling, which can only be done in consideration of an actual license application, and cannot be determined *a priori* by rule, as EPA presumes in its rule. EPA does not, and cannot, rely on universally applicable legislative facts to support this theory, for DOE's models will be[17] specific to Yucca Mountain. Likewise, the source EPA cites for its over-conservatism rationale is specific to DOE's Yucca-Mountain models. *See* 70 Fed. Reg. at 49021 (citing Cohen, Assumptions, Conservatisms, and Uncertainties in Yucca Mountain Performance Assessments (2005)). Accordingly, the inquiry about whether DOE's modeling efforts will be improperly conservative, improperly optimistic, or somewhere in between is a classic determination of adjudicative fact, and EPA has no power to extract that determination from the NRC's adjudicative process, prejudge its outcome, and use that prejudgment as a basis for its rule.

EPA's proposed rule not only would involve *ultra vires* resolutions of adjudicative facts; it would resolve those facts before they are ripe for adjudication. The EPA findings

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[17] EPA's attempt to alter its standard to accommodate the anticipated insufficiencies in DOE's modeling is thus suspect for the additional reason that EPA does not know whether those perceived insufficiencies actually will exist, and EPA has effectively altered its rule to accommodate perceived flaws in what is a partial draft License Application, since a complete *draft* is unavailable.

are based on what is, in effect, an incomplete collection of information, some of which may be relied upon by DOE in its eventual license application, and some of which may not be. Because DOE has not yet submitted an application (and has in fact taken every conceivable measure to hide it from public view), all of its modeling is preliminary and subject to change. The final application will undoubtedly include numerous important changes from the information relied on in this rule, and when DOE actually submits an application the perceived flaws that led EPA to adopt particular positions on various FEPs and skew its standards may no longer exist. Moreover, none of that preliminary modeling has been the subject of a full review and concurrence by DOE, NRC or EPA, and the iteration relied upon by EPA already has apparently been superseded by another draft. EPA's adjudicatory decisions thus are premature as well as *ultra vires*.

Each of these legal defects has the unlawful effect of depriving Nevada and other interested persons of their rights to an adjudicatory hearing on contested issues of adjudicatory fact under the Atomic Energy Act and NRC's Rules of Practice.

To be sure, to a limited extent a Yucca specific rule must be based on findings of adjudicative fact, for example, a finding that the Yucca site is such that reasonable projections of peak dose can be made. But clearly Congress limited such adjudicative fact-finding to those facts essential for the promulgation of health-based standards, properly defined as limits on radiation exposures, levels or concentrations in the environment. Moreover, the adjudicative findings necessary for standard-setting were to be made by NAS. EPA's findings of fact are well in excess of those necessary to accomplish this limited rulemaking function and go well beyond, and in some respects are inconsistent with, the findings of NAS. Indeed, as pointed out above, EPA's rule is in danger of complete collapse when the proposed findings of fact in the DOE license and the NRC findings of adjudicatory fact in the licensing process turn out to be inconsistent with the very premises for the EPA rule. Such a collapse would be avoided if EPA limited its rule, and its underlying findings, to policy judgments about acceptable levels of risk based on NAS findings of fact about Yucca.

XX. EPA's Rule Impermissibly Prejudges NRC Licensing

A. "Implementability" and Prejudgment

EPA's heavy reliance on the concept of "implementability" is the first indication of EPA's prejudgment, for EPA has defined its "implementability" goal in such a way that it assumes a license must be granted. EPA's proposed rule suggests that a standard must be "implementable," ostensibly meaning that it must provide a measure capable of distinguishing a good repository license application from a bad one. *E.g.* 70 Fed. Reg. at 49029. This definition is reasonable enough; a standard against which compliance could not be measured might as well be no standard at all. Yet the manner in which EPA applies this concept reveals, for numerous reasons, that EPA misconstrues it by deciding that any standard that might cause Yucca to fail is not implementable.

First, EPA impliedly defines an "implementable" standard as a standard that some repository somewhere could pass. Without offering any basis for this conclusion—and without acknowledging that it is directly contrary to the conclusions of the NAS, which determined that a traditional apportioned standard could be used through the time of peak dose—EPA then suggests that because of inherent "uncertainties," no repository anywhere could pass a traditional, 15 millirem/year standard, and that such a standard therefore is not implementable for longer-term compliance assessment.

Moreover, EPA has no basis for assuming that a "safe" repository could not pass a traditional 15 millirem/year standard, and that such a standard therefore is not implementable. The NAS came to no such conclusion, and instead determined that current site characterization capacities are sufficient to project compliance with a traditionally apportioned standard through the time of peak dose. Moreover, EPA's rule does not consider experience at other actual repository sites, and EPA therefore lacks any basis for asserting that no site could pass a 15 millirem standard. Another location with true geologic isolation—a site without permeable, fractured rock that allows groundwater to flow through the repository—might well pass the traditional 15 millirem standard even at peak dose. Indeed, as discussed below, DOE's WIPP repository -- the only operating repository in the world -- is just such a location. Having considered only Yucca Mountain in assessing whether 15 millirem/year is "implementable," EPA has no basis to suggest that the standard is universally impossible to meet.

Because EPA's "implementability"-based rejection of a traditional standard is based solely on its review of Yucca Mountain, that rejection is in reality a prejudgment that the only "implementable," and thus acceptable, standard is one that Yucca Mountain could meet. Implementability thus is only an excuse for setting a standard that allows Yucca Mountain to be licensed, regardless of its safety, and EPA's use of that concept betrays its procrustean attempt to predetermine the outcome of the licensing process.

B. Uncertainty and Prejudgment

EPA's treatment of supposed "uncertainty" further evinces prejudgment. Under EPA's reasoning, uncertainty and implementability are closely connected; because of compounding uncertainties, EPA believes, a low standard is not implementable for long-term compliance assessment, and a higher standard must be used. This reasoning amounts to a predetermination that Yucca Mountain should be licensed.

First, EPA's relaxation of standards betrays a prejudgment that the repository should be licensed even if DOE and NRC cannot determine whether it will work. Even if uncertainties do make predicting compliance with a traditional standard difficult regardless of site-specific characteristics,[18] that does not mean that the standard is not

[18] The NAS, of course, specifically rejected this position, finding that meaningful long-term compliance projections could be made and that those projections could be measured against a traditional, apportioned standard.

implementable, for there is nothing unimplementable or unreasonable about a standard that requires the applicant to bear the burden of addressing uncertainty. Just as the FDA does not license drugs until it has some certainty about how they will perform, and does not consider rules requiring such demonstrations "unimplementable," EPA cannot alter its standards to facilitate the licensing of a repository with uncertain prospects of success. Indeed, that uncertainty may reflect flaws in the siting or design of the repository, or may simply reflect the fact that DOE's modeling and site characterization capabilities are not sufficiently advanced for it to demonstrate whether or not a repository will perform adequately. Under such circumstances, uncertainty provides a reason *not* to license repositories, not an excuse to consider traditional health-based standards unimplementable. Relaxing standards to accommodate uncertainties indicates an unlawful predetermination that repositories should be licensed.

Second, because the key uncertainties EPA cites as affecting DOE's long-term performance assessment are *specific to Yucca Mountain*, EPA's implementability/ uncertainty rationale betrays EPA's attempt to predetermine licensing by tailoring the standard to accommodate the known *weaknesses* of the Yucca Mountain site.

Uncertainty exists at Yucca Mountain primarily because water naturally percolates through the repository due to fractured geology. For two primary reasons, that water flow makes engineering uncertainties crucially important. First, it promotes corrosion, which EPA has observed is "exactly the critical element in estimating the timing and magnitude of peak dose." 70 Fed. Reg. at 49026. Second, because it negates the existence of geologic containment, it places increased importance on the engineered barrier system, and while it is undisputed that those barrier systems will eventually fail, no one is certain when that failure will occur. Additionally, because water flow rates may vary, water infiltration creates some uncertainty about the rate at which radionuclides will move through the subsurface environment.

These uncertainties are not inherent in all potential repository sites. Instead, they are peculiar to the permeability and fractures of Yucca Mountain's rock.[19] At a site providing true geologic barriers—such as the WIPP site, where the geology provides total containment—neither source of uncertainty would exist. Water would not enter or leave the system, and inevitable failures of the engineered barriers would be compensated for by the impermeability of the surrounding geologic formation.

EPA's reliance on uncertainty as the basis for its lax standard therefore constitutes EPA's determination that the standard should be tailored to accommodate the flaws in the Yucca Mountain site. That rationalization and the resulting lax standard completely undermine the integrity of EPA's rulemaking by basing the standard on non-health-related factors that EPA has no power to consider. Additionally, that rationalization usurps the NRC's jurisdiction to determine whether or not the license should be issued by

[19] The importance of these two sources of uncertainty is vastly greater than that of most others. Additionally, many other uncertainty sources—the threat of volcanic or seismic activity, for example—also are site-specific.

crafting a standard to *ensure* that a license will issue. A standard designed to *measure* whether a repository protects public health cannot be tailored to the weaknesses of that very repository without tainting the entire licensing process with prejudgment.

XXI. EPA Improperly Delegates Its Own Rulemaking Role

In addition to usurping roles Congress delegated to other agencies, EPA's proposed rule would unlawfully delegate away EPA's own core responsibility for setting a standard. Rather than following Congress's and the court's direction to set a standard applicable to peak dose, EPA proposes to set little more than a guideline, and to allow the NRC to consider a modeled projection of compliance with that guideline as little more than a "factor" in its ultimate compliance determination. By declining to promulgate a true standard, EPA impermissibly would delegate its discrete and limited rulemaking role to the NRC.

The NWPA and EnPA direct EPA to promulgate a binding standard. EnPA section 801(a)(1) states that EPA's "standards shall prescribe the maximum annual effective dose equivalent to individual members of the public from releases" of radioactive material from the repository. *See NEI v. EPA*, 373 F.3d at 1262 (citing EnPA). The phrase "prescribe the maximum" clearly indicates Congress's demand for a binding limit, and does not allow for the possibility of approval of a repository predicted to produce higher doses. Likewise, Congress's use of the word "standard" indicates Congressional intent that the standard be an absolute limit; elsewhere in environmental regulation, where Congress has demanded that EPA "prescribe... standards," those standards are understood to provide limits that may not be exceeded. *See, e.g.*, 42 U.S.C. 7409 (providing for air quality standards, with which state air quality plans must demonstrate compliance); 42 U.S.C. § 9621 (requiring hazardous waste site cleanups to meet public health and safety standards). Finally, Congress's requirement that EPA promulgate its standards "by rule" indicates the binding nature of those standards; unlike policy statements or guidance documents, rules that implement Congress's statutory mandates by definition have coercive force. *See Chrysler Corp. v. Brown*, 441 U.S. 281, 302 n.31 (1979) (citing the 1947 Attorney General's manual); *Batterton v. Marshall*, 648 F.2d 694, 701-02 (D.C. Cir. 1980).

Notwithstanding those Congressional directives, EPA proposes, in parts of its new rule, that its standard would not be binding unless the NRC decides to treat it that way, and that the NRC would have discretion to license a site even where the compliance evaluation projects a violation of the standard. EPA does suggest that under its new rule, "the post-10,000 year analyses are now proposed to be part of the 40 CFR part 197 standards with a quantitative limit imposed." 70 Fed. Reg. at 49028.[20] However, EPA

[20] EPA's rule does also contain several statements suggesting that the standard will be binding. For example, EPA acknowledges that "we believe that the best way to address the Court decision is to establish a numerical compliance standard for the time of peak dose so that a clear test for compliance decision-making can be applied to the results of quantitative performance assessments." 70 Fed. Reg. at 49031. EPA also ostensibly

also proposes to "continue [40 CFR Part 197's] general approach" of leaving "the degree of 'weight' that should be given to these very long-term assessments" as "an implementation decision that should be left to the NRC to determine, by balancing the inherent uncertainties in these projections against the projected dose levels." *Id.*[21] Elsewhere, EPA suggests that compliance projections can "form a key *part* of the basis for a licensing decision," 70 Fed. Reg. at 49029 (emphasis added). It argues that "we do not want to place more regulatory emphasis on peak dose projections than can be justified." 70 Fed. Reg. at 49030. It suggests that "quantitative projections should be considered less for their strict numerical outcomes and more as one component in a qualitative evaluation of the overall safety case." *Id.* And it further states that NRC may consider a dose projection exceeding the dose standard not as a bar to licensing, but rather as only a "particularly important part of the 'full' record." 70 Fed. Reg. at 49034. Finally, in a statement that ignores the NAS's conclusions about the manageability of scientific uncertainty, EPA suggests that NRC's "regulatory judgment must bridge the gap between what science can show and the unprecedented time frames involved." 70 Fed. Reg. at 49030.

It is one thing to promulgate a dose standard and leave the implementation details (the selection of models, FEPs, and the like) to NRC. It is quite another to set a "standard" and give NRC the discretion to grant a license that does not comply with it.

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rejects a dose "target" in favor of a limit, though its description of that limit makes the distinction sound like one without a difference. *Id.* at 49033. And EPA does state that "DOE must satisfy NRC that a specified portion of the distribution satisfies the dose criterion." *Id.* at 49041. Those statements, if not contradicted elsewhere, would provide sufficient assurance that the standard truly will be a standard, but the presence of those other contradictory statements renders EPA's meaning ambiguous.

[21] EPA also states:

> We anticipate that if these very long-range performance projections (beyond 10,000 years) indicate that repository performance would degrade dramatically under a wide range of conditions at some point in time, that this would become a concern in the licensing decision. If such a dramatic deterioration were projected to occur close to the regulatory time period it would be a more pressing concern for licensing decisions than if it were to occur many hundreds of thousands of years in the future.

70 Fed. Reg. at 49028. This statement is problematic for several reasons. First, it indicates that EPA still construes the "compliance period" as 10,000 years in length, notwithstanding the clear recommendation of the NAS and holding of the Court. Second, by stating that significant deterioration after 10,000 years would be just a *concern*, it implies that such deterioration need not prevent licensing, even if it creates a violation of the standard. Those implications are wholly inconsistent with both Congress's requirement that EPA set a maximum dose standard and with the Court of Appeal's mandate that the standard, and thus the "regulatory time period," extend to peak dose.

These statements all suggest that EPA is granting NRC discretion to decide whether EPA's standard really will be a mandatory standard, or whether it will just be a guideline. But Congress did not delegate such decision-making authority to NRC; it tasked EPA with setting, "by rule," a standard, and directed NRC to see that the standard was implemented. EPA may not sub-delegate its standard-setting authority by allowing NRC to choose whether or not it must comply with EPA's rule. EPA must clarify that the standard will be what Congress demanded: a binding limit on the projected peak dose from the repository.

Indeed, EPA's new sub-delegation is particularly suspect because of its close resemblance to elements of the rule the court already set aside. In the original 40 C.F.R. Part 197 standard, EPA required DOE to provide dose projections through peak dose, but allowed NRC discretion to decide how to factor those projections into its licensing. The Court expressly rejected this approach, finding it inconsistent with Congress's mandate that EPA set a standard applicable through peak dose. 373 F.3d at 1273. Yet EPA's new rule, by again suggesting that NRC has discretion to grant a license despite projected exceedances of the dose limit, is functionally identical to the rule the Court already rejected as failing to fulfill EPA's statutory mandate.

Finally, EPA's direction to NRC regarding establishment of climate conditions and infiltration rates is no standard at all, but merely an unlawful intrusion into NRC's licensing process.

XXII. The New Rule Improperly Construes "Reasonable Expectation"

A. EPA's Attempt to Relax "Reasonable Assurance"

In its proposed rule, 70 Fed. Reg. at 49014, EPA purports to rely upon and apply a "Reasonable Expectation" standard in evaluating repository compliance, emphatically urging *NRC* to employ it as well in its *implementation* of dose and time-of-compliance standards and calling Reasonable Expectation not just an optional gauge of safety but "a critical element in implementing our standards." *Id.* at 49020. EPA thus seeks to base its rule on some special notion of "reasonable expectation" that distinguishes it from the traditional standard of reasonable assurance. It is impossible to understand what effect "reasonable expectation" had on EPA's proposal, because EPA does not explain how reasonable expectation is different from reasonable assurance. However, in the context of EPA's present rulemaking, "Reasonable Expectation" cannot mean anything significantly different from the meaning previously ascribed to it in Court by both EPA and NRC, when it was agreed that reasonable expectation and reasonable assurance meant the same thing in repository licensing. EPA cannot proceed as if the agreed judicial resolution of this issue had never happened. In Court, Nevada's challenge to use of a "Reasonable Expectation" standard was rendered moot by those agencies' agreement that it was an equivalent standard to the well-known and commonly construed "Reasonable Assurance" standard of safety that peppers all of NRC case law.

B. Background: Judicial Resolution of a Convoluted Disagreement

On June 21, 1983, NRC promulgated Final Rule 10 C.F.R. Part 60 (48 Fed. Reg. 28194), which explained:

> The Reasonable Assurance standard is derived from the finding the Commission is required to make under the Atomic Energy Act that the licensed activity provide "adequate protection" to the health and safety of the public; the standard has been approved by the Supreme Court. *Power Reactor Development Co. v. Electrical Union*, 367 U.S. 396, 407 (1961). This standard, in addition to being commonly used and accepted in the Commission's licensing activities, allows the flexibility necessary for the Commission to make judgmental distinctions with respect to quantitative data which may have large uncertainties (in the mathematical sense) associated with it.

Id. at 28204.

The Commission explained that the Reasonable Assurance standard does not create a standard that is impossible to meet. On the contrary, it parallels language the Commission has applied in contexts other than that of a nuclear waste repository, such as the licensing of nuclear reactors, for many years.

NRC proposed amendments to its repository licensing rule in 1999. 64 Fed. Reg. 8640 (Feb. 22, 1999). The Commission proposed that the results of a performance assessment be the sole quantitative measure used to demonstrate compliance with post-closure dose limits, providing "a Reasonable Assurance, on the basis of the record before the Commission, that the performance objective will be met is the general standard that is required." *Id.* at 8650. The NRC specifically recognized that in establishing Reasonable Assurance, allowance must be made for the time period involved, the hazards and the uncertainties involved, and assumed that the applicant would use complex predictive models supported by limited data from field and laboratory tests and would necessarily rely on computer modeling to determine whether a proposed repository met performance objectives. *Id.*

When NRC published its Final Rule, 66 Fed. Reg. 55732 (Nov. 2, 2001), it explained in response to public comments its continuing reliance on the Reasonable Assurance standard. Specifically addressing a comment filed by EPA, NRC noted EPA's position that Reasonable Assurance was *not appropriate* for use in the licensing of a repository where projections of performance have inherently large ranges of uncertainty. *Id.* at 55,739. Instead, EPA proposed the application of a looser, "Reasonable Expectation" standard, because it asserted that Reasonable Assurance had come to be associated with a level of confidence that is not appropriate for the very long-term analytical projections that would be necessary for evaluating Yucca Mountain. *Id.* In response, NRC explained: "It is the Commission's responsibility to determine whether DOE has or has not demonstrated compliance. The Commission does not believe that

NRC's use of 'Reasonable Assurance' as a basis for judging compliance compels focus on extreme values for representing the performance of a Yucca Mountain repository. Further, if DOE is authorized to file a License Application, and if the Commission is called on to make a decision, irrespective of the term used, the Commission will consider the full record before it." *Id.* at 55739-40.

Nonetheless, NRC made what it considered to be a semantic concession, and a partial one at that. It agreed to utilize a "Reasonable Expectation" standard for evaluation of Yucca's post-closure performance assessment but to continue to utilize Reasonable Assurance for pre-closure compliance assessment. *Id.* at 55740. At the same time, the Commission made clear its view that the choice of wording was a distinction without a difference, explaining: "The Commission will adopt EPA's preferred standard of 'reasonable expectation' for purposes of judging compliance with the numerical post-closure performance objectives. However, the Commission wants to make clear that its proposed use of 'reasonable assurance' as a basis for judging compliance was not intended to imply a requirement for more stringent analyses (e.g., use of extreme values for important parameters) or for comparison with potentially more stringent statistical criteria." *Id.* at 55740.

In its contemporaneous 2001 issuance of its original Part 197 (66 Fed. Reg. 32074), EPA discussed its Reasonable Expectation standard, conceding: "We believe that Reasonable Expectation provides an appropriate approach to compliance decisions; however, with respect to the level of expectation applicable in the licensing process, NRC may adopt its proposed alternative approach." *Id.* at 32101. At the same time, EPA emphatically backed off on the perception it had created that Reasonable Expectation was somehow intended to be a more lenient standard, observing in response to public comments: "Some comments suggest that our approach would allow the use of less rigorous science for the assessment of disposal system performance and licensing. This perception may have arisen from our choice of wording in the proposal, where we stated that NRC may elect to use a more 'stringent' approach. *Such an interpretation was not our intent*. . . . We therefore must disagree with these comments that Reasonable Expectation requires less rigorous proof than NRC's Reasonable Assurance approach. We do not believe that the Reasonable Expectation approach either encourages or permits the use of less than rigorous science in developing assessments of repository performance for use in regulatory decision making. On the contrary, the Reasonable Expectation approach takes into account the inherent uncertainties involved in projecting disposal system performance." *Id.* at 32102. (Emphasis supplied.)

Significantly, EPA added that Reasonable Expectation "requires that the uncertainties in site characteristics over long time frames and the long-term projections of expected performance of the repository are fully understood before regulatory decisions are made." *Id.* EPA explained that performance scenarios should be developed without omitting important elements simply because they may be difficult to quantify with high accuracy, and said that elicited values for relevant data should not be substituted for actual field and laboratory studies. *Id.* EPA went on to explain that the gathering of credible information that would allow a better understanding of the uncertainties in site characterization data that would bear on the long-term performance of the repository should not be subjugated simply for convenience, insisting: "We do not believe that Reasonable Expectation in any way encourages less than rigorous science and analysis." *Id.* at 32102-3.

EPA denied the suggestion that its use of a Reasonable Expectation approach intrudes inappropriately into the area of *implementation*, which EPA said is the province of NRC. *Id.* at 32103. In this regard, EPA deferred to NRC's judgment: "The implementing agency is responsible for developing and executing the implementation process and, with respect to the level of expectation applicable in the licensing process, is free to adopt an approach it believes is appropriate." *Id.* This concession was made by EPA in the face of "a majority of public comments" stating that it was unnecessary for EPA to include assurance requirements in its rule because that was an implementation matter properly within NRC's jurisdiction. *Id.* EPA concluded: "Therefore, based upon the public comments we received regarding this rule . . . we did not include assurance requirements in this rule." *Id.*

EPA expanded on its discussion of Reasonable Expectation in its "Evaluation of Potential Economic Impacts of 40 C.F.R. 197: Public Health in Environmental Radiation Standards for Yucca Mountain, Nevada" (June 2001). EPA emphasized that Reasonable Expectation would not exclude important parameters from performance assessments because they are difficult to quantify to a high degree of confidence. *Id.* at 5-2. EPA explained that many natural features important to repository performance cannot be extensively characterized, and many exhibit a high degree of inherent variability. *Id.* at 5-5. EPA insists that Reasonable Expectation requires performance assessments for a geologic repository to recognize the inherent uncertainties and limitations of characterizing the natural system. *Id.* at 5-6. EPA acknowledged that "bounding" approaches that exclude important processes that will affect performance are inappropriate because these processes are not readily quantified with high precision and accuracy, and they pose a danger of disguising important aspects of the site performance. *Id.* at 5-11.

After both EPA's and NRC's initial Yucca Mountain regulations were promulgated, NRC promulgated a proposed rule to address *which* FEPs (features, events, and processes) would be required to be included in DOE's performance assessments for the Yucca repository. 67 Fed. Reg. 3628 (Jan. 25, 2002). NRC noted that EPA's standards in general terms did not require the addressing of "unlikely" FEPs, but authorized the proposed rulemaking amendment to 10 C.F.R. Part 63 because "EPA did not define unlikely FEPs in its standards, but rather, *left the specific probability of the unlikely FEPs for NRC to define.*" *Id.* at 3628. (Emphasis supplied.) NRC explained its rationale for dealing with the FEP issue well before the licensing proceeding:

> Although the Commission could review and approve a probability limit in the context of its review of a potential DOE License Application, it is proposing to set this limit in advance, through the rulemaking process, so that it will have the advantage of public views on this question, and so that

> DOE, interested participants, and the public will have knowledge, before the License Application, of what probability the Commission would find acceptable.

Id. at 3629.

The NRC specified "unlikely" and "very unlikely" probabilities of occurrence and provided that very unlikely FEPs need not be considered by DOE, but that "unlikely" FEPs must be considered in the performance assessment for the individual protection standard. *Id.* at 3630.

Any remaining concern that Reasonable Expectation might be a more lenient standard than Reasonable Assurance (which had been stoutly denied by EPA), and any concern that NRC's adoption of Reasonable Expectation for the assessment of post-closure compliance assessment at Yucca Mountain was an unlawful departure from its longstanding (and Supreme Court approved) Reasonable Assurance standard, were put to rest in the oral argument and final decision of the *NEI* case. In that case, Nevada argued that: "[T]hat in other contexts, NRC requires reasonable assurance that the licensed activity adequately protects the public health and safety and that, in jettisoning the time-tested and Supreme Court-approved standard (citation omitted), in favor of a 'vague' 'reasonable expectation' standard, NRC 'overt[ly]' violated the AEA and the NWPA and otherwise acted arbitrarily and capriciously." 373 F.3d at 1300.

The Court, however, concluded that it would not address the matter because, in the presence of EPA counsel, NRC had admitted in oral argument that there was "no consequential difference" between the Reasonable Assurance and Reasonable Expectation standards and that the two are in fact "virtually indistinguishable." *Id.* The court went on to note that, during oral argument, NRC counsel confirmed that the two standards are "substantively identical." *Id.* The court noted Nevada's satisfaction with NRC's concession that Reasonable Assurance and Reasonable Expectation are identical standards. *Id.*

C. EPA's Reversion to a More Lenient Standard

EPA's current proposed rule is a radical departure from the advertised bases of both the Reasonable Expectation and the Reasonable Assurance concepts, in that EPA's proposal (1) fails to focus performance assessments and analyses on the *full range of defensible and reasonable parameter distributions*; and (2) seeks to invade the jurisdiction of NRC as the implementing authority for licensing of the proposed Yucca repository.

In its analysis of DOE's Yucca Mountain performance assessments, predating the EPA proposed rule, Cohen & Associates noted that:

- "Inappropriate simplifications can mask the effects of processes that will, in reality, determine disposal system performance, if the uncertainties involved with these simplifications are not recognized." OAR-2005-0083-0085, at 12-2.

- "If the uncertainties in site characterization information and the modeling of relevant features, events, and processes are not fully understood, results of bounding analyses may not be bounding at all." *Id.*

- "The Reasonable Expectation approach is aimed simply at focusing attention on understanding the uncertainties in projecting disposal system performance so that regulatory decision making will be done with a full understanding of the uncertainties involved." *Id.*

In sum, to the extent EPA's discussion, reasoning, and application of a new "Reasonable Expectation" standard can even be understood, it appears vaguely to apply a set of criteria that together amount to far less than the simple and well-understood concepts of either Reasonable Assurance or Reasonable Expectation.

XXIII. <u>The New Rule Draws a False Comparison to WIPP</u>

EPA's attempt to analogize the Yucca situation to that of DOE's repository site for the Waste Isolation Pilot Plant ("WIPP") in Carlsbad, New Mexico, is grossly misplaced. EPA certified the WIPP site under 42 C.F.R. Part 191. The compliance standard for that site was a wholly appropriate 15 millirem/year, and the compliance period was 10,000 years. EPA attempts to suggest that the Yucca situation is "unprecedented" relative to WIPP because at Yucca, EPA is now required by the Court to evaluate performance out to a time period of one million years. For several reasons, this suggestion is a distortion of the facts and could not be more wrong.

First, the WIPP repository is a site for medium-level transuranic radioactive waste, while the Yucca repository must handle the much more radioactive high-level radioactive waste and spent nuclear fuel.

Second, the WIPP repository is sited not in fractured volcanic tuff but in a large, stable, and fully isolating salt deposit. The NAS has recognized since 1957 that salt deposits provide the safest possible site for a repository because water can neither get into the repository nor get out of it as a result of the well-known absorptive characteristics of salt. *The Disposal of Radioactive Waste on Land*, Publication 519, NAS (1957), at 3-4. NAS noted that a salt deposit provides a stable, isolating geologic setting because "no water can pass through salt" and its "fractures are self-sealing." *Id.* at 4. Yucca's billions of known fractures are clearly not self-sealing.

In connection with judicial review of WIPP, the D.C. Circuit Court noted that "[s]alt formations ... should prove suitable for disposal of radioactive waste because their low permeability serves to prevent leakage and the plasticity in response to pressure allows fractures in the formations to heal themselves. The salt ... will gradually encase the waste deposited in the underground rooms ... *isolating it* from the accessible environment. *New Mexico v. Watkins,* 969 F.2d 1122, 1125 (D.C. Cir. 1992)(*per curiam*)(emphasis added). For that reason, EPA's 15 millirem/year compliance standard was referred to as the "no migration rule" *Id., citing* 42 U.S.C. § 10141(a); 40 C.F.R. §§ 191.11-.18. That name could of course never be applied to Yucca.

Third, in *NEI,* the Court did not require EPA to extend the compliance period at Yucca to one million years. Rather, it required EPA to extend the compliance period to the time of peak dose/risk, whenever that is expected to occur. It is presumed that this is within one million years, but it could be longer (there is no reason to prejudge this fact in the EPA rule). At Yucca, an untenable peak dose is expected to occur in the accessible environment around the site very shortly after the waste packages fail. That is because Yucca's fractured geology is non-isolating, making the repository more like a septic field than a geologic vault. At WIPP, peak dose never occurs (or it remains at zero) because the geologic medium is perfectly isolating. Another way of stating this is that peak dose occurs at a time period of infinity. And indeed, had EPA specified an "unprecedented" *infinite* compliance period for WIPP, this would not have hindered its licensing or increased its performance uncertainty in any way.

Fourth, at WIPP, the geology was known by DOE and EPA to be so perfectly isolating that *no credit whatsoever was given to man-made waste packages* in that repository's total system performance assessment. *See* 63 Fed. Reg. 27,354-27,369 (1998). A 10,000-year compliance period therefore allowed performance modelers ample time to test the geologic integrity of the site, because it assumed, essentially, that the waste packages had failed in year 1. Nevada would be completely satisfied for DOE and EPA to make the assumption that all of the waste packages at Yucca fail in year 1, and to require modelers to ensure compliance for only a 10,000-year period thereafter. That is because the same analysis done at Yucca as that done at WIPP would show the Yucca repository to grossly fail a compliance standard of 15 millirem/year during the first 10,000 years in that situation. At Yucca, the man-made waste containers provide 100% of the repository's performance during the first 10,000 years, assuming DOE's optimistic assumptions about container life are accepted. But as soon as those containers are presumed to have failed, the repository flunks any compliance standard even remotely similar to that used at WIPP.

In short, EPA's references to the WIPP site as justification for EPA's proposed new approach at Yucca is both highly disingenuous and irresponsible.

XXIV. EPA's Assumptions About Climate and Infiltration are Arbitrary and Erroneous

EPA makes three very broad assumptions about climatic and hydrologic behavior at Yucca. These are that (1) future climatic conditions at Yucca can be bounded by the observed range of conditions over past glacial-interglacial cycles; (2) consideration of climate changes after 10,000 years will introduce uncertainties that do not exist in the period before 10,000 years; and (3) only long-term average responses of the system to changes in infiltration are of relevance. However, as is explained in detail in the report attached in Appendix E, prepared by Dr. M. C. Thorne with input from eminent climatologists Dr. Jonathan Overpeck, Dr. Thomas Wigley, and hydrologist Dr. Howard Wheater, these conclusions are not adequately substantiated by EPA. The full Appendix E must be considered. The effects of different climates after 10,000 years can be better investigated using current and developing techniques that would command substantial support in the scientific community. Therefore, EPA's climatic bounding and infiltration conclusions are at best premature, and at worst unsound. Certainly, these effects are not appropriately the subject of advance specification by rule. *See Climatic Considerations Relevant to the Draft EPA Rule*, by Dr. Michael C. Thorne. Moreover, as Dr. Thorne points out, EPA has unreasonably failed to consider the impact of anthropogenic releases of carbon dioxide on climate and infiltration.

As a result, EPA's assumptions about climate and infiltration over the long term at Yucca are arbitrary and capricious.

Other Problems with the Proposed Rule

XXV. <u>The New Rule Violates the Information Quality Act</u>

EPA's proposed rule violates the Information Quality Act, 44 U.S.C. § 3516 note (Title V, Treasury and General Government Appropriations Act for Fiscal Year 2001, § 515), and OMB's regulations promulgated thereunder, 67 Fed. Reg. 8452 (Feb. 22, 2002). This is because the Cohen Report, which forms EPA's critical scientific basis for the rule, is clearly a "Highly Influential Scientific Assessment" or, at the least, an "Influential Scientific Assessment," that requires under the IQA an adequate peer review, yet no such review was ever conducted. This failure is significant for, as OMB has pointed out, "when an information product is a critical component of rule-making, it is important to obtain peer review before the agency announces its regulatory options so that any technical corrections can be made before the agency becomes invested in a specific approach or the positions of interest groups have hardened." *Id.*

Given the plethora of technical errors and obvious biases in the Cohen Report, which emerged not as a peer reviewed scientific study but an unabashed advocacy piece, this omission was legally and scientifically fatal.

XXVI. <u>The New Rule Fails to Protect Against Plutonium Hazards</u>

On August 3, 2005, the Institute for Energy and Environmental Research (IEER) released a credible scientific report contending that EPA's federally allowed Maximum Contaminant Level ("MCL") level of drinking water contamination by plutonium-239 and other radioactive materials with similar properties is 100 times too high because it is based on obsolete, 1950s science. Nevada's expert Dr. M. C. Thorne was one of the peer reviewers of the study. The report, *Bad to the Bone: Analysis of the Federal Maximum*

Contaminant Levels for Plutonium-239 and Other Alpha-Emitting Transuranic Radionuclides in Drinking Water, authored by Dr. Arjun Makhijani, president of IEER, is attached as Appendix F to these comments. Since plutonium-239 is one of the long-term risks posed by the Yucca repository, Nevada believes that the plutonium MCLs must be revisited by EPA before permitting the proposed Yucca radiation standard to go into effect. Plutonium and other alpha emitters will constitute the largest contributors to long term radiation dose to humans from the repository.

The IEER study bases its conclusion on well-known advances over the past three decades in the scientific understanding of the behavior in the body of plutonium and other alpha-emitting, long-lived transuranic radionuclides. These radionuclides are now widely understood to concentrate near the bone surface and deliver a dose per unit intake that is far higher than previously estimated by EPA. Yet, EPA has thus far refrained from making more stringent its plutonium MCLs.

XXVII. The New Rule Misquotes NAS on Geologic Stability

EPA's proposed rule presumes that the period of geologic stability is 1,000,000 years. While this may prove to be a reasonable limit to the performance assessment, what NAS actually said was that the period of geologic stability was "on the order of 10^6 years." NAS Report at 69. The rule should not absolutely preclude consideration of time scales in excess of 1,000,000 years if justified by considerations of geologic stability and the need to assess long-term performance of the natural barriers.

XXVIII. The New Rule Would be Unconstitutional

All of the above criticisms of EPA's proposed rule highlight what at bottom appears to be a palpable and, indeed, shameless effort to make a nuclear waste repository fit at Yucca Mountain, no matter what. In their own terms, those criticisms raise discrete legal issues that independently call into serious question the validity of the rule as proposed. At the same time, those distinct issues manifest agency action that is profoundly at odds with fundamental norms of the structure of dual sovereignty set out in the Constitution.

Key here is the fact that the Constitution does not create a unified national government, but a federation of sovereign states whose existence preceded the Union. The attributes of sovereignty possessed by the States are "fundamental postulates implicit in the constitutional design." *Alden v. Maine,* 527 U.S. 706, 728-29 (1999). Indeed, the sovereignty of the States is a "separate and distinct structural principle" that "inheres in the system of federalism established by the Constitution." *Id.* at 730. This principle has been elaborated upon and applied in a variety of contexts by the Supreme Court. *See* Robert J. Cynkar, *Dumping on Federalism,* 75 U. COLO. L. REV. 1261, 1278-99 (2004). This constitutional status of the States means that they are entitled to equal dignity and respect as sovereigns. Though the Supremacy Clause mandates that federal power appropriately exercised governs over competing laws or policies of the States, viewed through the Constitution's prism of federalism, the appropriate -- that is, the constitutional

-- exercise of federal authority requires such federal power to be exercised on the basis of generally applicable, rational, facially neutral criteria. Federal power does not extend so far as to allow the imposition of arbitrary burdens on particular States, or on any State.

By straining to make the repository fit at Yucca, EPA has abandoned any pretense of a rational basis for its rule and of equal treatment for Nevada from among other possible sites, thereby infringing Nevada's constitutionally protected rights as a sovereign. Even the federal government's prerogatives under the Property Clause do not override competing constitutional principles, or allow the federalist structure of the Constitution to be so twisted, as to allow this proposed rule to pass constitutional muster. Further analysis of this constitutional issue with respect to Yucca is contained in an attached law review article, Robert J. Cynkar, *Dumping on Federalism*, University of Colorado Law Review, Vol. 75, No. 4 (Fall 2004), which is attached as Appendix F.

XXIX. Tables Highlighting EPA's Infractions

To assist the reader in understanding several key concerns with the proposed rule, Nevada has prepared two tables, drawing from the rule and its supporting materials posted in the rulemaking docket. Table 1 contrasts statements from the NAS Report with those of EPA in the proposed rule, demonstrating that the rule is neither based upon, nor consistent with, key recommendations of NAS. Table 2 contrasts what EPA has said in prior rulemaking with what it now proposes, demonstrating substantial departures from its past statements and policies.

Table 1: Based Upon and Consistent With the Findings and Recommendations of the National Academy of Sciences?

EnPA directs EPA to promulgate a rule "based upon and consistent with the findings and recommendations" of the National Academy of Sciences' technical bases report. The United States Court of Appeals for the D.C. Circuit affirmed this mandate, vacating portions of EPA's prior rule because they were not "based upon and consistent with" the NAS report. *NEI v. EPA*, 373 F.3d 1251 (D.C. Cir. 2004). Yet EPA's new rule again is, in multiple and important ways, thoroughly inconsistent with the NAS's report. This table highlights some of the key inconsistencies.

What the NAS Said	What EPA Says and Proposes to Do
On the importance of peak dose...	
"We recommend... the use of a standard that sets a limit on the risk of individuals of adverse health effects from releases from the repository...(and) **that compliance with the standard be measured at the time of peak risk,** whenever it occurs." NAS Report at 2 (emphasis added).	"**[W]e do not want to place more regulatory emphasis on peak dose projections than can be justified...** In what we see as the best solution to this difficulty, today we are proposing that the individual protection standard consist of two parts, which will apply over different time frames." 70 Fed. Reg. at 49030 (emphasis added).
On appropriate standards...	
[A] general consensus exists among national and international bodies on a framework for protecting the public health that provides a limit of 1 milliSievert (mSv) (100 millirem (mrem)) per year effective dose for continuous or frequent exposures from all anthropogenic sources of ionizing radiation other than medical exposures. A general consensus also appears to exist among national authorities in various countries to accept and use the principle of apportioning this total radiation dose limit among the respective anthropogenic sources of exposure, typically allocating to high-level waste disposal a range of 0.1 to 0.3 mSv (**10 to 30 mrem**) per year. NAS Report at 4 (emphasis added; parentheses in original).	*EPA proposes to allow Yucca Mountain—a single source—to expose people to 350 mrem a year.*

On the proper performance measure...	
"We recommend that the **mean** values of calculations be the basis for comparison with our recommended standards." NAS Report at 123 (emphasis added).	"NAS did not speak explicitly to any particular performance measure to be used in determining compliance with regulatory standards. This decision was to be left to EPA in the course of rulemaking." 70 Fed. Reg. at 49043. "For the period extending beyond 10,000 years, we propose to use the **median** of the distribution of doses calculated from the performance assessments as the compliance measure... ." 70 Fed. Reg. at 49046 (emphasis added).
On science, modeling, uncertainty, and the relevance of 10,000 years...	
"The current EPA standard contains a time limit of 10,000 years for the purpose of assessing compliance. **We find that there is no scientific basis for limiting the time period of an individual-risk standard in this way.**" NAS Report at 6 (emphasis added). "We see no technical basis for limiting the time period of concern to a period that is short compared to the time of peak risk or the anticipated travel time." NAS Report at 57.	"In formulating an approach to compliance out to the time of peak dose, we **have established 10,000 years as an indicator for times when uncertainties in projecting performance are more manageable... .**" 70 Fed. Reg. at 49029 (emphasis added). *EPA proposes to establish a dose limit of 15 mrem (mean) for the first 10,000-year period of the simulation, and a limit of 350 mrem (median) for the post-10,000-year period.*
"One commonly expressed concern regarding the performance assessment modeling is that it requires simulating performance at such distant times in the future that no confidence can be placed in the results... This argument has been used to support the concept of a 10,000-year cutoff []. **We do not believe, however, that there is a scientific basis for limiting the analysis in this way.**" NAS Report at 71 (emphasis added).	"We believe that the most problematic aspect of extending the compliance period to peak dose is the uncertainty involved in making projections over such long time frames... . This remains a critical factor in formulating today's proposal." 70 Fed. Reg. at 49025.
"Implicit in setting a Yucca Mountain standard, is the assumption that EPA, USNRC, and DOE can, with some degree of confidence, assess the future performance of a repository system or even its components. This premise raises the basic issue of whether scientifically justifiable analyses of repository behavior over many thousands of years in the future can be made. **We conclude that such analyses are possible, within the restrictions noted in this report.**" NAS Report at 1 (emphasis added).	"[R]egulatory judgment must bridge the gap between what science can show and the unprecedented time frames involved." 70 Fed. Reg. at 49030.

"We conclude that these physical and geologic processes are sufficiently quantifiable and the related uncertainties sufficiently boundable that the performance can be assessed over time frames during which the geologic system is relatively stable or varies in a boundable manner. The geologic record suggests that this time frame is on the order of [one million] years." NAS Report at 9. "In comparison with many other fields of science, earth scientists are accustomed to dealing with physical phenomena over long time scales. In this perspective even the longest times considered for repository performance models are not excessive." NAS Report at 71.	"However, we also believe that over the very long periods leading up to the time of peak dose, the uncertainties in projecting climatic and geologic conditions become extremely difficult to reliably predict and a technical consensus about their effects on projected performance in the licensing period would be very difficult, or perhaps impossible, to achieve." 70 Fed. Reg. at 49029.
More on science, modeling, uncertainty, and the relevance of 10,000 years...	
"Because there is a continuing increase in uncertainty about most of the parameters describing the repository system farther in the distant future, it might be expected that compliance of the repository in the near term could be assessed with more confidence. **This is not necessarily true**:.. For example, uncertainties in waste container lifetimes might have a more significant effect on assessing performance in the initial 10,000 years than in the performance in the range of 100,000 years." NAS Report at 72 (emphasis added).	"[O]ur view, and the view of many others (including NAS, which should be clear from the above citation: "Because there is a continuing increase in uncertainty...") is that the uncertainties generally increase with time, at least to the time of peak dose. 70 Fed. Reg. at 49026. "We believe rising uncertainties justify adopting a different (higher) dose level." 70 Fed. Reg. at 49032.
On climate...	
"We further conclude that the probabilities and consequences of modifications by climate change... are sufficiently boundable that these factors can be included in performance assessments that extend over this time frame." NAS Report at 9.	"We are concerned about the possibility of over-speculation of climatic change over such extremely long time periods..." 70 Fed. Reg. at 49058.
On seismicity and hydrology...	
"With respect to the effects of seismicity on the hydrologic regime, the possibility of adverse effects due to displacements along existing fractures **cannot be overlooked.**" NAS Report at 93 (emphasis added).	"However, we are proposing today that DOE's analysis for seismic events **may exclude the effects of seismicity** on the hydrology of the Yucca Mountain disposal system." 70 Fed. Reg. at 49056 (emphasis added).

Table 2: EPA, Then and Now

In its new rule, EPA departs from consistent past policies in numerous, unexplained, and inexplicable ways. This table summarizes a few of the most egregious examples.

What EPA Has Said in the Past:	What EPA Now Proposes:
On appropriate standards...	
"[N]o regulatory body we are aware of considers doses of 150 mrem to be acceptable." EPA, Response to Comments, 40 C.F.R. part 197, at 3-8 (2001) (emphasis added). "The risk level associated with **70 mrem** is about five times as high the risk level associated with the individual-protection limit. **This is well above the NAS-recommended level and unprecedented in the current regulations of this and other nations for this activity.** It also is significantly inconsistent with the individual protection limit of 15mrem CEDE/yr in our generic standards (40 C.F.R. Part 191). This would result in a risk level at Yucca Mountain that is significantly higher than that at any facility that falls under 40 C.F.R. Part 191." Response to Comments at 4-5 to 4-6 (emphasis added). "A **25 mrem** standard would be "(1) higher than that recommended by the NAS...; (2) inconsistent with [EPA's] generic disposal standards at 40 CFR. part 191...; and (3) even further outside the preferred EPA lifetime risk range." Response to Comments at 4-5 (2001) (emphasis added).	"We would also view **350 mrem/yr** as representing a satisfactory level of performance should it be the "true" value at such long times." 70 Fed. Reg. at 49038. EPA's proposed rule "adds a standard of **350 mrem/yr** to apply beyond 10,000 years within the period of geologic stability." 70 Fed. Reg. at 49061.
On apportionment...	
"The apportionment of the total dose limit among different sources of radiation is used to ensure that the total of all included exposures is less than 1 mSv (100 mrem) CED/yr. Thus, ICRP recommends that national authorities apportion or allocate a fraction of the 1 mSv (100 mrem)-CED/yr limit to establish an exposure limit for SNF and HLW disposal facilities. Most other countries have endorsed the apportionment principle." 66 Fed. Reg. at 32089 (EPA, 2001).	"[W]e would argue that **allocation to a single source at the time of peak dose could be reasonable**, as other contributors currently in the Yucca Mountain area are negligible by comparison." 70 Fed. Reg. at 49041 (emphasis added). *EPA actually proposes to allocate to one source much more than its traditional limit on doses from all sources combined.*

<table>
<tr><td>"70 mrem from one source is too high a proportion of the annual 100 mrem recommended by the NCRP and ICRP (excluding background, occupational, accidental and medical sources). The apportionment of the total dose limit among different sources of radiation is used to insure that the sum, or total, of all included exposures is less than 1 mSv (100 mrem)."

Response to Comments at 4-6 (emphasis added).</td><td></td></tr>
<tr><td colspan="2" align="center">On the appropriate performance measure...</td></tr>
<tr><td>"We propose a compliance measure we believe is reasonable but still conservative: the mean of the distribution of projected doses from DOE's performance assessment... [I]n the case of Yucca Mountain, the mean is an appropriate measure."

66 Fed. Reg. at 32125 (2001) (emphasis added).</td><td>"For the period extending beyond 10,000 years, we propose to use the median of the distribution of doses calculated from the performance assessments as the compliance measure... ."

70 Fed. Reg. at 49046 (emphasis added).</td></tr>
<tr><td colspan="2" align="center">On how to deal with uncertainty...</td></tr>
<tr><td>"[I]n addressing uncertainties [in quantitative risk assessment] however, EPA generally uses conservative assumptions to ensure that risks are not underestimated."

56 Fed. Reg. 7750 (EPA, February 25, 1991).</td><td>"We believe rising uncertainties justify adopting a different (higher) dose level."

70 Fed. Reg. at 49032 (parentheses in original).</td></tr>
<tr><td colspan="2" align="center">On intergenerational equity...</td></tr>
<tr><td>"With respect to radioactive waste disposal, we believe the fundamental principle of inter-generational equity is important. We should not knowingly impose burdens on future generations we ourselves are not willing to assume. Disposal technologies and regulatory requirements are developed with the aim of preventing pollution from disposal operations, rather than assuming that clean-up in the future is an unavoidable cost of disposal operations today. Designing a disposal system, and imposing performance requirements that avoid polluting resources that reasonably could be used in the future, therefore, is a more appropriate choice than imposing clean-up burdens on future generations."

66 Fed. Reg. at 32107 (emphasis added).</td><td>EPA proposes allowing thousands of future generations to face 350 mrem (median) anthropogenic exposures from just one source – a level of exposure over an order of magnitude higher than we allow at present.</td></tr>
</table>

On pre-specifying modeling parameters...	
"Specifying "modeling techniques and assumptions... go(es) well beyond the simple statement of a compliance measure. We did not incorporate a similar level of detail in the Yucca Mountain standards because we believe we must specify only what is necessary to provide the context for implementation that NRC will execute." 66 Fed. Reg. at 32126 (2001).	*EPA now proposes to specify numerous modeling assumptions, including the climate DOE must model, and the engineering, seismic, and volcanic scenarios it must, and must not, consider.*

* * * *

Documents Submitted by the State of Nevada for the Administrative Record in support of the State of Nevada's Comments

	Date	Description
1	1947	Attorney General's Manual on the Administrative Procedure Act Full document: http://www.law.fsu.edu/library/admin/1947cover.html
2	1985/07/01	ICRP Publication 46, Radiation Protection Principles for the Disposal of Solid Radioactive Waste (1985) Full document: http://docket.epa.gov/edkpub/do/EDKStaffItemDetailView?objectId=090007d4800802bb
3	1991/07/01	Protecting the Nation's Ground Water: EPA's Strategy for the 1990's (The Final Report Of The EPA Ground-Water Task Force) Full document: http://docket.epa.gov/edkpub/do/EDKStaffItemDetailView?objectId=090007d480074d8a
4	1995	Principles of Radioactive Waste Management (IAEA 1995) Full document: http://docket.epa.gov/edkpub/do/EDKStaffItemDetailView?objectId=090007d4800802b9
5	1995/10/17	Nuclear Waste Technical Review Board Transcript – Testimony of Steve Brocoum (pp. 152-57)
6	1996/01/30	Statement for the Record, Presentation to the U.S. Nuclear Regulatory Commission, Status of the Civilian Radioactive Waste Management Program by Daniel A. Dreyfus, Director (pp. 15-17)
7	1996/03/27	PowerPoint Presentation by Steve Brocoum (DOE) to Advisory Committee on Nuclear Waste (pp. 3-5, 12-13)
8	1996/04/30	Nuclear Waste Technical Review Board Transcript – Testimony of Lake Barrett (pp. 14-17)
9	1996/04/30	PowerPoint Presentation by Steve Brocoum (DOE) to Nuclear Waste Technical Review Board (pp. 11-13)
10	1997/10/22	Presentation to the Nuclear Waste Technical Review Board Status of the Civilian Radioactive Waste Management Program by Lake H. Barrett, Acting Director (pp. 5-7)
11	1997/12/24	IAEA, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management Full document: http://www.iaea.org/Publications/Documents/Infcircs/1997/infcirc546.pdf
12	1998	Ray Clark, Environmental Radiation Protection Standards for Yucca Mountain: Considerations on Issues Full document: http://66.102.7.104/search?q=cache:hPpgYAb8eZgJ:www.epa.gov/rpdweb00/docs/yu
13	1999/08/01	Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV: Background Information Document for 40 C.F.R. Part 197 [EPA 402-R-01-004] (Executive Summary, Chapters 2, 9 and 10, and Appendices I, II, and VI) Full document: http://www.epa.gov/radiation/yucca/bid.htm or on Docket OAR-2001-0007-0028 at http://docket.epa.gov/edkpub/do/EDKStaffItemDetailView?objectId=090007d4800762cd
14	2000/02/28	State of Nevada's Comments to DOE's DEIS (Table of Contents only) Full document: http://www.state.nv.us/nucwaste/eis/yucca/ymdeis.htm

	Date	Description
15	2001/06	Evaluation of Potential Economic Impacts of 40 C.F.R. 197 (OAR-2001-0007-0097) Full document: http://docket.epa.gov/edkpub/do/EDKStaffItemDetailView?objectId=090007d4800808e2
16	2001/12	Joint NEA-IAEA International Peer Review of the Yucca Mountain Site Characterisation Project's Total System Performance Assessment Supporting the Site Recommendation Process (Summary, Chapters 1-5, and Appendix 3) Full document: http://ocrwm.doe.gov/documents/ymipr_a/index2.htm
17	2002/12/02	Petitioner State of Nevada's Opening Brief in No. 01-1516 (D.C. Circuit)
18	2004/01/14	Oral Argument Transcript in No. 01-1516 (D.C. Circuit) (pp. 17-33)
19	2005	Kristin Schrader-Frechette, Mortgaging the Future: Dumping Ethics with Nuclear Waste, 11 Science and Engineering Ethics (2005, Issue 4) Full document: http://www.nd.edu/~kshrader/pubs/epa-yucca-oct-2005-art-sci-eng-eth.pdf
20	2005/01/27	EPA's Response to Freedom of Information Act Request by Charles J. Fitzpatrick
21	2005/04/11	Email from John Kessler re: EPRI Report on Yucca Mountain standard licensing options for very long time frames
22	2005/10/04	IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management Full document: http://www.iaea.org/Publications/Documents/Conventions/jointconv_status.pdf
23	undated	EPA Radon Frequent Questions (from website) Full document: http://www.epa.gov/radon/radonqa1.html

Appendix A

MIKE THORNE AND ASSOCIATES LIMITED

(Director: Dr M C Thorne)

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EXTERNAL MEMORANDUM

Date: 10 November 2005
From: M C Thorne
Subject: International Literature and Health Effects of an Annual Effective Dose of 350 mrem

In the draft EPA standard considerable emphasis is placed on using natural background as a basis for deriving the numerical value of the standard to be applied in the period beyond 10,000 years. However, the arguments for doing this are not well-supported by the references cited. For example, at page 49035 of the draft, the NEA is cited as stating that:

'In view of the way in which uncertainties generally increase with time, or simply for practical reasons, some cut-off time is inevitably applied to calculations of dose or risk. There is, however, generally no cut-off time for the period to be addressed *in some way* in safety assessment, which is seen as a wider activity involving the development of a range of arguments for safety.'

However, it is more helpful to reproduce the full paragraph from the NEA report.

The long timescales addressed in safety assessments arise from the long half lives of some of the isotopes in the waste and the high degree of effectiveness with which deep geological disposal facilities are expected to contain radioactivity – safety studies for deep geological repositories tend to focus on the distant times when releases eventually occur. There are no ethical arguments that justify imposing a definite limit to the period addressed by safety assessments, in spite of the technical difficulties that this can present to those conducting such assessments. It is an ethical principle that the level of protection for humans and the environment that is applicable today should also be afforded to humans and the environment in the future, and this implies that the safety implications of a repository need to be assessed for as long as the waste presents a hazard. In view of the way in which uncertainties generally increase with time, or simply for practical reasons, some cut-off time is inevitably applied to calculations of dose or risk. There is, however, generally no cut-off time for the period to be addressed *in some way* in safety assessment, which is seen as a wider activity involving the development of a range of arguments for safety.

It is also important to recognize what the NEA meant by long timescales in safety assessments. This is made clear at pages 13 and 14 of the cited NEA report. The relevant text is reproduced below.

Over long enough timescales, however, even the most stable engineered materials and geological environments are subject to perturbing events and changes. For example, the possibility of new features and deformation in the repository host rock must be considered over timescales in the order of, say, 10^5 or 10^6 years, no matter how carefully a site is chosen for its stability. These events and changes are subject to uncertainties, which generally increase with time and must be taken into account in safety assessments. Eventually, but at very different times for different parts of the system, uncertainties are so large that predictions regarding the evolution of the repository and its environment cannot meaningfully be made (see Box 1).

As discussed in the next section, arguments for safety can still be made that are likely to be adequate for repository licensing provided a repository is well designed and a suitable, geologically stable site is selected. Well-supported statements regarding the radiological consequences of such a repository can be made for the prolonged period over which the stability of the geological environment can be assured, whereas a less rigorous assessment of radiological consequences is likely to be adequate at later times, on account of radioactive decay and the resulting decreased radiological toxicity of the waste. Nevertheless, an acknowledgement of the limits of predictability of the system in both regulations and in safety cases is important for credibility in the eyes of the public and of other stakeholders.

Thus, the NEA view is that well-supported statements regarding the radiological consequences of a repository can be made for the period over which geological stability can be assured. Beyond that period, a less rigorous assessment is required. It seems clear that the period to be addressed 'in some way' is beyond the period of geological stability and extends indefinitely. The NEA provides no justification for treating the period beyond 10,000 years in this way. Indeed, the only timescales explicitly cited in the above extracts are beyond 10^5 or 10^6 years. Furthermore, in the period for which quantitative assessments can be carried out, 'it is an ethical principle that the level of protection for humans and the environment that is applicable today should also be afforded to humans and the environment in the future'. This does not seem to justify a relaxation of standards at some time within that interval.

At page 49035, a draft ICRP document is cited. Again a selective quotation is used. The statement quoted is that 'Weights can also be assigned according to the time at which the exposure will occur.' However, the EPA fails to state that this quotation is from a section addressing collective dose and not individual dose. Furthermore, the context does not relate specifically to solid radioactive waste disposal. Finally, the quotation is from a consultation document that has not been approved by the Commission and was specifically designated as not for citation. Numerous individuals and groups have commented on this document and it cannot be construed as the agreed position of the ICRP on the issues discussed.

At page 49036, the NEA is further cited. For convenience, the full text is given below, with the selected quotation in bold.

In one of the papers presented at the *timescales workshop* [27], in order to balance ethical and technical considerations and public concerns, a series of time-graded containment objectives is suggested with two target times.

- It is suggested that the initial period of 500 years corresponds to the period of greatest public concern. For this period the objective of total containment is proposed, at least for spent fuel and reprocessed high-level waste in view of the high hazard. This period may overlap with a period of monitoring during which a repository is kept open and unsaturated: in many national programmes, there are proposals for an extended period of monitored, retrievable underground storage. The period may also coincide, at least to some extent, with a phase of relatively complex transient phenomena, including resaturation of the repository and its surroundings. If complete containment can be assured during the transient phase, this can reduce the need to model these phenomena in detail, although the implications of transient phenomena on the longer-term characteristics of the disposal system must be considered.

- In the time period up to **100 000 years** – the end point roughly corresponding to the crossover point on activity curves – **a dose constraint derived from natural background radiation levels is prescribed.**
- **Beyond some 100 000 years, the proposed objective is that the eventual redistribution of the residual activity by natural processes remains indistinguishable from natural regional variations in radiation levels.**

Reference 27 is:

Long Timescales, Low Risks: Rational Containment Objectives that Account for Ethics, Resources, Feasibility and Public Expectations – some thoughts to provoke discussion, N.A. Chapman, in *The Handling of Timescales in Assessing Post-closure Safety of Deep Geological Repositories*. Workshop Proceedings, Paris, France, 16-18 April 2002, available from the NEA, Paris, 2002.

Bearing in mind that this quotation is from an individual opinion paper and does not represent a national or NEA view, reference to page 152 of the cited reference shows what Professor Chapman meant by a dose constraint derived from natural background radiation levels. There he stated 'The performance measure appropriate to this period, and to the approach advocated here, would be to have reasonable expectation that any impacts (assuming the same biosphere as today) are less than about 10% of the world-wide variation in normal background radiation (excluding the highly variable radon contribution): a figure of around 0.3 mSv/a is appropriate.'

For reference, 0.3 mSv/a corresponds to 30 mrem per year and not 350 mrem per year. Note also that Professor Chapman excludes radon from his comparison.

At page 49037, the EPA also cites UK guidance relating to the geological disposal of low and intermediate level radioactive wastes. The citation is from paragraph 6.22. The full text of paragraphs 6.21 and 6.22 is given below, with the cited text shown in bold.

6.21 No definite cut-off in time is prescribed either for the application of the risk target or the period over which risk should be assessed. The timescales over which assessment results should be presented is a matter for the developer to consider and justify as adequate for the wastes and disposal facility concerned.

6.22 **At times longer than those for which the conditions of the engineered and geological barriers can be modelled or reasonably assumed, scoping calculations or qualitative arguments may be used to** indicate the continuing level of safety. **Comparisons with the ambient levels of radioactivity in the environment may also be appropriate** (see Requirement R4, Paragraph 6.26). Further comments on assessment calculation timescales are given in Paragraph 8.23.

Paragraph 6.26 imposes the strong additional requirement that 'It shall be shown to be unlikely that radionuclides released from the disposal facility would lead **at any time** [emphasis added] to significant increases in levels of radioactivity in the accessible environment.' Paragraph 8.23 is cited in full below.

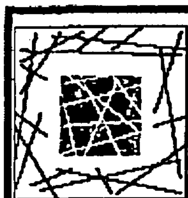
8.23 In general, assessments of the radiological impact of a facility should cover the timescale over which the models and data by which they are generated can be considered to have some validity. In the very long term, irreducible uncertainties about the geological, climatic and resulting geomorphological changes that may occur at a site provide a natural limit to the timescale over which it is sensible to attempt to make detailed calculations of disposal system performance. The timescale over which the Agency will expect to see detailed calculations of risk will therefore depend on the site and the facility and it is a matter for the developer to justify. Simpler scoping calculations and qualitative information may be required to indicate the continuing safety of the facility at longer times.

It should be noted that the compliance criterion in the UK is a target not a limit, i.e. compliance with it is not absolutely required. However, it is set at an annual risk of one in one million per year and is based on a risk factor of 0.06 per Sievert, i.e. it corresponds to a target on annual effective dose of 16.7 μSv (1.67 mrem). This risk target is applied over the whole period for which the conditions of the engineered and geological barriers can be modelled or reasonably assumed. The period is not defined by some degree of increase in uncertainty but applies to the whole period for which the models and data have some validity. Even beyond that time, scoping calculations and qualitative arguments may be used. Comparisons with background may be used as a second line of argument and do not stand alone as a criterion of safety. Furthermore, the comparison with background is framed in terms of significant increases in levels of radioactivity and not in terms of doses.

In practice, assessments of deep geological disposal in the UK compute radiological risk out to very long times. This is illustrated by Box 7 from the NEA report cited above, which shows the five timeframes used by UK Nirex Ltd.

Box 7. Illustration of the presentation of a safety assessment based on five time frames

The figure provides an illustration of what is currently envisaged in terms of the assessment and presentation of each of the proposed five time frames in the planned update to the Nirex generic post-closure performance assessment (GPA).



Time frame 1: Waste containers as emplaced

- Institutional control and monitoring (may include long-term storage period)
- Physical barrier intact, containment of radionuclides
- Repository starting to resaturate
- Releases limited to minor diffusive releases through vents and gaseous

Key Performance Indicators:

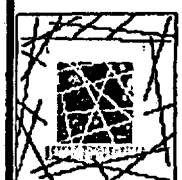
- Decrease in radionuclide inventory
- Zero flux from near field
- Gaseous releases

Confidence arguments:

- Steel corrosion measurements
- Decay of short-lived radionuclides

Modelling approaches:

- Decay within packages
- Gas generation and Transport



Time frame 2: Physical and chemical barriers evolving

- Repository fully saturated
- Physical barrier may start to break down but waste form limits mobility
- Many radionuclides relatively insoluble, greatest release by diffusion
- Degradation of organics producing complexants
- Gas generation and migration

Key Performance Indicators:

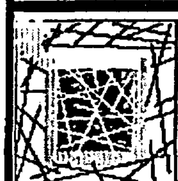
- Decrease in inventory
- Flux from near field
- Gaseous releases

Confidence arguments:

- Comparisons with corrosion of Roman nails
- Cement analogues

Modelling approaches:

- Package-scale model
- Near-field chemistry



Time frame 3: Chemical barrier

- Reducing conditions in near field fully established
- Corrosion causes failure of significant number of packages
- Advective-diffusive release of radionuclides, particularly those which are poorly sorbed
- Gas generation and migration

Key Performance Indicators:

- Flux from near field
- Gaseous releases

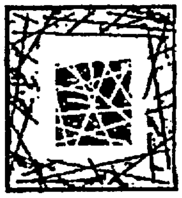
Confidence arguments:

- Cement analogues
- Maqarin site – limited movement
- of radionuclides away from repository

Modelling approaches:

- Repository-scale near-field model
- Steady-state, regional-scale
- groundwater flow

Box 7. Illustration of the presentation of a safety assessment based on five time frames (cont'd)



Time frame 4: Stable geological barrier

- Most waste packages have failed, offering little resistance to radionuclide migration, therefore the near field is treated as homogeneous
- Migration of radionuclides from near field through far field

Key Performance Indicators	*Confidence arguments:*	*Modelling approaches:*
• Fluxes out of near and far field • Radiological risk • Environmental effects • Comparisons with natural fluxes	• Maqarin site – limited migration • Oklo – retardation • Palaeohydrogeology – geosphere stability	• Homogeneous near-field 'soup' model • Groundwater transport models

Time frame 5: System responding to external change

- Homogeneous near field
- Migration of radionuclides from near field through far field
- Need to consider climate change and hydrogeological changes
- Releases to different climate states

Key Performance Indicators	*Confidence arguments:*	*Modelling approaches:*
• Radiological dose or risk • Comparison with background radiation levels	• Comparisons with natural radiation levels	• Homogeneous near-field 'soup' model • Reference geosphere • Reference biospheres representing different climate states

Note that radiological risk remains a key performance indicator even in Time frame 5.

From the above, it is clear that the EPA has selectively and misleadingly quoted from both overseas and international literature in an attempt to justify setting a standard based on natural background. The further issue that then arises is the potential health implications of setting a compliance standard of 350 mrem per year (recalling that this standard is applied to the median of the assessed doses and that the arithmetic mean (or expectation value) of annual effective dose is anticipated to be about a factor of three higher than the median.

Information on the effects of exposure of humans to ionising radiations is very extensive. Although a principal source of information is epidemiological investigations of the survivors from the atomic bomb explosions at Hiroshima and Nagasaki, many other human populations have been exposed and data from those populations generally corroborate, or are not in conflict with, the data on the atomic bomb survivors. In addition, extensive intact animal and *in vitro* studies have been undertaken to elucidate the mechanisms by which radiation effects are induced. These various studies are regularly reviewed internationally by the United Nations Scientific Committee on the Effects of Atomic Radiations (UNSCEAR) and UNSCEAR reports form part of the basis on which the ICRP develops its recommendations. In the United States, the National Research Council of the National Academy of Sciences also regularly produces reviews of the health risks from exposure to ionising radiations. Its most recent report on this subject was published in 2005 and represents an authoritative current statement of the consensus view on radiation risks at low levels of exposure.[1] For conciseness, that review is subsequently referred to as BEIR VII(2).

The Committee that produced BEIR VII(2) adopted a linear no-threshold (LNT) model for evaluating radiation effects. Thus, the increase in risk is directly proportional to the increment of dose throughout to low dose and dose rate regime. This implies that natural background radiation is considered to be carcinogenic, as is any increment on natural background. The Committee specifically considered whether low doses are substantially more or less harmful than estimated by the linear no-threshold model.

As to whether low doses are substantially more harmful than estimated by the linear no-threshold model, the Committee concluded (page 19):

In sum, the total body of relevant research for the assessment of radiation health effects provides compelling reasons to believe that the risks associated with low doses of low-LET radiation are no greater than expected on the basis of the linear, no-threshold model.

As to whether low doses are substantially less harmful than estimated by the linear no-threshold model, the Committee stated (page 19):

...some materials provided to the Committee suggest that the LNT model exaggerates the health effects of low levels of ionizing radiation...The Committee also does not accept this hypothesis. Instead, the Committee concludes that the preponderance of information indicates that there will be some risk, even at low doses...

Both the epidemiologic data and the biological data are consistent with a linear model at doses where associations can be measured. The main studies establishing the health effects of ionizing radiation are those analyzing survivors of the Hiroshima and Nagasaki atomic bombings in 1945. Sixty-five percent of these survivors received a low dose of radiation; that is, low according to the definition used in this report (equal to or less than 100 mSv). The arguments for thresholds or beneficial health effects are not supported by these data. Other work in epidemiology also supports the view that the harmfulness of ionizing radiation is a function of dose. Further, studies of cancer in children following exposure *in utero* or in early life indicate that radiation-induced cancers can occur at low doses. For example, the Oxford Survey of Childhood Cancer, found a "40 percent increase in cancer rate among children up to [age] 15." This increase was detected at radiation doses in the range 10 to 20 mSv.

In this context, it is relevant to note that 350 mrem per year is 3.5 mSv per year. Thus, exposure for between three and six years at that rate would result in a dose in the range over which a 40 percent increase in the cancer rate in children has been directly observed.

In the Executive Summary to their report (page 28), the BEIR VII(2) Committee states that:

[1] National Research Council of the National Academies, BEIR VII-Phase 2, Health Risks From Exposure to Low Levels of Ionizing Radiation, The National Academies Press, Washington, D.C.

The committee has developed and presented in the text the committee's best possible risk estimates for exposure to low-dose, low-LET radiation in human subjects. As an example, Table ES-1 shows the estimated number of incident cancer cases and deaths that would be expected to result if a population of 100,000 persons with an age distribution similar to that of the entire US population was each exposed to 0.1 Gy, and also shows the numbers that would be expected in the absence of exposure...

The estimates are accompanied by 95% subjective confidence intervals (*i.e.* random as well as judgmental) that reflect the most important uncertainty sources, namely statistical variation, uncertainty in the factor used to adjust risk estimates for exposure at low doses and dose rates, and uncertainty in the method of transport...

The excess cancer cases per 100,000 of the population from exposure to 0.1 Gy (equivalent to 0.1 Sv or 100 mSv of low-LET radiation) are listed in Table 1.

Gender and Cancer Type	Best Estimate	95 Percent Confidence Interval	
		Lower Bound	Upper Bound
Male: All solid cancers	800	400	1600
Male: Leukemia	100	30	300
Male: Total	900	430	1900
Female: All solid cancer	1300	690	2500
Female: Leukemia	70	20	250
Female: Total	1370	710	2750

Table 1: Excess Cancer Cases per 100,000 of the US Population from Exposure to 0.1 Gy of Low LET Radiation

Corresponding data for excess cancer deaths are given in Table 2.

Gender and Cancer Type	Best Estimate	95 Percent Confidence Interval	
		Lower Bound	Upper Bound
Male: All solid cancers	410	200	830
Male: Leukemia	70	20	220
Male: Total	480	220	1050
Female: All solid cancer	610	300	1200
Female: Leukemia	50	10	190
Female: Total	660	310	1390

Table 2: Excess Cancer Deaths per 100,000 of the US Population from Exposure to 0.1 Gy of Low LET Radiation

Note that the totals listed in Tables 1 and 2 are not given explicitly by the BEIR VII(2) Committee. They have been obtained by summing the values for total solid cancers and leukaemia.

From the above data, and weighting data for males and females equally, the excess risk of inducing cancer in a member of the US population from a dose of 0.1 Gy of low-LET radiation has a best estimate 0.01135 and a 95^{th} percentile range of 0.0057 to 0.02325. The excess risk of causing death from cancer has a best estimate 0.0057 and a 95^{th} percentile range of 0.00265 to 0.0122.

For comparison, a dose rate of 350 mrem (3.5 mSv) per year of low-LET radiation would deliver a total lifetime (80 years) dose of around 0.28 Sv. For low-LET, whole body radiation, the absorbed dose in Gy is numerically equal to the effective dose in Sv, *i.e.* 0.28 Sv is equivalent to 0.28 Gy. Thus, lifetime exposure at the proposed dose limit would correspond to a risk of inducing cancer of 0.032 (range 0.016 to 0.065) and a risk of causing death from cancer of 0.016 (range 0.0074 to 0.034). It should be kept in mind that the arithmetic mean (or expectation value) of the annual effective dose that corresponds to a median annual effective dose is about a factor of three larger. Thus, the expectation value of the lifetime risk of causing death through cancer if the median dose just complies with the dose limit is 0.048 (range 0.022 to 0.102).

Lifetime risks of inducing cancer or causing death through cancer of several percent are very high and cannot be regarded as acceptable. In this context, it is relevant to refer to the most recent, published basic recommendations of the ICRP, ICRP Publication 60[2]. The relevant text relating to dose limits for members of the public is given in summary paragraphs S39 to S41. These are reproduced in full below.

(S39) The scope of the dose limits for public exposure is confined to the doses incurred as a result of practices. Doses incurred in situations where the only available protective action takes the form of intervention are excluded from that scope. Separate attention has also to be paid to potential exposures. Radon in dwellings and in the open air, radioactive materials, natural or artificial, already in the environment, and other natural sources are examples of situations that can be influenced only by intervention. Doses from these sources are therefore outside the scope of the dose limits for public exposure. The conduct of intervention involves occupational exposure and should be treated accordingly.

(S40) The Commission now recommends that the limit for public exposure should be expressed as an effective dose of 1 mSv in a year. However, in special circumstances, a higher value of effective dose could be allowed in a single year, provided that the average over 5 years does not exceed 1 mSv per year.

(S41) In selecting the limit on effective dose, the Commission has sought a value that would be only just short of unacceptable for continued exposure as the result of deliberate practices the use of which is a matter of choice. This does not imply that higher doses from other sources, such as radon in dwellings, should be regarded as unacceptable. The existence of these sources may be undesirable but is not a matter of choice. The doses can be controlled only by intervention, which will also have undesirable features.

Releases of radionuclides from a repository at Yucca Mountain would be expected to give rise to continued exposures, so the principal dose limit value of 1 mSv (100 mrem) per year would be applicable. Effective doses of this magnitude would be only just short of unacceptable. Furthermore, the principal dose limit applies to exposure of individuals from all relevant practices. However, in practice, 'almost all public exposure is controlled by the process of constrained optimisation and the use of prescriptive

[2] 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Annals of the ICRP, **21**(1-3).

limits...The dose constraint should be applied to the mean dose to the critical group from the source for which the protection is being optimised. Occasionally, the same group will also be critical for other sources, or if the critical groups are different, each group may incur some dose from the sources for which it is not critical. If the exposures in any critical group are likely to approach the dose limit for public exposure..., the constraints applied to each source must be selected to allow for any significant contribution from other sources to the exposure of the critical group.

In summary, an arithmetic mean dose to the critical group from all relevant practices should be less than 1 mSv per year as such a dose would be only just short of unacceptable. Disposal of radioactive wastes at Yucca Mountain would constitute one such practice. The EPA argues at page 49041 of the draft standard that allocation of 100 mrem per year to a single source (the proposed repository) at the time of peak dose 'could be reasonable, as other contributors currently in the Yucca Mountain area are negligible by comparison.' The EPA further comments that 'to assume (or even to estimate the chance) whether, how, or where other radiation facilities could develop in the far future would require immense speculation about the long-term evolution of government programs, population demographics, and technology.' While this is clearly a reasonable statement, it implies that there is no strong argument against the possibility of such facilities being created. Furthermore, the nature of a geological radioactive waste disposal facility is such that there can be no guarantee, in the long term, that there would be knowledge of the presence of such a facility. Thus, it would not be possible to take the existence of the facility into account when determining the location of future hazardous facilities. In these circumstances, it seems more appropriate to set the standard at a fraction of the principal dose limit, to allow for the possibility of development of such future facilities, noting that remote and sparsely populated areas have been preferred locations for nuclear and other hazardous facilities in the past.

In the context of the discussion of a potential 100 mrem per year dose standard, the EPA draft rule (page 49041) states:

> Nevertheless, we have decided not to propose a peak dose standard of 100 mrem/yr because, over the very long term, we believe that natural background levels to which individuals are or could currently be exposed provides a more reasonable context in which to judge the performance of the Yucca Mountain disposal system.

It should be noted that the ICRP set their 1 mSv per year limit based on both considerations of health detriment and on a comparison with natural background. This is described at paragraphs 190 and 191 of ICRP Publication 60.

> (190) At least two approaches are possible in choosing a dose limit for public exposure. The first is the same as that used for choosing occupational limits[3]. Assessing the consequences is no more difficult than in the occupational case, but judging the point at which these consequences can reasonably be described as unacceptable is much more difficult. The second approach is to base the judgement on the variations in the existing level of dose from natural sources. This natural background may not be harmless, but it makes only a small contribution to the health detriment which society experiences. It may not be welcome, but

[3] This is acceptability of health consequences to the individual, see ICRP Publication 60, Section 5.3.

the variations from place to place (excluding the large variations in the dose from radon in dwellings) can hardly be called unacceptable.

(191) The consequences of continued additional exposure giving annual effective doses in the range from 1 mSv to 5 mSv...provide no easy basis for judgement, but do suggest a value of the annual dose limit not much above 1 mSv...Excluding the very variable exposures to radon, the annual effective dose from natural sources is about 1 mSv, with values at high altitudes above sea level and in some geological areas of at least twice this. On the basis of these considerations, the Commission recommends an annual limit on effective dose of 1 mSv...

It is noted that the ICRP comparison with natural background excluded the contribution from radon. In contrast, the EPA in their draft rule (page 49037) made comparisons with natural background defined as follows:

For purposes of this discussion, natural background radiation consists of external exposures from cosmic and terrestrial sources, and internal exposures from indoor exposures to naturally occurring radon.

It needs to be pointed out that high exposures to indoor radon are not generally regarded as acceptable and that national programs throughout the world are directed to identifying homes with unusually high radon levels, and to providing advice and assistance on mitigating those levels (see, for example, A Citizen's Guide to Radon: The Guide to Protecting Yourself and Your Family from Radon, U.S. EPA 402-K02-006, Revised September 2005, www.epa.gov/radon/pubs/citguide.html).

In conclusion:

- The international and overseas literature provides no support for arguing that calculations of radiological impact should be assessed against more relaxed standards beyond 10,000 years;
- References cited by the EPA in support of their position either imply or state dose constraints of substantially less than 100 mrem per year applying over timescales of 100,000 years or longer;
- Where natural background has been proposed for use as a basis for assessment, it has been on timescales beyond that of geological stability and/or as one of multiple lines of argument;
- A quotation from the ICRP ostensibly supporting the EPA position is from an unpublished document that has not been approved by the Commission and that was distributed for consultation on the understanding that it would not be cited;
- Furthermore, the text cited does not relate to solid radioactive waste disposal and concerns collective dose not individual dose;
- Application of the draft EPA standard implies that the radiation dose that could be received in three to six years would result in a dose in the range over which a 40 percent increase in the cancer rate in children has been directly observed;
- Application of the draft EPA standard implies a potential lifetime risk of causing death through cancer of up to 4.8 percent;
- The draft EPA standard is a factor of 3.5 larger than the principal dose limit for members of the public recommended by the ICRP;

- That principal dose limit was described by the ICRP as just short of unacceptable for continued exposure and was based both on considerations of health effects and variations in natural background;
- The principal dose limit defined by the ICRP relates to all practices; for a single practice, such as the disposal of radioactive waste at Yucca Mountain, some apportionment of that limit would be expected, as the potential development of future practices in the region involving the use of ionising radiation or radioactive materials cannot be excluded from consideration;
- Whereas the ICRP made comparisons with variations in natural background excluding radon, the EPA made comparisons with the total exposure to natural background including radon;
- High exposures to indoor radon are not generally regarded as acceptable and national programs throughout the world are directed to identifying homes with unusually high radon levels, and to providing advice and assistance on mitigating those levels.

Mike Thorne and Associates Limited

Michael Thorne

Qualifications PhD FSRP
Year of birth [redacted]
Nationality [redacted]

KEY SKILLS

- Radiological protection
- Assessing the radiological safety of disposal of radioactive wastes
- Distribution and transport of radionuclides in the environment
- Expert elicitation procedures
- Probabilistic safety studies
- Development of safety criteria
- Pharmacodynamics

CAREER HISTORY

2001- <u>Mike Thorne and Associates Limited</u>

Development of Models for Radionuclide Transfers to Sewage Sludge and for Evaluating the Radiological Impact of Sludge applied to Agricultural Land
Client – Food Standards Agency

Includes a review of literature and the development and implementation of probabilistic models for such transfers.

Development of Biokinetic Models for radionuclides in Animals
Client – Serco Assurance

Development of updated biokinetic models for use by the Food Standards Agency in their SPADE and PRISM modelling systems

Review Studies for the Proposed Australian National Radioactive Waste Repository
Client – RWE NUKEM

Reviews of reports on animal transfer factors and of the potential effects of climate change on the repository plus development of a model for the biokinetics of the ^{226}Ra decay chain in grazing animals.

Development and Application of a Model for Assessing the Radiological Impacts of ^{3}H and ^{14}C in Sewage Sludge
Client – NNC Ltd

Development of a model based on physical, chemical and biochemical principles for the uptake of 3H and 14C into sewage sludge and their subsequent distribution and transport after application of the sludge to agricultural land.

Support for development of the Drigg Post-closure Radiological Safety Assessment
Client - BNFL

Support in the areas of FEP analysis, biosphere characterisation, human intrusion assessment and the effects of natural disruptive events. In addition, provision of advice of future research initiatives that should be pursued by BNFL.

Co-ordination of biosphere research and participation in BIOCLIM
Client – UK Nirex Ltd

Co-ordination of research on climate change, ice-sheet development, near-surface hydrology and radionuclide transport, as well as participation in an international programme on the implications of climate change for radioactive waste disposal.

Review of Parameter Values
Client – AEA Technology/Serco Assurance

Review of biosphere parameter values for use in the ANDRA assessment model AQUABIOS.

Effects of Radiation on Organisms Other Than Man
Client – AEA Technology/Serco Assurance

Study for ANDRA to identify appropriate indicator organisms and develop appropriate dosimetry and effects models for those organisms.

Development of a Database related to Emergency Planning
Client – AEA Technology (Rail)

Identification of relevant international, overseas and national legislation, regulations and guidance, and production of brief summaries of the documents.

Dose Reconstruction for Workers on a Uranium Plant
Client - McMurry and Talbot

Dose reconstruction for the plaintiffs in a case relating to the Paducah Gaseous Diffusion Plant.

Dose Reconstruction for a Worker Exposed to Pu and Am
Client – Pattinson and Brewer

Dose reconstruction for a worker exposed by a puncture wound in the finger while working at a glove box.

1998-2001 <u>AEA Technology</u>

Assessment of Remediation Options for Uranium Liabilities in Eastern Europe
Client - European Commission

Studies of remediation requirements relating to mines, waste heaps and hydrometallurgical plant in Bulgaria, Slovakia and Albania.

Evaluation of Unusual Pathways for Radionuclide Transport from Nuclear Installations
Client – Environment Agency

Review of literature and conduct of formal elicitation meetings to determine potential pathways and evaluate their radiological significance.

Revision of Exemption Orders Made Under the Radioactive Substances Act
Client – DETR

Review of requirements for revision and preparation of a draft text for the purposes of consultation.

Support Studies on the Drigg Post-closure Performance Assessment
Client - BNFL

Support in the areas of FEP analysis, biosphere characterisation, human intrusion assessment and the effects of natural disruptive events. In addition, provision of advice of future research initiatives that should be pursued by BNFL.

Development of Models for the Biokinetics of H-3, C-14 and S-35 in Farm Animals
Client - FSA

Review of relevant literature, development of appropriate biokinetic models and implementation in stand-alone software.

Integration of Aerial and Ground-based Monitoring in the Event of a Nuclear Accident
Client - FSA

Desk-based review and simulation study designed to determine optimum monitoring strategies for different types of accidents.

Elicitation of Parameter Values for use in Radiological Impact Assessment Models
Client - FSA

Expert elicitation study to provide distributions of parameter values for use in the suite of assessment models currently used by the FSA for routine and accidental releases.

Biosphere Research Co-ordination and Assessment Studies
Client - United Kingdom Nirex Ltd

Continuation of a programme of work originally undertaken at Electrowatt Engineering (UK) Ltd

Site Investigation and Risk Assessment - Hilsea Lines
Client - Portsmouth City Council

Radiological assessment of a radium-contaminated site.

1987-1998 Electrowatt Engineering (UK) Ltd

Evaluation of Inhalation Doses from Uranium
Client - Baron & Budd

Provision of expert witness support in a class action relating to environmental exposure from a uranium plant.

Biosphere Studies Relating to Drigg
Client - BNFL

Provision of advice on time-dependent biosphere modelling for the Drigg low-level radioactive waste disposal facility.

Development of a Siting Policy for Nuclear Installations: Harbinger Project and Follow-up Study
Client - HSE/NSD

Review of existing policy and development of alternatives as a precursor to application to a wide range of installations, not restricted to commercial reactors.

Support to the Rock Characterisation Facility Public Enquiry
Client - UK Nirex Ltd

Preparation of position papers and rebuttals of evidence.

Radiation Doses to an Individual as a Consequence of Working on the San Onofre Nuclear Power Plant
Client - Howarth & Smith

Interpretation of personal and area monitoring data for legal purposes.

Interpretation of Uranium in Urine Data for the Fernald, Ohio Feed Materials Processing Center
Client - Institute for Energy and Environmental Research

Interpretation of urinalysis and lung counting data, and appearance as an expert witness in the associated trial.

Determination of Failure Probabilities for use in PRA
Client - Nuclear Installations Inspectorate

Development of new approaches to the use of Bayes Theorem in defining component failure probabilities for use in PRA when statistics on actual failures are limited.

Review of Inventory Information
Client - UK Nirex Ltd

Review of uncertainties in inventories of individual radionuclides.

ALARP Study of Options for the Treatment, Packaging, Transport and Disposal of Plutonium Contaminated Material
Client - UK Nirex Ltd

Use of multi-attribute utility analysis to establish which option is preferred.

Expert Judgement Estimation of Intrusion Model Parameters
Client - British Nuclear Fuels plc

Project Manager of a study assessing the risks of human intrusion into Drigg radioactive disposal site using expert judgement techniques.

Brainstorming Study of Risks Associated with Building Structures
Client - Building Research Establishment

Participation in a classification study of the health risks associated with buildings including both injuries and disease.

Rongelap Resettlement Project
Client - Marshall Islands Government

Participation in an oversight committee evaluating the radiological safety of Rongelap in the context of resettlement by its evacuated community.

Radiological Consequences of Deferred Decommissioning of Hunterston A
Client - Scottish Nuclear Ltd

Project Manager of a study of the radiological impacts of groundwater transport of radionuclides, releases to atmosphere and intrusion.

Reviews of Safety Documentation
Client - UK Nirex Ltd

Review of safety related documentation for Packaging and Transport Branch.

The Sheltering Effectiveness of Buildings in Hong Kong
Client - Ove Arup & Partners

Project Manager of a study evaluating the shielding effectiveness of all types of building in Hong Kong for volume sources of photons in air and surface deposition sources.

Assessment of the Radiological Impact of Releases of Radionuclides from Premises other than Licensed Nuclear Sites
Client - Ministry of Agriculture, Fisheries and Food

Project Manager of a study to identify representative premises, obtain data on their releases of radionuclides and assess radiological impacts using a new methodology developed for the project.

Assessment of the Radiological Implications of Uranium and its Radioactive Daughters in Foodstuffs
Client - Ministry of Agriculture, Fisheries and Food

Project Manager of a review study of concentrations of uranium and its daughters in foodstuffs, taking local and regional variations in uranium concentrations in soils, sediments and waters into account.

Radionuclides in Sewage
Client - Her Majesty's Inspectorate of Pollution

Project Manager of a study including a desk review on alternative methods of disposal of sewage sludges, interpretation of monitoring data relating to radionuclide discharges from Amersham International to the public sewer system, development of a model for radionuclide transport in sewers, and collection and analysis of effluent, foul water, sediment, sludge and other samples suitable for use in model validation studies.

Accident Consequence Calculations
Client - Nuclear Installations Inspectorate

Project Manager of a study to assess the radiological consequences of various atmospheric releases using the MARC code.

Definition of Threshold Recording Levels for Drums of ILW
Client - UK Nirex Ltd

Project Manager of a study of the implications of post-closure radiological impacts of radioactive waste disposal in defining Threshold Recording Levels for radionuclides in individual waste drums.

Definition of Expert Judgment Exercises Relating to Nuclear Safety
Client - Commission of the European Communities

Project Manager for a study defining expert judgment exercises relating to conceptualisation, representation and input data specification. Included a comprehensive review of available formal expert judgment procedures, and mathematical and behavioural aggregation techniques.

Definition of Research Requirements Relating to the Use of Expert Judgment in Parameter Value Elicitation for Reactor Safety Studies in a UK Context
Client - Nuclear Safety Research Management Unit, HSE

Development of proposals for using combined behavioural and mathematical aggregation procedures in formal elicitations of expert judgment.

Development Priorities for the Drigg Technical Development Programme
Client - British Nuclear Fuels plc

Provision of detailed advice to BNFL on future design options, and research and development priorities, in relation to radioactive waste disposal at Drigg.

Channel Tunnel Safety Studies
Client - Channel Tunnel Safety Authority

Provision of advice and guidance on safety criteria appropriate to the Fixed Link, on the classes of Dangerous Goods that may properly be carried and on the overall characteristics of the proposed Safety Case.

Development of Societal Risk Criteria
Client - Marathon Oil

Interpretation of F-N curves in the context of the offshore oil/gas industry, taking risk aversion into account.

Impacts of Salt Dispersal on Plant Communities
Client - Sir William Halcrow

Evaluation of salt dispersal from a major road in winter in relation to adjacent Sites of Special Scientific Interest.

Offsite Consequence Assessments
Client - Nuclear Electric

Studies of the offsite radiological impacts of atmospheric and liquid releases of radioactive materials from Magnox stations.

Dry Run 3
Client - Her Majesty's Inspectorate of Pollution

Uncertainty and bias studies involving formal expert judgment procedures to develop a conceptual model of those factors and interrelationships which are of significance in determining the post-closure radiological impact of a deep geological repository for radioactive wastes. This project also included advice on data and models to be used for post-closure radiological assessments.

Radiological Assessments of Drigg
Client - British Nuclear Fuels plc

Project Manager for post-closure radiological impact assessments of the Drigg LLW disposal site. Also included specification and development of computer codes relating to the radiological impact of fires, releases of radioactive gases produced by microbial action and metal corrosion, and human intrusion.

Biosphere Co-ordination
Client - UK Nirex Ltd

Co-ordination of the UK Nirex Ltd Biosphere Research Programme from its inception, including requirements definition, technical management of all projects and QA surveillance as the Client's Representative.

Biosphere Support for the Nirex Disposal Safety Assessment Team
Client - AEA Technology

Development of approaches for assessing the radiological impact of releases of radionuclides to the biosphere, plus advice on radiological protection criteria, definition of individual risk, implications of conventionally toxic chemicals in wastes and a variety of other matters.

Evaluation and Radiological Assessment of Liquid Effluent Releases from Various Premises
Client - Her Majesty's Inspectorate of Pollution

Reviews of monitoring data and evaluations of radiological impact, primarily related to Harwell, Aldermaston, Capenhurst and Amersham International.

Evaluation of the Radiological Impact of Overseas Nuclear Accidents
Client - Her Majesty's Inspectorate of Pollution

Studies of the impact of potential overseas nuclear accidents on the UK, with emphasis on survey and monitoring requirements, and the selection of appropriate radiation detection equipment for monitoring.

Bilsthorpe Power Station
Client - British Coal/East Midlands Electricity

Preparation of an Environmental Statement with emphasis on atmospheric dispersion of SO_2 and NO_x.

Gas Generation in Radioactive Waste Disposal Facilities
Client - AEA Technology

Development of a coupled microbial degradation and corrosion model for gas generation in repositories for LLW and ILW.

Effects of Chernobyl on Drinking Water Supplies
Client - Her Majesty's Inspectorate of Pollution

Evaluation of the radiological implications of enhanced concentrations of radionuclides in water supplies in England and Wales subsequent to the Chernobyl accident.

Sea Disposal of Radioactive Wastes
Client - UK Nirex Ltd

Participation in an Environmental Impact Assessment of the proposed resumption of sea-dumping of radioactive wastes.

UK Research Related to Radioactive Waste Management
Client - Her Majesty's Inspectorate of Pollution

Identification of gaps in the UK national research effort related to radioactive waste management.

Research Requirements for Repository Design and Site Investigations
Client - UK Nirex Ltd

Review of research requirements for repository design and site investigations in relation to LLW and ILW disposal in near-surface and deep repositories.

1985 - 1986 **International Commission on Radiological Protection, Sutton, Surrey, England**

Scientific Secretary responsible for arranging and minuting meetings, administrative arrangements, technical review of reports, editing of the Commission's journal, liaison with other international organisations and public relations.

1979 - 1985 **ANS Consultants Ltd, Epsom, Surrey, England**

Reviews of data on the distribution at transport of radionuclides in terrestrial and aquatic ecosystems (see publications list).

Development of a dynamic model for radionuclide transport in agricultural ecosystems and implementation of the model on various microcomputer systems.

Photon and neutron shielding studies of radiochemical plant, together with area classification and ALARA studies.

A review of UK use of the criticality code MONK and other approaches to criticality safety assessment.

Radiological and conventional safety aspects of Magnox reactor decommissioning.

Development of metabolic models for inclusion in ICRP Publication 30.

Development of pharmacodynamic models for toxic chemicals.

Review of neutron activation analysis in studies of radionuclide transport in soils and plants.

Experimental studies on radionuclide transport in soils and plants using various photon-emitting radionuclides.

Support for DoE work on probabilistic risk assessment of LLW and ILW disposal.

Review of UK research requirements for HLW disposal.

Post-closure radiological impact assessment of the proposed LLW and ILW facility at Elstow, Bedfordshire.

Development of a generalised biosphere model for use in probabilistic risk assessments of solid radioactive waste disposal.

Initial development of a mathematical model for use in assessing the radiological impact of contaminated groundwater.

Development, computer implementation and comprehensive documentation of a model to calculate the radiological impact of intrusion into radioactive waste repositories.

Development of a general-purpose computer code for solving first-order differential equations using a hybrid Predictor-Corrector/Runge-Kutta method.

Studies on the potential radiological consequences of Magnox reactor accidents.

1974 - 1979 <u>Medical Research Council Radiobiology Unit, Chilton, Didcot, Oxon, England</u>

Development of dosimetric and metabolic models for use in ICRP Publication 30.

Studies on the metabolism of plutonium in bone and relationships to blood flow.

Theoretical studies on radionuclide metabolism and dosimetry.

Development of techniques in neutron-induced autoradiography and alpha imaging.

Image analysis studies of plutonium in bone, uranium in lungs, lysosomal inclusions in cells and heterochromatin.

Studies on the clearance of inhaled UO_2.

Alpha spectroscopy in support of toxicity studies with Ra-224.

Data analysis in connection with experimental animal studies on the potential efficacy of neutron therapy using 42 MeV neutrons.

1971 - 1974 <u>University of Sheffield</u>

Experimental studies on the reaction $\gamma + p \rightarrow \pi^0 + p$ at photon energies between 1 and 3 GeV, using a linearly polarised photon beam.

PROFESSIONAL ACTIVITIES AND MEMBERSHIP

- Fellow of the Society for Radiological Protection and Immediate Past President
- Member of the Eco-ethics International Union
- Visiting Fellow at the Climatic Research Unit, University of East Anglia

SELECTION OF PUBLICATIONS

A measurement of the beam asymmetry parameter for neutral pion photoproduction in the energy range 1.2 - 2.8 GeV. P.J.Bussey, C. Raine, J.G. Rutherglen, P.S.L. Booth, L. Carroll, G.R. Court, A.W. Edwards, R. Gamet, C.J. Hardwick, P.J. Hayman, J.R. Holt, J.N. Jackson, J. Norem, W.H. Range, F.H. Combley, W. Galbraith, V.H. Rajaratnam, C. Sutton and M.C. Thorne. London Conference (1974) Abstract 997.

The measurement of the polarisation parameters S, P and T for positive pion photoproduction between 500 and 1700 MeV. P.J. Bussey, C. Raine, J.G. Rutherglen, P.S.L. Booth, L.J. Carroll, P.R. Daniel, C.J. Hardwick, J.R. Holt, J.N. Jackson, J.H. Norem, W.H. Range, F.H. Combley, W. Galbraith, V.H. Rajaratnam, C. Sutton, M.C. Thorne and P. Waller. Nuclear Physics, B104, (1976) 253-276.

The polarised beam asymmetry in photoproduction of eta mesons from protons 2.5 GeV and 3.0 GeV. P.J. Bussey, C. Raine, J.G. Rutherglen, P.S.L. Booth, L.J. Carroll, P.R. Daniel, A.W. Edwards, C.J. Hardwick, J.R. Holt, J.N. Jackson, J. Norem, W.H. Range, W. Galbraith, V.H. Rajaratnam, C. Sutton, M.C. Thorne and P. Waller. Physics Letters, 61B, (1976) 479-482.

Aspects of the dosimetry of plutonium in bone. M.C. Thorne. Nature, 259, (1976) 539-541.

The toxicity of Sr-90, Ra-226 and Pu-239. M.C. Thorne and J. Vennart. Nature 263, (1976) 555-558.

Radiation dose to mouse testes from Pu-239. D. Green, G.R. Howells, E.H. Humphreys and J. Vennart with Appendix by M.C. Thorne. Published in "The Health Effects of Plutonium and Radium", Ed. W.S.S. Jee, (J.W. Press, Salt Lake City, Utah, 1976).

The distribution and clearance of inhaled uranium dioxide particles in the repository tract of the rat. Donna J. Gore and M.C. Thorne. In "Inhaled particles IV", Ed. W.H. Walton, (Pergamon Press, Oxford, 1977) pp. 275-284.

Theoretical aspects of the distribution and retention of radionuclides in biological systems. M.C. Thorne. J. Theor. Biol., 65, (1977) 743-754.

Aspects of the dosimetry of emitting radionuclides in bone with particular emphasis on Ra-226 and Pu-239. M.C. Thorne. Phys. Med. Biol., 22, (1977) 36-46.

A new method for the accurate localisation of Pu-239 in bone. D. Green, G. Howells and M.C. Thorne. Phys. Med. Biol., 22, (1977) 284-297.

The measurement of blood flow in mouse femur and its correlation with Pu-239 deposition. E.R. Humphreys, G. Fisher and M.C. Thorne. Calcif. Tiss. Res., 23, (1977) 141-145.

The distribution of plutonium-239 in the skeleton of the mouse. D. Green, G.R. Howells, M.C. Thorne and J. Vennart. In "Proceedings of the IVth International Congress of the International Radiation Protection Association Vol. 2 (Paris 1977).

The visualisation of fissionable radionuclides in rat lung using neutron induced autoradiography. D.J. Gore, M.C. Thorne and R.H. Watts. Phys. Med. Biol., 23 (1978) 149-153.

Lymphoid tumours and leukaemia induced in mice by bone-seeking radionuclides. J.F. Loutit and T.E.F. Carr with an appendix by M.C. Thorne. Int. J. Radiat. Biol., 33, (1978) 245-263.

Plutonium-239 deposition in the skeleton of the mouse. D. Green, G.R. Howells and M.C. Thorne. Int. J. Radiat. Biol., 34, (1978) 27-36.

Imaging of tissue sections on Lexan by alpha-particles and thermal neutrons; an aid in fissionable radionuclide distribution studies. D. Green, G.R. Howells, M.C. Thorne and R.H. Watts. Int. J. Appl. Radiat. Isotopes, 29, 285-295 (1978).

Analytical techniques for the analysis of multi-compartment systems. M.C. Thorne. Phys. Med. Biol., 24, 815-817 (1979).

The initial deposition and redistribution of Pu-239 in the mouse skeleton: implications for rodent studies in Pu-239 toxicology. D. Green, G.R. Howells and M.C. Thorne. Br. J. Radiol., 52, 426-427 (1979).

Bran and experimental colon cancer. M.C. Thorne. Lancet, ii, 13 January 1979, p.108.

Quantitative microscopic studies of the distribution and retention of Pu-239 in the ilium of the female CBA mouse. D. Green, G.R. Howells and M.C. Thorne. Int. J. Radiat. Biol., 36, 499-511 (1979).

Techniques for studying the distribution of alpha emitting and fissionable radionuclides in histological lung sections. T. Jenner and M.C. Thorne. Phys. Med. Biol., 25, 357-364 (1980).

Morphometric studies of mouse bone using a computer-based image analysis system. D. Green, G.R. Howells and M.C. Thorne. J. Microscopy, 122, 49-58 (1981).

A semi-automated technique for assessing the microdistribution of ^{239}Pu deposited in bone. D. Green, G.R. Howells and M.C. Thorne. Phys. Med. Biol., 26, 379-387 (1981).

Radionuclide distribution and transport in terrestial and aquatic ecosystems, Volumes 1 to 6. P.J. Coughtrey, M.C. Thorne et al. A.A. Balkema, Rotterdam 1983-1985.

Dynamic models for radionuclide transport in soils, plants and domestic animals. M. C. Thorne and P. J. Coughtrey. In: Ecological Aspects of Radionuclide Release (Ed. P. J. Coughtrey). British Ecological Society Special Publication No. 3, Blackwell, Oxford, 1983.

Studies on the mobility of radioisotopes of Ce, Te, Ru, Sr and Cs in soils and plants. P.J. Coughtrey, M.C. Thorne, D. Jackson and G.F. Meekings. In: CEC Symposium on the Transfer of Radioactive Materials in the Terrestial Environment Subsequent to an Accidental Release to Atmosphere. Dublin, April 1983.

A study of the sensitivity of a dynamic soil-plant-animal model to changes in selected parameter values. M.C. Thorne, P.J. Coughtrey and G.F. Meekings. In: CEC Symposium on the Transfer of Radioactive Materials in the Terrestial Environment Subsequent to an Accidental Release to Atmosphere. Dublin, April 1983.

Microdosimetry of bone: Implications in radiological protection. M.C. Thorne. In: Metals in Bone, N.D. Priest (Ed.) MTP Press, Lancaster (1985), pp. 249-268.

Non-stochastic effects resulting from internal emitters: dosimetric considerations. M.C. Thorne. J. Soc. Rad. Prot., 6 (1986).

Pharmacodynamic models of selected toxic chemicals in man. Vol. 1. Review of metabolic data. M.C. Thorne, D. Jackson and A.D. Smith. MTP Press, Lancaster, 1986.

Pharmacodynamic models of selected toxic chemicals in man. Vol. 2. Routes of intake and implementation of pharmacodynamic models. A.D. Smith and M.C. Thorne. MTP Press. Lancaster 1986.

Generalised computer routines for the simulation of linear multi-compartment systems. D.Jackson, A.D. Smith, M.C. Thorne and P.J. Coughtrey. Environmental Software, 2 (1987), 94-102.

The demonstration of a proposed methodology for the verification and validation of near field models. J-M. Laurens and M.C. Thorne. In: Proceedings of an NEA Workshop "Near-field Assessment of Repositories for Low and Medium Level Radioactive Waste". pp. 297-310. NEA/OECD, Paris, 1987.

Principles of the International Commission on Radiological Protection System of Dose Limitation. Br. J. Radiol., 60 (1987), 32-38.

The origins and work of the International Commission on Radiological Protection. H. Smith and M.C. Thorne. Invest. Radiol., 22 (1987), 918-921.

The potential for irradiation of the lens and cataract induction by incorporated alpha-emitting radionuclides. D.M. Taylor and M.C. Thorne. Health Phys., 54 (1988), 171- 179.

Forum on alpha-emitters in bone and leukaemia: Introduction and commentary. M.C. Thorne. Int. J. Radiat. Biol., 53 (1988), 521-539.

Radiological protection and the lymphatic system: The induction of leukaemia consequent upon the internal irradiation of the tracheo-bronchial lymph nodes and the gastrointestinal tract wall. K.F. Baverstock and M.C. Thorne. Int. J. Radiat. Biol., 55 (1989), 129-140.

The Biosphere: Current Status. NSS/G106. M.C. Thorne. Available from UK Nirex Ltd, Curie Avenue, Harwell, 1989.

The development of an overall assessment procedure incorporating an uncertainty and bias audit. M. C. Thorne and J-M. Laurens. Proceedings of an International Symposium on Safety Assessment of Radioactive Waste Repositories. OECD Paris (1990), 673-681.

Implications of environmental change for biosphere modelling: work for UK Nirex Ltd. M.C. Thorne. Proceedings of an International Symposium on Safety Assessment of Radioactive Waste Repositories. OECD Paris (1990), 860-865.

The Biosphere: Current Status, December 1989. NSS/G114. M.C. Thorne. Available from UK Nirex Ltd, Curie Avenue, Harwell, 1990.

The Nirex Overview. M.C. Thorne and D. George. In: Future Climate Change and Radioactive Waste Disposal: Proceedings of an International Workshop. C.M. Goodess and J.P. Palutikof (Eds). NSS/R257. Available from UK Nirex Ltd, Curie Avenue, Harwell, 1991.

A review of expert judgment techniques with reference to nuclear safety. M. C. Thorne and M. M. R. Williams, Progress in Nuclear Energy, 27 (1992), 83-254.

NSARP Reference Document: The Biosphere, January 1992. Nirex Report No. NSS/G119 M.C. Thorne. 1993.

The use of expert opinion in formulating conceptual models of underground disposal systems and the treatment of associated bias. M.C.Thorne, Journal of Reliability Engineering and Systems Safety, 42 (1993), 161-180.

UK Nirex Ltd Science Report No S/95/003, Nirex Biosphere Research: Report on Current Status in 1994, M C Thorne (Ed.), UK Nirex Ltd, July 1995.

UK Nirex Ltd. Science Report No S/95/012, Vol 3, A J Baker, C P Jackson, J E Sinclair, M C Thorne and S J Wisbey, Nirex 95: A Preliminary Analysis of the Groundwater Pathway for a Deep Repository at Sellafield: Volume 3 - Calculations of Risk, UK Nirex Ltd, July 1995.

Nirex 95: An Assessment of a deep repository at Sellafield, A J Baker, G E Hickford, C P Jackson, J E Sinclair, M C Thorne and S J Wisbey, TOPSEAL 96, Demonstrating the Practical Achievements of Nuclear Waste Management and Disposal, European Nuclear Society, pp. 125-132, 1996.

Consideration of post-closure controls for a near surface low level waste disposal site, Clegg, R, Pinner, A, Smith, A, Quartermaine, J and Thorne, M C, In: Planning and Operation of Low Level Waste Disposal Facilities, IAEA, Vienna, 1997.

The estimation of failure rates for low probability events, M M R Williams and M C Thorne, Progress in Nuclear Energy, 31 (1997), 373-476.

A comparison of independently conducted dose assessments to determine compliance and resettlement options for the people of Rongelap Atoll, S L Simon, W L Robison, M C Thorne, L H Toburen, B Franke, K F Baverstock and H J Pettingill, Health Physics, 73(1), 133 - 151, 1997.

A Guide to the Use and Technical Basis of the Gas Evolution Program MICROX: A Coupled Model of Cellulosic Waste Degradation and Metal Corrosion, R Colosante, J E Pearson, S Y R Pugh, A Van Santen, R G Gregory, M C Thorne, M M R Williams and R S Billington, Nirex Safety Studies Report NSS/R167, July 1997.

UK Nirex approach to the protection of the natural environment, M J Egan, M C Thorne and M A Broderick, Stockholm Symposium.

Post-closure performance assessment: treatment of the biosphere, M A Broderick, M J Egan, M C Thorne and J A Williams, Winnipeg Symposium.

The application of constraint curves in limiting risk, M C Thorne, J. Radiol. Prot., Vol. 17, 275-280, 1997.

The biosphere in post-closure radiological safety assessments of solid radioactive waste disposal, M C Thorne, Interdisciplinary Science Reviews, Vol. 23, 258-268, 1998.

An illustrative comparison of the event-size distributions for γ-rays and α-particles in the whole mammalian cell nucleus, K Baverstock and M C Thorne, Int. J. Radiat. Biol., 74, 799-804, 1998.

Southport '99, Achievements and Challenges: Advancing Radiation Protection into the 21st Century, Proceedings of an International Symposium, M C Thorne (Ed.) Society for Radiological Protection, London, 1999.

Modelling radionuclide distribution and transport in the environment, K M Thiessen, M C Thorne, P R Maul, G Prohl and H S Wheater, Environmental Pollution, 100, 151-177, 1999.

Use of a systematic approach for the Drigg post-closure radiological safety assessment, G Thomson, M Egan, P Kane, M Thorne, L Clements and P Humphreys, DisTec 2000, Disposal Technologies and Concepts 2000, Kontec Gesellschaft für technische Kommunication mbH, Tarpenring 6, D-22419, Hamburg, 413-417, 2000.

Validation of a physically based catchment model for application in post-closure radiological safety assessments of deep geological repositories for solid radioactive wastes, M C Thorne, P Degnan, J Ewen and G Parkin, Journal of Radiological Protection, 20(4), 403-421, 2000.

An approach to multi-attribute utility analysis under parametric uncertainty, M Kelly and M C Thorne, Annals of Nuclear Energy, 28, 875-893, 2001.

Radiobiological theory and radiation protection, M C Thorne, British Nuclear Energy Society International Conference on Radiation Dose Management in the Nuclear Industry, May 2001.

Development of a solution method for the differential equations arising in the biosphere module of the BNFL suite of codes MONDRIAN, M M R Williams, M C Thorne, J G Thomson and A Paulley, Annals of Nuclear Energy, 29, 1019-1039, 2002.

A model for evaluating radiological impacts on organisms other than man for use in post-closure assessments of geological repositories for radioactive wastes, M C Thorne, M Kelly, J H Rees, P Sànchez-Friera and M Calvez, J. Radiol. Prot., 22, 249-277, 2002.

Background Radiation: Natural and Man-made, M C Thorne, BNES 4th International Conference on Health Eeffects of Low-level Radiation, 22-24 September 2002, Keble College, Oxford, UK, CD Available from BNES.

Background Radiation: Natural and Man Made, M C Thorne, Journal of Radiological Protection, 23, 29-42, 2003.

Comments from the Society for Radiological Protection on ICRP Reference 02/305/02 – Protection of Non-Human Species From Ionising Radiation, M C Thorne, Journal of Radiological Protection, 23, 107-115, 2003.

Estimation of animal transfer factors for radioactive isotopes of iodine, technetium, selenium and uranium, M C Thorne, J. Environ. Radioact., In the press.

Appendix B

Some Comments on the Proposed Yucca Mountain Compliance Standards

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October 15, 2005

On July 9, 2005, the U. S. Court of Appeals for the District of Columbia Circuit ruled that the compliance period for the proposed Yucca Mountain, Nevada nuclear waste facility be extended from 10,000 to 1,000,000 years. The 1,000,000-year time frame is in keeping with the recommendations made by the Committee on Technical Bases for Yucca Mountain Standards of the National Research Council/National Academy of Sciences in their 1995 report, ***Technical Bases for Yucca Mountain Standards.***[1]

In response to the Court's ruling, on August 22, 2005 the U.S. Environmental Protection Agency (EPA) issued a proposed rule in the **Federal Register** (40 CFR Part 197, *Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada*, **Federal Register**, Vol. 70, No. 161, pp. 49014–49065). The purpose of this document is to comment on one aspect of the proposed ruling - the type of measurement to be used to summarize the results of the computer simulations done by the Department of Energy in the Total System Performance Assessments (TSPA). As seen in the following table, the EPA altered both the type of measurement and the maximum dose used to evaluate scenarios after the first 10,000 years.

Time Span	***Type of Measurement***	***Maximum Dose***
Less Than or Equal to 10,000 Years	Arithmetic Mean	15 mrem/year
Greater than 10,000 Years	Median	350 mrem/year

The use of the arithmetic mean and the 15 mrem/year maximum dose over the first 10,000 years are carried over from the earlier EPA ruling. However, the type of measurement and maximum dose recommended by EPA for the mandated extension beyond10,000 years are dramatically different. The EPA suggests that the median rather than the mean be used as the compliance measurement and that the maximum allowable dose be increased from 15 to 350 mrem/year.

In brief, the EPA argues that the use of the median rather than the arithmetic mean is justified because of the statistical distribution of TSPA simulation results. The EPA further argues that the value of 350 mrem/year is justified because of the high level of uncertainty in the estimates and that the level is similar to the values of current ambient dose levels for neighboring states.

Summary of Conclusions

We believe that the change in the compliance measurement from the mean to the median is not justified on a number of grounds:

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[1] "We believe that compliance assessment is feasible for most physical and geologic aspects of repository performance on the time scale of the long-term stability of the fundamental geologic regime—a time scale that is on the order of 10^6 years at Yucca Mountain—and that at least some potentially important exposures might not occur until after several hundred thousand years. For these reasons, we recommend that compliance assessment be conducted for the time when the greatest risk occurs, within the limits imposed by long-term stability of the geologic environment." (NAS, 1995, pp. 6–7).

(1) It is clear that the NAS recommended the use of the mean;
(2) The EPA rejects the arithmetic mean to exclude "very high dose projections resulting from scenarios that are unlikely to occur". However, each TSPA-SR model simulation result has an equal probability of occurring, which means that all scenarios are equally unlikely to occur. It is not clear why any result should be excluded when all results are equally likely. If on the other hand, there are differences in the probability of specific scenarios occurring, the analyst should use the arithmetic mean weighted by the relative probability of occurrence;
(3) The EPA use of the median masks the fact that the distribution of simulation results implies an extremely high probability of non-compliance. At 300,000 years, approximately 42% of the TSPA-SR simulations exceed the 350 mrem/year maximum allowable dose advocated by EPA. With a 42% non-compliance rate, any measure that suggests that the facility is in compliance (as the median does) is at best misleading.[2]

The NAS recommendation concerning the type of measurement

The NAS recommends using the "expected value of the probabilistic distribution".[3] To a statistician—indeed to a scientist—the phrase "expected value" is a term with a very precise mathematical meaning. Quoting from Hogg and Craig, ***Introduction to Mathematical Statistics*** (5th Edition, 1995, page 52), a standard text that is frequently used for the first Junior- or Senior-level mathematical statistics course in statistics departments:

"The expectation of a random variable is

$$E(X) = \sum_x x \times f(x)\text{, in the discrete case}$$

or

$$E(X) = \int_{-\infty}^{\infty} x \times f(x)dx\text{, in the continuous case.}$$

Sometimes the expectation $E(X)$ is called the *mathematical expectation of X* or the *expected value of X*."[4]

Since the TSPA simulation results all have an equal probability of occurring, the expected value of the set is computed as the sum of the values divided by the number of values that are summed—the arithmetic mean:

$$\bar{X} = \sum_{i=1}^{n} X_i \Big/ n$$

It seems clear that the NAS expected that the arithmetic mean be used to characterize statistical distributions arising from the compliance assessments.

[2] These conclusions apply only to the TSPA-SR and cannot also be assumed to apply to the TSPA-LA.
[3] The phrase is used at least three times in the NAS document—on page 42, on page 65, and finally on page 68.
[4] Essentially the same definition appears in Lindgren, ***Statistical Theory*** (4th Edition, 1993) on page 90 for the discrete case and page 94 for the continuous case.

EPA rejects the arithmetic mean so as to exclude "very high dose projections resulting from scenarios that are unlikely to occur"

The EPA rejects use of the mean as the measure of central tendency for the period after 10,000 years because:

> "we are concerned that the arithmetic mean is too easily influenced by extremes in the distribution, particularly very high dose projections resulting from scenarios that are unlikely to occur. A conservative approach to constructing and evaluating performance scenarios tends to generate high-end results and a simple averaging of these results would drive the arithmetic mean to higher values that would not be as representative overall of the actual distribution of projected doses." (Page 49043)

This quote seems to imply that a high-dose TSPA-SR model realization is somehow less likely than one from the middle of the swarm. This is not true; in fact, any one of the 300 realizations is as likely as any other of the 300. If the EPA had been able to compute the probability associated with a realization, the model would have generated two outputs at a time point: X_i, the dose level for the ith realization and p_i, its associated likelihood. In this case the mean would have been computed as:

$$\bar{X} = \left(\frac{\sum_{i=1}^{n} p_i X_i}{\sum_{i=1}^{n} p_i} \right)$$

This is the probability-weighted mean. The computation of the median would also have become more complicated. In addition to sorting the values into ascending order, it would have been necessary to carry along the associated likelihoods. The median is the value X_k (in the sorted data) for which the quantity $\sum_{i=1}^{k} p_i \Big/ \sum_{i=1}^{n} p_i$ first equals or exceeds 0.5.

When viewed as a probability-weighted mean, the simple arithmetic means gives equal weight to each of the values:

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i = \frac{\sum_{i=1}^{n} \frac{1}{n} X_i}{\sum_{i=1}^{n} \frac{1}{n}} \quad \text{(The denominator is 1.)}$$

When written in this more complicated way, one can see that the probabilities associated with each of the values are $1/n$; that is, each realization is as likely as any other.

Although you can't say that this realization, because it is extreme, is by itself less likely than any of the others, you can say that realizations falling into a range of doses are more or less likely than realizations falling into a different, but equally wide, range. For example, it is true that at the 300,000-year point, realizations between 250 and 300 (about 6.1% of the time) are more likely to occur than those between 550 and 600 (about 2.4% of the time).

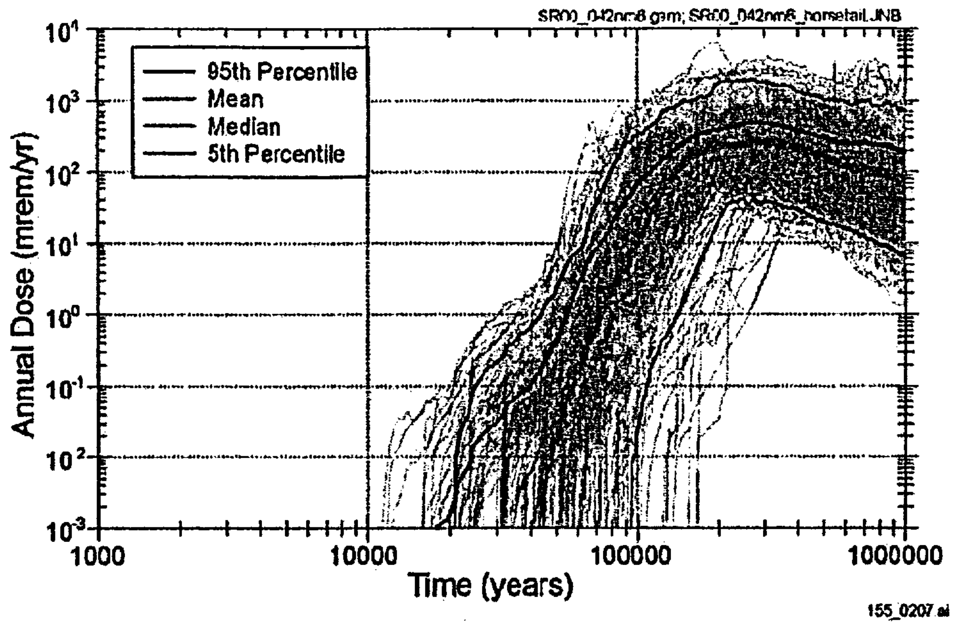
The EPA use of the median masks the fact that the distribution of simulation results implies an extremely high probability of non-compliance

To date, there are several versions of the TSPA model, but our attention will focus on the TSPA-SR (Site Recommendation) model. This model simulates the flow of radioactive materials from drums inside the Yucca Mountain repository to the outside environment (mainly to the water table and from there to the critical group). The ultimate output of the model is the dose (in mrem/year) to which the critical group is exposed and the dose changes over time. Physical processes that are modeled by a large number of equations govern the flow from the repository. The operation of each of these processes depends upon a certain number of physical parameters and the values of these parameters may not be known with certainty. The DOE dealt with this uncertainty in two ways.

If the parameter is important (could have a big effect on the final dose) and if enough is known about the statistical distribution of the parameter, then a random number generator simulating the parameter's statistical distribution is used to generate a potential value for it. On the other hand, it the parameter is less critical to the output or knowledge of the distribution is limited, then a single point estimate is used for the value of the parameter. These single values are chosen to be conservative, that is, to yield higher rather than lower estimates of the dose.[5]

For a single run of the simulation model (or realization), values for each of the statistically modeled parameters were determined by generating a random number from each of the appropriate random number generators and plugging them into the appropriate equations. This means that the parameter values used on one run of the model will not be the same as those used on the next and, consequently, that the output will vary from one run to the next. In the face of this uncertainty, the model is run 300 times and various summary statistics are computed from the model's output. Here is a graph of the output of the 300 realizations of the TSPA-SR model:

[5] To the extent that conservative assumptions (i.e., assumptions leading to higher doses) are used for both the TSPA parameters modeled by distributions and those for which just point estimates are used, the entire set of realizations is shifted upwards (by an unknown amount)— not just the extremely high ones.



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Source: SSPA Volume 2 (BSC 2001 [DIRS 154659]).

NOTE: Summary curves show the 95th, 50th (median), and 5th percentiles, as well as the mean. Results based on the TSPA-SR base-case model.

Figure 2-4. TSPA-SR Base-Case Model: 300 Realizations of Million-Year Annual Dose Histories for Nominal Performance

Note that the time and dose axis are both on logarithmically spaced scales. The light gray lines represent a single realization. The model indicates that there is virtually no discharge for the first 10,000 years and the point of peak discharge occurs between 200,000 and 300,000 years. Also the mean exceeds the median, indicating that the underlying distribution of the simulation results is positively skewed.

Clearly an issue arises when, as in this case, the selection of one type of measurement over another completely changes the conclusions concerning compliance. The use of the median suggests compliance while the mean suggest non-compliance. In these cases, insight into the appropriate measure (if only one measure is allowed) can be obtained by analyzing the distribution of the simulation results. There may be some comfort in using the median if the distribution of simulation results is concentrated about the median. Specifically, if the distribution is so concentrated that a relatively small percent of simulation results exceed the maximum allowable dose.

The EPA proposed rules includes a quotation from the NAS report supporting the criteria of a reasonable level of confidence.[6]

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[6] Federal Register, Vol. 70, No. 161, Monday, August 22, 2005, Page 49029

"No analysis of compliance will ever constitute an absolute proof; the objective instead is a reasonable level of confidence in analyses that indicates whether limits established by the standard will be exceeded" (NAS Report p. 71).

The simulation results are not available so it was not possible to precisely compute the percent of the simulation results that exceed the maximum allowable dose. However, it is possible to closely replicate the computation information available from the analysis commissioned by the EPA and conducted by Cohen Associates (Cohen).[7] In that report the authors addressed the uncertainties in the parameters and outputs of the TSPA models. As part of their evaluation, they concluded that the lognormal distribution would be a good first approximation to the statistical distribution of model outputs. To the extent that the lognormal distribution is a good fit to the TSPA model output, it is possible to estimate the fraction of TSPA runs that exceed the proposed dose limit.

The following table is adapted from the Cohen report.[8] Using the 95th percentile and median taken by eye from the plot of TSPA-SR runs, the authors estimated the parameters of the underlying lognormal distribution, *mu* and *sigma*.[9]

		Annual Dose Forecast		*Parameter Estimate*		*Standard*	*Lognormal*
ID	*Year*	*95th Centile*	*Median*	*mu*	*sigma*	*Deviation*	*Mean*
1	21,000	0.0025	n/a	-11.4	3.29	0.56	0.003
2	50,000	2.3	0.02	-3.91	2.88	82.2	1.27
3	70,000	40	0.8	-0.22	2.38	229	13.6
4	100,000	300	10	2.30	2.07	714	85.0
5	200,000	1,600	240	5.48	1.15	778	465
6	300,000	2,000	280	5.63	1.20	1,019	572

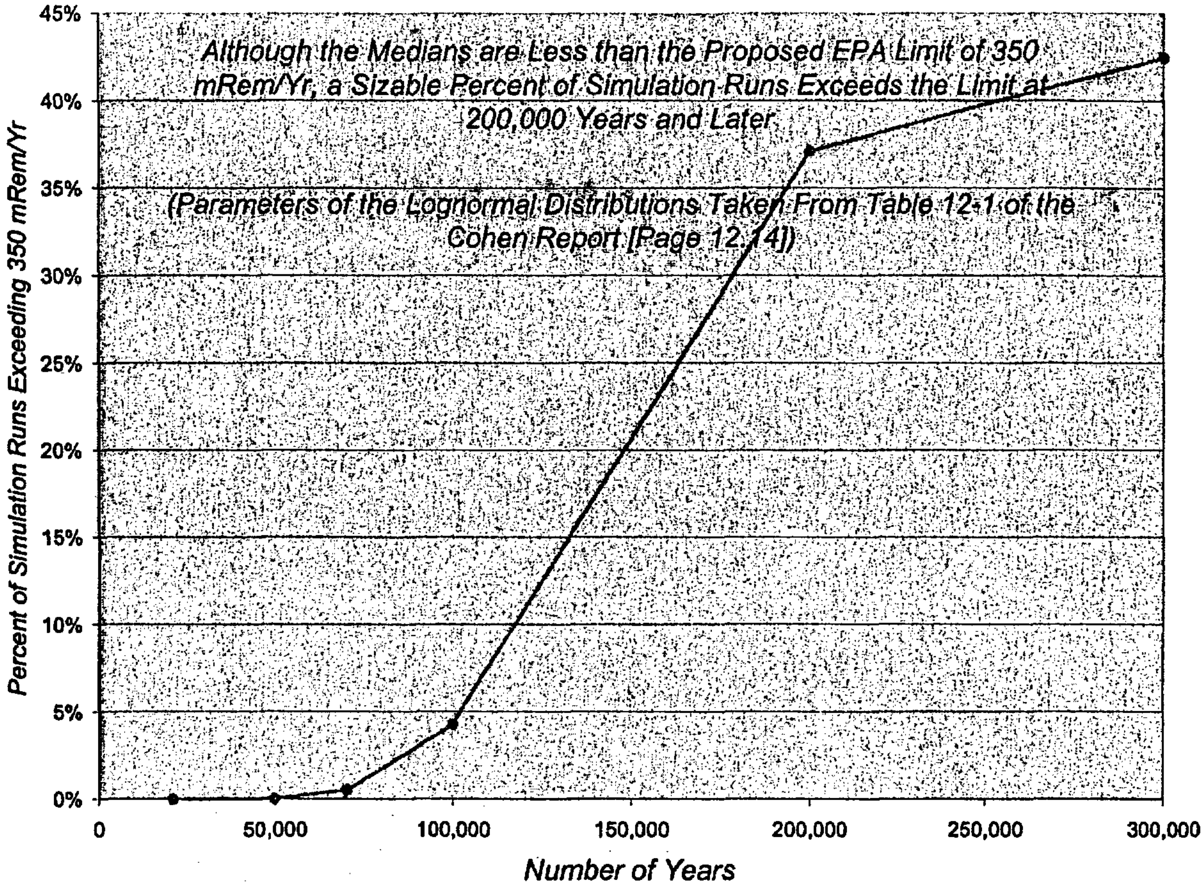
mu Estimate of the mean of the logarithms of the annual dose realizations
sigma Estimate of the standard deviation of the logarithms of the annual dose realizations

Assuming that a lognormal distribution is a good first approximation to the TSPA-SR outputs, the fraction of realizations that would exceed 350 mrem/year is computed as follows:

$$\Pr(X > 350) = 1 - \Phi\left(\frac{\log(350) - mu}{sigma}\right)$$

$\Phi(z)$ is the integral of the normal distribution from $-\infty$ to z; it can be computed using the built-in Excel function NORMSDIST( ). The fractions over 350 were computed for each of the six time points appearing in Table 12–1 of the Cohen report. They are presented in the following graph:

[7] "Revised Final Draft, Assumptions, Conservatisms, and Uncertainties in Yucca Mountain Performance Assessments", Contract Number EP-D-05-002, Work Assignment No. 1-08, Subtask 2, August 8, 2005.
[8] See Table 12–1 on page 12–14 of the Cohen report.
[9] The column labeled "Lognormal Mean" does not appear in Table 12–1, but was computed as exp(mu + $sigma^2$/2). Note that this is the theoretical mean of the lognormal distribution; it is not the mean as read from the plot of TSPA-SR results. See Evans, M., Hastings, N., and Peacock, B. **Statistical Distributions**, 3rd Ed., John Wiley, 2000, pages 129–133.



The fraction of runs that exceed the maximum of 350 mrem/year begins to increase at 100,000 years reaching 37% at 200,000 years and 42% at 300,000 years. It seems clear that the fraction of the simulation results over 350 mrem/year would likely exceed 30% to 1,000,000 years. That is, for the 800,000 years from 200,000 to 1,000,000 years the maximum dose would be exceeded at least 30% of the time.

Given the high percent of the simulation results that exceed the maximum allowable dose, it is clear that the use of the median is excluding more than a limited number of low probability events. Thirty-seven and 42 percent of the simulation runs can not be considered low-probability events.

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"Mass Tort Claim Processing Facilities: Keys to Success," Loyola of Los Angeles Law Review, Volume 31, Number 2 (January 1998)

"How Children Spend Their Time: A Sample Survey for Use in Exposure and Risk Assessment," with A. Silvers, D. Rourke and R. Lorimor. Risk Assessment, Volume 14, Number 6 (December 1994).

"The Computerization of Mass Tort Settlement Facilities," with J. Gurney. Law and Contemporary Problems, Autumn 1991.

The Environmental Audit Handbook. With T. Truitt, D. Berz, D. Weinberg, J. Molloy, G. Price, and L. Truitt, New York: Executive Enterprises Publications, Inc. Second Edition, 1983.

Report of the Study of PCBs in Equipment Owned by the Electric Utility Industry. Published by the Edison Electric Institute, February 1982.

Analysis of PCB Capacitor Disposal Capacity. Report prepared for the Edison Electric Institute, November 1982.

Judicial Staffing. Report published by the Wisconsin Supreme Court, 1980.

Wisconsin Case Processing. Report published by the Wisconsin Judicial Planning Committee, Summer 1978.

Maryland Court Personnel: District Court Staffing. Report published by the Administrative Office of the Maryland Courts, Summer 1987.
Profile of the Tennessee Courts. Report published by the Tennessee Supreme Court, Fall 1977.

Tennessee Court Reorganization Plan. Report published by the Tennessee Supreme Court, Fall 1977.

"An Empirical Test of the Relationship of Evidence to Belief Systems and Attitude Change." Human Communication Research, Winter 1975.

"An Assessment of Videotape in Criminal Courts," with E. Short and M. Marsh. Brigham Young University Law Review, Volume 1975, No. 2.

A Two-Way Interactive Video/Audio Arraignment System for Suffolk County, New York: Implementation Issues and Costs. Report prepared for the American University, November 1975.

"The Effects of Videotape Testimony in Jury Trials: Studies on Juror Decision Making, Information Retention, and Emotional Arousal," with G. Miller, D. Bender, F. Boster, N. Fontes, J. Hocking, and H. Nicholson. Brigham Young University Law Review, Volume 1975, No. 2.

An Evaluation of the District of Columbia Model Court. Report prepared for the National Clearinghouse of Criminal Justice Planning and Architecture, January 1976.

Videotape Recording in the California Criminal Justice System. Report published by the California Office of Criminal Justice Planning, March 1975.

"The Development of Interpersonal Communication Theory," with D. Cushman. Today's Speech, Winter 1974.

"Real vs. Reel: What's the Verdict?" with G. Miller, D. Bender, and H. Nicholson. Journal of Communication, Summer 1974.

"The Application of Cybernetics to Human Communication Theory." Meeting of International Communication Association, 1972.

"Effects of Videotaped Testimony on Information Processing and Decision-Making in Jury Trials," with G. Miller, F. Siebert, D. Bender, and H Nicholson. Legal Communication Workshop, 1974.

"Videotape Recording in the California Criminal Justice System: Impacts and Cost," with E. Short and M. Marsh. California Public Defenders Association, 1975.

LEGAL EXPERIENCE AND TESTIMONY:

A. H. Robins Company, Inc., et al. (Case No. 85-01307-R)
Deposition
Trial
(Also provided deposition testimony)

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Trial: 1991

Eagle-Picher Industries, Inc., et al. (Case No. 1–91–00100)
Deposition: September, 1995;
Trial: October, 1995.

Fanning, et al. v. AcroMed Corporation, et al. (Civil Action No. 97–381 and ALL ACTIONS)
Deposition: April, 1997
Trial:

Fuller-Austin Insulation Company (Case No. 98–2038)
Trial: October, 1998.
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Falise, et al. v. The American Tobacco Company, et al. (Case No.: CV 97-7640)
Trial: December, 2000
(Also provided deposition testimony)

Asbestos Claimants v. The Babcock & Wilcox Company
Trial: October, 2001
(Also provided deposition testimony)

Fuller-Austin Insulation Company v. Fireman's Fund Insurance Company, et al. (Case No. BC 116835)
Trial: March, 2003
(Also provided deposition testimony)

Babcock & Wilcox Company, et al.
Confirmation Hearing: September, 2003
(Also provided deposition testimony)

Sheila Brown et al. v. American Home Products Corporation (Civil Action No. 99-20593)
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    Deposition
    Testimony
Gerald Ahern, et. al. vs. Fiberboard Corporation, et. al., 1994
    Deposition
    Testimony
Ezell Thomas, et. al. vs. R.J. Reynolds Tobacco Company, et. al., 1999
    Deposition
Fiberboard Corporation and Owens Corning vs. R.J.Reynolds Tobacco Company, et. al., 1999
Western Mac Arthur Company and Mac Arthur Company vs. General Accident Insurance Co. of America; United States Fidelity & Guaranty Co.; Argonaut Insurance Company, 1999
    Affidavit
CSX Transportation, Inc. and American Home Ins. Co., 2000
    Deposition
ADR Proceeding Celotex vs. Travelers Casualty and Surety Co. and London Market Insurers, 2000
Owens Corning Bankruptcy Proceedings, 2001
    Deposition, 2004
Burns and Roe Enterprises, Inc. Bankruptcy Proceedings, 2002
Michael Albanese vs. Compaq Computer Corporation, 2002
    Affidavit
U.S. vs. Tyson Foods, Inc., 2002
ADR Proceeding ACandS, Inc. vs. Travelers Casualty and Surety Co., 2003
Western Mac Arthur Company and Mac Arthur Company Bankruptcy Proceedings, 2003
Oglebay Norton Bankruptcy Proceedings, 2004
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Appendix C

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EXTERNAL MEMORANDUM

Date: 10 November 2005
From: M C Thorne
Subject: The Role of Uncertainties in Defining the Proposed Standard

Commentary

The EPA comments (page 49035) 'that having determined that it would be appropriate to propose a numerical peak dose standard for the period of geological stability beyond 10,000 years, we must then determine the appropriate level for that standard. We consider several factors in selecting the level proposed today. First, and most significant, is the issue of uncertainty in long-term projections. Uncertainties are problematic not only because they are challenging to quantify, but also because their impact will differ depending on initial assumptions and the time at which peak dose is expected to occur. Further, the natural tendency in modeling long-term processes is to introduce additional conservatisms to help ensure that actual performance will be no worse than projected performance.'

Based on this comment, the EPA (page 49035) reiterates its earlier view that 'setting a strict numerical standard at a level of risk acceptable today would ignore this cumulative uncertainty and the extreme difficulty of using highly uncertain assessment results to determine compliance with that standard'.

Thus, the EPA seems to be arguing for a much laxer standard after 10,000 years on two grounds relating to uncertainty. The first is that the increasing uncertainty justifies allowing for the possibility that the assessed dose would be greater than the standard imposed up to 10,000 years after closure and that this allowance can be achieved by specifying a laxer standard after 10,000 years. The second is that increasing uncertainties after 10,000 years will require greater use of cautious or bounding assumptions, so that the assessed doses will be higher than those that would have been estimated had it been possible to make realistic assumptions, such that compliance with a laxer standard will actually imply compliance with some stricter standard.

While there are various sources of uncertainty associated with the repository system that increase with time (S. Cohen & Associates, 2005), it is important to recognize that:

- Some of the uncertainties are associated with future human actions and are addressed through prescriptive rule making, e.g. by defining the characteristics of the exposed group;
- Many of the uncertainties relate to the behavior of the repository system, but do not affect strongly the radiological impacts associated with the system;
- The various uncertainties cannot be combined in a simple fashion, and their combined effect may not increase significantly with time, even if individual uncertainties increase with time.

In evaluating the Draft EPA Rule, it is important to recognize that the EPA is proposing that compliance with the draft standard should be demonstrated by undertaking probabilistic calculations with the DOE Total System Performance Assessment (TSPA) model. In that model, multiple realizations of the future performance of the proposed disposal system are evaluated. Each realization is characterized by parameter values selected from uncertain distributions. Thus, the results obtained from each realization differ (see Figure 1[1]) and it is the ensemble of such results that has to be compared with the standard.

[1] Although illustrations are presented from existing TSPA calculations in this memorandum, it is important to emphasize that judgment on the suitability of the Draft EPA standard cannot and should not be based on the quantitative results that have been presented to date. It cannot be known in advance what distributions of results will arise from the TSPA calculations undertaken for Licence Application, nor can any assumptions be made as to the degree to which those calculations will be based on cautious (or non-cautious) conceptual models and parameter value distributions.

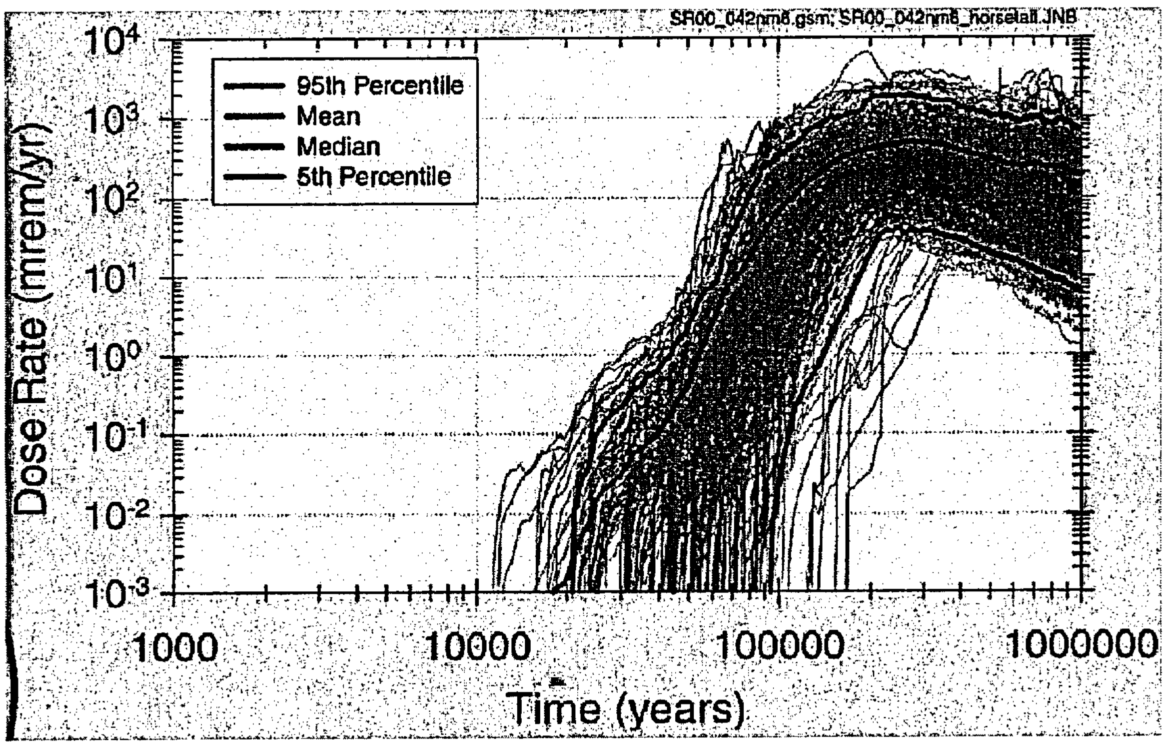

Figure 1: TSPA-SR One-Million-Year Dose Histories for Nominal Case (as Figure 12.1 of S Cohen & Associates, 2005, but reproduced from SSPA, Volume 2, Figure 3.1.2-1)

Figure 1 shows various statistical measures of the distribution. These are the arithmetic mean, median, and 5th and 95th percentiles. Results from the individual realizations are also shown. For the period up to 10,000 years, the EPA is proposing that the arithmetic mean value should be compared with a dose limit of 15 mrem, whereas beyond 10,000 years the EPA is proposing that the median value should be compared with a dose limit of 350 mrem. From Figure 1, it will be seen that the arithmetic mean value exceeds the median value at all times of interest and, in particular, at the time of peak dose. This result is general for any distribution that is positively skewed. The median value at any specific time is obtained by rank-ordering the results obtained from the individual realizations at that time and selecting the value of the mid-ranking result. Thus, if there were 300 realizations, the median would lie between the values of the 150th and 151st after they had been rank ordered by value. In contrast, the arithmetic mean is defined as the sum of all the results at a particular time divided by the number of realizations.

S Cohen & Associates (2005; page 12-5) comment that an advantage of the arithmetic mean as a measure of central tendency is that, 'for almost any form of underlying population distribution, normal or not, the arithmetic mean is an unbiased estimate of the true mean of the population distribution.' Here, the true mean is the value of the arithmetic mean that would be obtained from an infinite number of realizations. However, they also consider that 'the arithmetic mean often is a poor measure of central tendency for environmental data...In any run of the performance assessment model with several hundred realizations, there may be several extreme values...the arithmetic mean is not robust because a single unusual value can cause a very large deviation of the arithmetic mean from the center of the distribution of values in the data...When applied to data with positive values that are skewed to the right, the arithmetic mean usually lies above the median value. In some cases, the arithmetic mean may exceed 95% of the values. In extreme cases, the arithmetic mean may exceed all values other than the single highest value in the data.'

S Cohen & Associates (2005; page 12-6) also comment that the 'median is a very robust estimator of the center of a distribution of values. This estimator is robust because there can be a substantial number of unusual values, either high or low, yet the median is not distorted by these unusual values.'

Although the median can be a more robust measure of central tendency than the arithmetic mean, often implying that a well-defined value will be obtained from a smaller number of realizations[2], this does not make it an appropriate measure for comparing with a regulatory standard. Because the arithmetic mean is an unbiased estimator of the true mean, irrespective of the number of realizations, it provides a direct estimate of the expectation value of the dose, i.e. each realization contributes in direct proportion to the dose associated with it. In contrast, two distributions of values of dose can have identical median values, but very different potential health implications. For example, the set of 11 doses {0.5, 1.0, 1.2, 1.3, 1.4, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3} has a median of 1.8. This is identical to the median of the set {0.5, 1.0, 1.2, 1.3, 1.4, 1.8, 2.5, 3.8, 6.2, 9.3, 12.5}. However, the latter distribution includes much higher values above the median. Effectively, use of the median as a measure of performance totally discounts the absolute magnitude of values higher than the median. As radiation protection regulation is based on the concept of a linear no-threshold relationship between dose and effect at low doses and dose rates, the arithmetic mean dose gives an unbiased estimate of the expectation value of health detriment at any time, whereas the median dose does not have a well-defined relationship to health detriment.

Rather than arguing that there is a problem with the arithmetic mean because it is not a robust measure of central tendency, it is more appropriate to argue that the arithmetic mean is an appropriate unbiased measure of repository performance and that it may (or may not) require more realizations to achieve a converged estimate of the mean than of the median, depending upon details of the shapes of the underlying distributions from which parameter values are selected. Furthermore, the insensitivity of the median to unusually high values is a weakness for safety assessment purposes, in that it specifically fails to give any recognition to those particular parameter value combinations that are prejudicial to repository safety. Indeed, considering Figure 1, there is a strong argument that, if some percentile of the distribution of results is to be used rather than the

[2] It should be noted that the value of the median is not necessarily less uncertain than the value of the arithmetic mean for a fixed number of realizations. Indeed, for a normal distribution, the standard error on the median of a sample is slightly more than 25% greater than the standard error on the sample mean. However, the median is less uncertain for distributions that exhibit significant tails.

arithmetic mean, that percentile should not be the 50^{th} (i.e. the median), but some higher value such as the 95^{th}, so that situations prejudicial to safety are expressly addressed, but without going to the non-robust extreme of considering the single worst realization.

It might be argued that the realizations giving rise to high doses and, therefore, lying at high percentiles of the distribution, should be disregarded because they represent unrealistic combinations of parameter values. However, EPA cannot know *a priori* that this will be the case. Any cautious assumptions adopted by the DOE could equally well affect all realizations and there is no intrinsic reason to prefer one realization to another. Furthermore, until the TSPA-LA is presented, it cannot be determined what, if any, cautious assumptions will be adopted by DOE. It is, of course, appropriate for DOE and other interested parties (e.g. NRC) to examine the results from assessment calculations to determine whether the individual realizations and the overall sets of realizations are appropriate for use for compliance purposes. Such an examination might result in the exclusion of individual realizations or the requirement to rerun the calculations with modified models or altered sampling of the input parameter values, e.g. to reflect accurately any dependencies between the various parameters. However, once this iterative evaluation of the quality of the assessment has been completed, there should be no reason to give preference to one realization over another in the final evaluation of compliance. On this point, it is important to emphasize that high dose outliers are potentially important indicators of performance that need to be scrutinized closely. A key issue in safety assessment is to identify potential circumstances that could be prejudicial to safety and then to determine whether any actions can be taken to prevent or mitigate such circumstances. High dose outliers are such potentially important indicators of performance. Although not directly relevant to the issues addressed in this memorandum, it is important to emphasize that the safety of the proposed Yucca Mountain facility needs to be evaluated against the full range of results obtained and not just against some central tendency in those results, irrespective of how that central tendency is defined.

It should also be noted that if the median was used as a basis for compliance with a constant standard from the time of repository closure onward, an increase in uncertainty with time would not, in itself, necessarily result in greater difficulty in complying with the standard. However, for positively skew distributions, as typically occur in assessment studies, if the median remains constant in time and the uncertainty increases, the arithmetic mean will increase, so compliance with a constant standard will become more difficult with increasing uncertainty. This is illustrated in Figure 2.

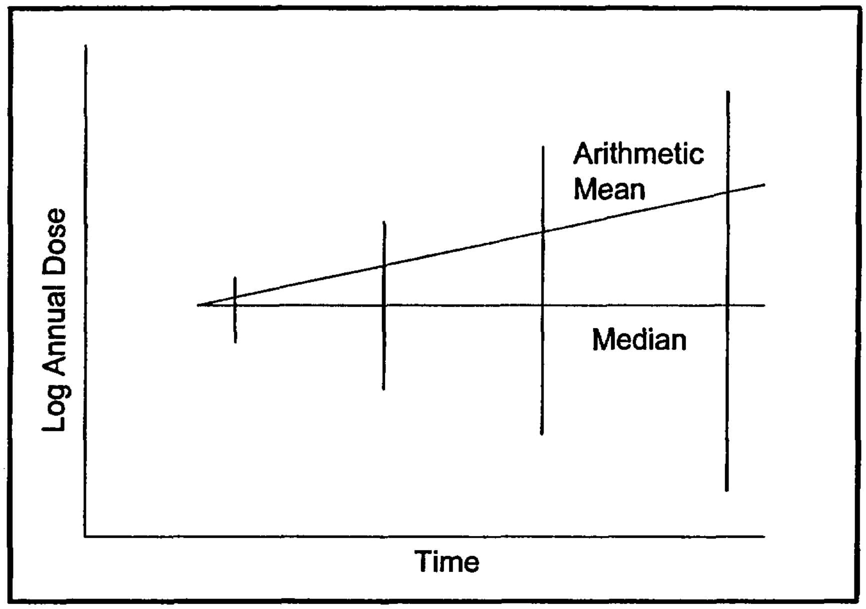

Figure 2: Relationship between the Median and Arithmetic Mean for a Positively Skew Distribution

Here a lognormal distribution underlies the range of variation at each time. As time increases, the range of variation increases, but because the range increases both to lower values and to higher values, the median can remain constant (imagine the vertical distance of each value from the median being multiplied by a constant scale factor greater than one as you move from one time to the next). Interestingly, the arithmetic mean value in this system does not remain constant, but increases, because it reflects the magnitudes of the individual values and not just whether they are above or below the median value. This distinction is general for positively skew distributions and can be quantified for particular examples. Thus, for the example of the commonly used lognormal distribution:

$$\mu = \exp(M + \sigma_g^2/2)$$

where μ is the arithmetic mean, M is the median and σ_g is the geometric standard deviation. Thus, for constant median M, the value of the arithmetic mean increases as the degree of uncertainty (measured by the magnitude of σ_g) increases.

On this basis, the use of the median as a compliance measure diminishes the importance of changes in uncertainty with time relative to use of the arithmetic mean. However, it is not accepted that the uncertainty in performance at Yucca Mountain does increase substantially with time. This is demonstrated by a careful consideration of Figure 1. Both the median and 95th percentile can be seen at 50,000 years, where they differ by three orders of magnitude. At the peak, around 200,000 years, they differ by only one order of magnitude and this difference persists through to the end of the simulation.

Thus, no justification for an increase in uncertainty with time can be argued from this figure.

Similar results arise for a case with early waste package failure, as illustrated in Figure 3.

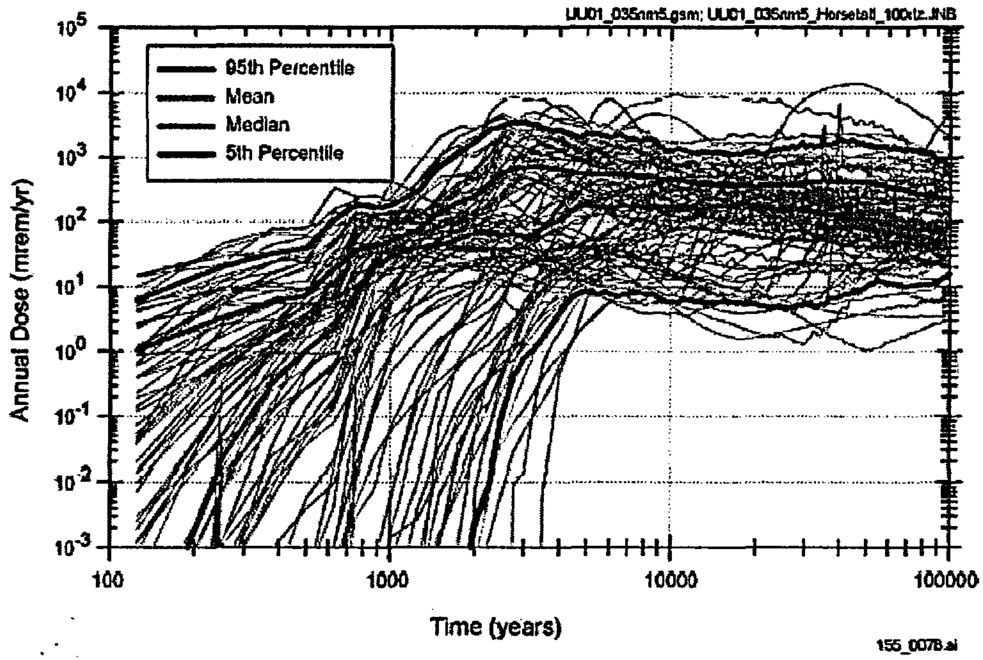

Figure 3: Figure 3.2.2-12 from Volume 2 of the SSPA, illustrating a Case with the Base Case Seepage Model and Neutralized Waste Packages and Drip Shields

Note that, in this case, the uncertainty decreases until it reaches a fairly constant value from approximately 4,000 years onward.

However, care should be exercised in interpreting this type of presentation. This is because the figures confound uncertainty in timing with uncertainty in the magnitude of the peak dose that arises. This is illustrated schematically in Figure 4.

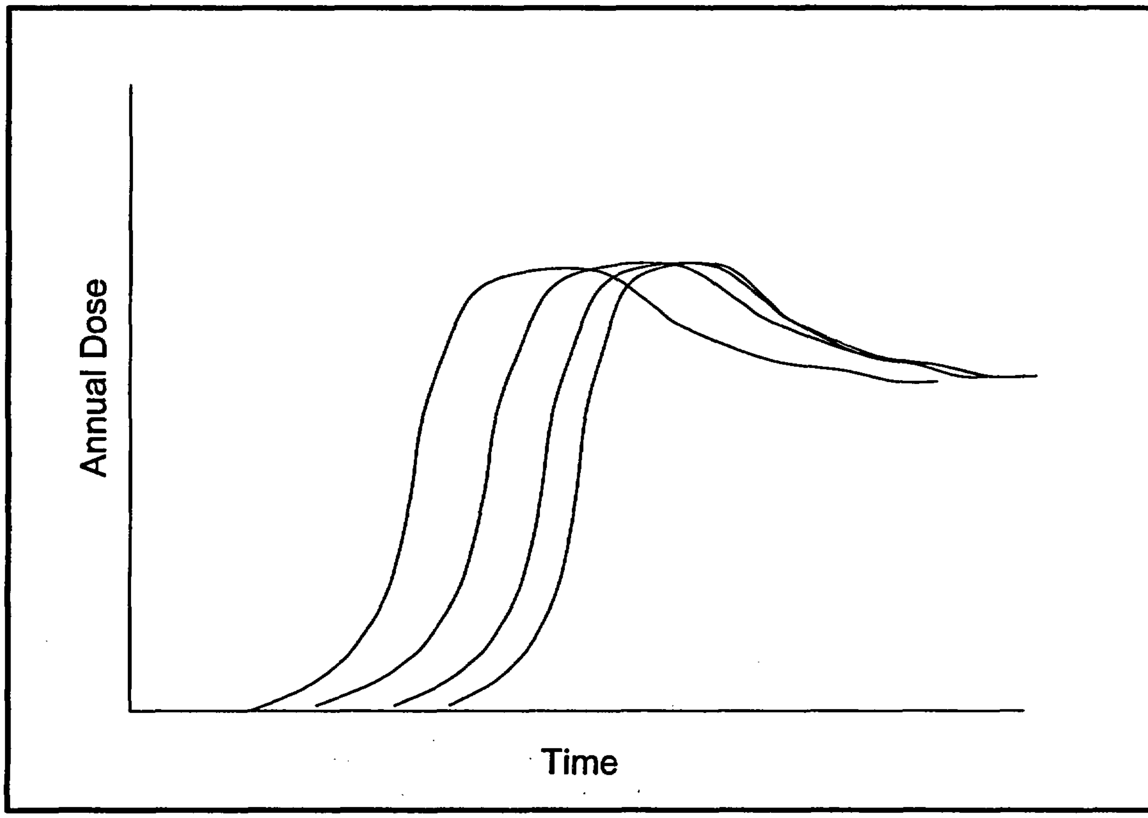

Figure 4: Illustrative Patterns of Variations in Annual Dose with Time

In Figure 4, all the dose-time curves are identical in shape. However, they have been moved relative to each other along the time axis and either stretched or compressed in time relative to the reference curve. Thus, there is no difference in the peak dose received, i.e. in this hypothetical illustration there is no uncertainty in the peak dose. However, comparing the curves in respect of the annual dose at a particular time, there is no uncertainty at early times, because all the doses are zero, the uncertainty then increases, because the curves rise at different times, and then decreases as the curves converge. Similar effects, though less extreme, can be seen in Figures 1 and 3. Thus, in Figure 1, the uncertainty between 10,000 and 100,000 years is largely due to the time at which the increase in dose occurs and only secondarily due to the magnitude of that increase. Uncertainties in timing give rise to an effect termed 'risk dilution'. It is noted that this effect is not addressed in the Draft EPA Rule. As a compliance standard is being set through to the period of peak dose, it would be appropriate to discuss whether that standard should apply to the mean (or median) value of the peak doses from the various realizations or the peak value of the mean (or median) dose from all realizations as a function of time.

The shape of the uncertainty envelope can also be affected by the inclusion of two distinct failure modes in the same plot. This is illustrated by Figure 5.

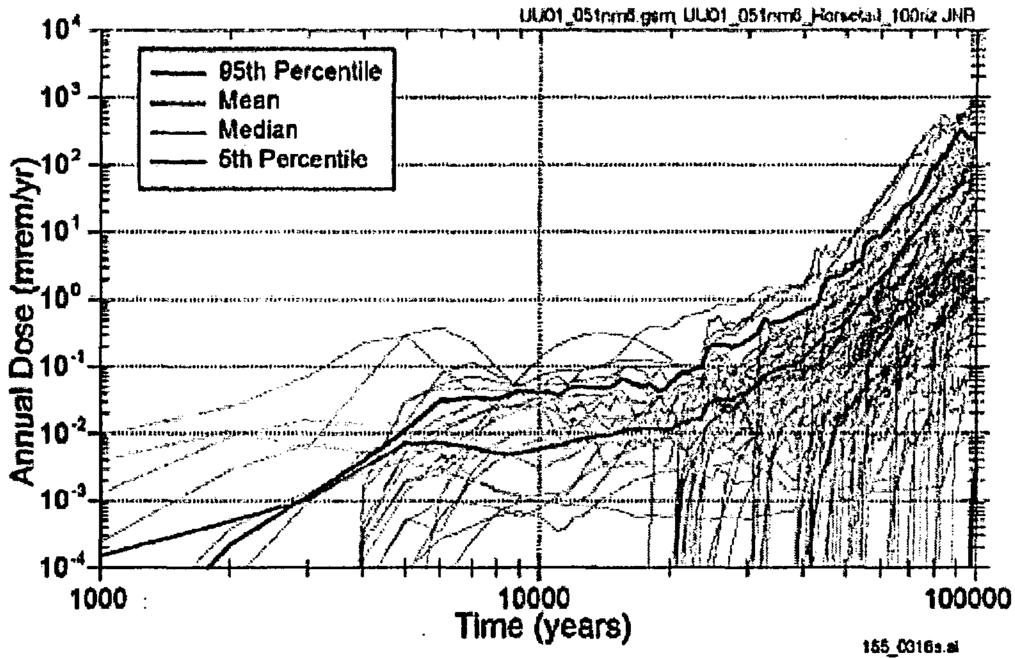

Figure 5: Figure 3.2.5.4-1 from Volume 2 of the SSPA, illustrating the Sensitivity of Annual Dose to Additional Uncertainty associated with Early Waste Package Failures due to Improper Heat Treatment

In Figure 5, the uncertainty to 40,000 years is very large (note that the median does not appear on the figure and the mean is higher than the 95th percentile over the first 2,500 years. Beyond 40,000 years there is a transition from a system dominated by releases from the waste packages that failed early to a system dominated by more general waste package failure. Beyond that time, as it becomes increasingly likely that the majority of the packages have failed, the uncertainty range decreases and, by 100,000 years, the difference between the median and the 95th percentile is only about a factor of twenty.

It should also be noted that 10,000 years does not represent a time at which there is necessarily a qualitative change in system performance. Thus, in Figure 1, the qualitative change occurs beyond 20,000 years. In Figure 3, there is no qualitative change and system performance remains much the same from 2,000 to 100,000 years. In Figure 5, the qualitative change occurs beyond 20,000 years, when early package failure becomes dominated by more general package failure.

S Cohen & Associates (2005) argue for an increase in uncertainty with time based on Figure 12-4 of their report. In relation to that figure they state (page 12-14) that the 'uncertainty in the forecast increases dramatically over time'. However, this is because they have expressed the uncertainty in absolute terms, rather than in relation to the median dose. This is demonstrated by the data in Table 1. These are taken from Table 12-1 of S Cohen & Associates (2005) and underpin their Figure 12-4.

Year	**Annual Dose Forecast (mrem y^{-1})**		**Ratio of 95th Percentile to Median**
	Median	**95th Percentile**	
21,000	-	0.0025	-
50,000	0.02	2.3	115
70,000	0.8	40	50
100,000	10	300	30
200,000	240	1600	6.7
300,000	280	2000	7.1

Table 1: Median and 95th Percentile Dose Estimates given in Table 12-1 of S Cohen & Associates (2005)

Thus, a correct statement is that the absolute magnitude of the uncertainty increases with time, but the relative degree of uncertainty decreases.

A further consideration in respect to uncertainty is shown in Figure 6.

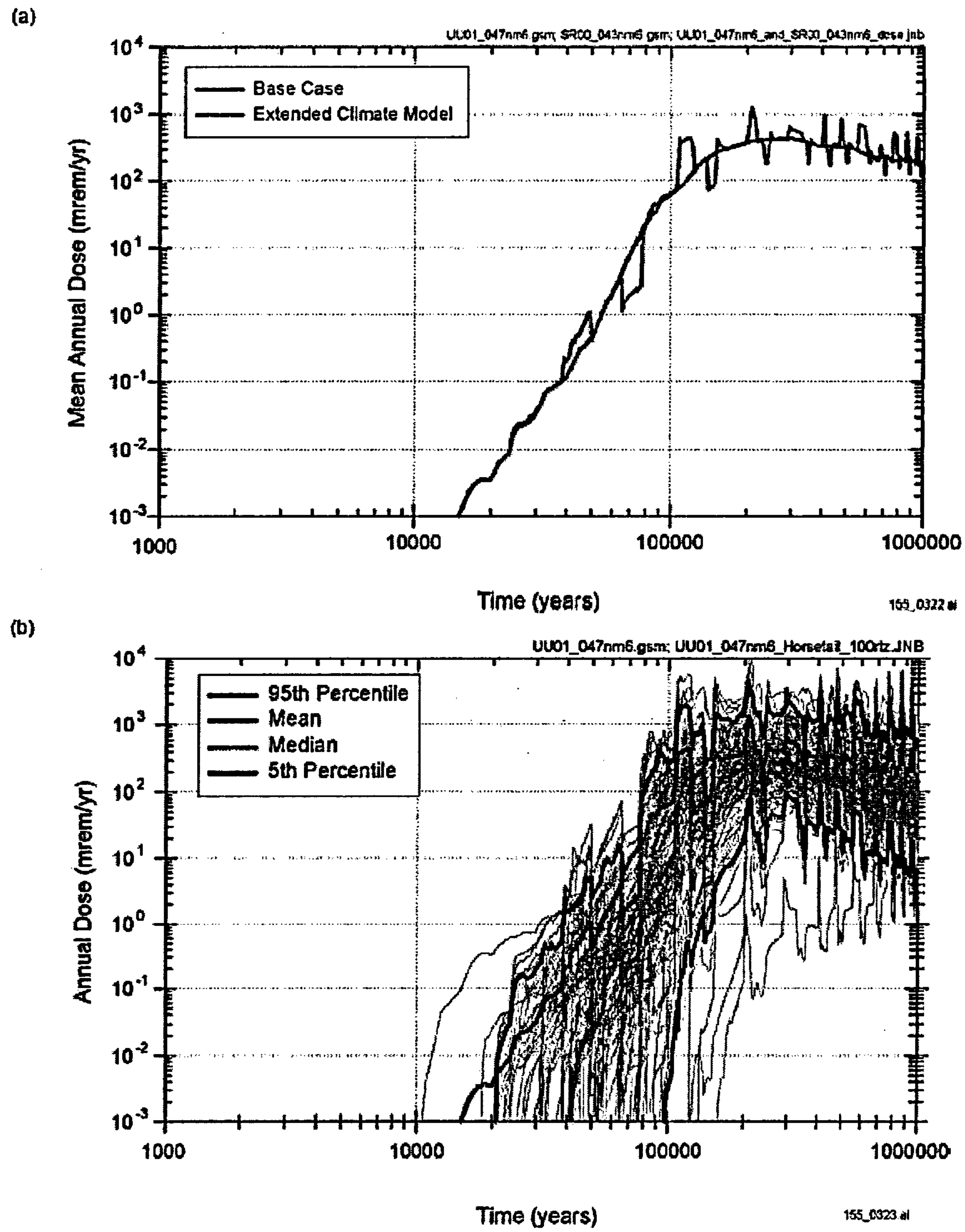

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Figure 6: Figure 3.2.1-1 from Volume 2 of the SSPA, illustrating Annual Dose Histories from the Extended Climate Model and the Base Case

The TSPA-SR base-case climate model was developed for the 10,000 year regulatory period and had no changes of climate state after 2,000 years. An extended climate model for the period from 10,000 years to one million years was also developed. In this model, six climate states were determined for the post-10,000 year period. The extended base-case climate model is the same as the base-case climate model until 38,000 years, i.e. there is no change in climate state from 2,000 years to 38,000 years, which is when the first glacial period is estimated to occur. The next glacial periods occurs at 106,000 years and 200,000 years. Glacial periods are 8,000 to 40,000 years in duration and recur approximately every 90,000 years, on average. Figure 6, part a compares the mean data from the base case run to one million years, i.e. with no climate change beyond 2,000 years, and the extended climate model. Comparison of these mean curves when long-term climate change is taken into account reveals increased uncertainty, reflected in the more variable nature of the mean annual dose in the extended climate model case. However, Figure 6, part b shows that this is not the full story. The spikiness arises because the changes of climate are represented as discrete switches between one climate state and another at pre-defined, identical times in all realizations. In practice, climate changes continuously. Furthermore, even if the process is simplified in terms of instantaneous switches, e.g. by arbitrarily defining boundaries between the states in terms of mean annual precipitation, the timing of those changes is uncertain and should not be the same in every realization. Both of these considerations would smooth the dose curve from that shown for the extended climate model case. Thus, the increased uncertainty that might be inferred from Figure 6 is an artifact of the modeling procedure used and does not relate to the actual system being simulated.

There remains the consideration as to whether extension of the calculations beyond 10,000 years involves the use of more cautious assumptions. It should first be noted that the various calculations described above and others presented in the SSPA were undertaken by running calculations defined for 10,000 years through to either 100,000 years or one million years, i.e. there were no changes in assumptions at 10,000 years. The exception is the climatological modeling illustrated in Figure 6. However, in that case changes of climate state had been defined in the period up to 10,000 years and an extended sequence of changes of state was defined for the period through to one million years.

Although it seems plausible to argue that uncertainties in system performance could increase with increasing time into the future, this is not borne out by the results reported in the SSPA and it is of interest to examine why this is the case. For this purpose, it is appropriate to consider the following components of the system:

- Infiltration as determined by climatic conditions;
- Entry of water into the drifts;
- Corrosion of drip shields and waste packages;
- Percolation of water into waste packages and leaching of radionuclides;
- Transport of radionuclides through the unsaturated zone;
- Transport of radionuclides through the saturated zone;
- Abstraction of radionuclides from a groundwater well, transport in the biosphere and radiation exposes of the Reasonably Maximally Exposed Individual (RMEI).

It is relevant to note that the next one million years is assumed to be an appropriate period over which geological stability of the Yucca Mountain area can be assumed. Thus, changes in hydrogeology, hydrogeochemistry, radionuclide transport and radiological impacts can be evaluated within a well-defined geometrical and stratigraphic framework (setting aside igneous and seismic events, as these are addressed separately).

The infiltration of water into the unsaturated zone at Yucca Mountain will be determined by changes in climate. The DOE has assumed that future climatic conditions at Yucca Mountain will lie within the envelope of climatic conditions that has occurred over the Quaternary (approximately the last 1.6 million years). On this basis, the DOE has identified a set of potential future climate states and has used these in modeling (see Figure 6). Radiological impacts tend to be increased when infiltration is increased, as in the glacial state.

In their report, S Cohen & Associates (2005, page 1-11) state that 'the possibility of anthropogenic climate forcing has also not been included in the modeling of future climates. This could introduce a significant measure of uncertainty to long-term dose predictions.' The reader could easily misunderstand this statement and think that 'long-term' referred to the period beyond 10,000 years. However, this clearly cannot be the case. Even without the imposition of controls on fossil fuel usage, limitations on available resources imply that rates of utilization similar to those occurring at the present day cannot persist for more than a few centuries. Thus, atmospheric concentrations of carbon dioxide are likely to peak on a similar timescale. Although there is some inertia in the climate system in responding to enhanced greenhouse-gas concentrations, largely because of the large thermal inertia of the oceans, various experiments with atmosphere-ocean general circulation models (AOGCMs) and Earth Models of Intermediate Complexity (EMICs) have demonstrated that global warming is likely to peak soon after atmospheric carbon dioxide levels reach their maximum concentration. Thus, the most extreme warming change to the global climate system due to anthropogenic effects is likely to occur on a timescale of a few hundred to, at most, a few thousand years. Thereafter, with a reduction in fossil fuel usage, atmospheric carbon dioxide concentrations are expected to decline, though the slow turnover of some sinks for carbon dioxide means that enhanced atmospheric concentrations and the corresponding global warming could persist for tens to hundreds of thousands of years. In addition, other changes, such as loss of the Greenland ice cap, could result in changes to the climate system over the next few thousand years that could persist for hundreds of thousands of years.

Whereas the magnitude of changes in precipitation and infiltration at Yucca Mountain in colder climate episodes can potentially be constrained by reference both to climate modeling studies and climatic reconstructions based on palaeoenvironmental data, future changes in climate and infiltration in an anthropogenically modified warm climate can only be estimated by climate modeling. If the nature of such climate changes was necessarily towards increased aridity, then it could be argued that performance of the system would be improved. However, this is not the case. Global warming is associated with increased evaporation and a strengthening of the hydrological cycle, with delivery of increased energy and moisture to the atmosphere. In these circumstances, substantial reorganization of atmospheric systems can occur and these have the potential to increase precipitation at the site. In particular, there could be an increase in the number and intensity of storm events.

On this argument, the inclusion of anthropogenic climate forcing would result in increased uncertainty in estimates of precipitation and infiltration in the next 10,000 years. Beyond that time, the anthropogenic effect would be expected to weaken slowly. If peak doses were assessed to occur on a 100,000 year timescale, the anthopogenic disturbance on climate and hence the associated uncertainty would either be similar to that in the first 10,000 years or somewhat reduced.

Unsaturated zone flow through Yucca Mountain above the drifts would be largely governed by the present day lithology. As the system is reasonably taken to be geologically stable on a one million year timescale, there is no reason why flow in this zone for prescribed infiltration conditions should be more uncertain beyond 10,000 years than it is before 10,000 years.

On reaching the vicinity of the drifts, uncertainties arise as to the degree to which the infiltrating water enters the drifts and is available for corrosion of the drip shields and waste packages. These uncertainties arise from the spatial heterogeneity of the host rock and the effects of drift excavation, which induces mechanical disturbance and stress redistribution in the host rock, creating a zone with altered formation properties (S Cohen & Associates, 2005, page 2-13). The excavation effects will occur at the beginning of the 10,000 year period. Furthermore, in the first few hundred years, the high temperature of the repository will modify inward flows and the distribution of water in the host rock and may also alter fracture apertures through dissolution and precipitation of minerals. However, these transient changes will die away well within the 10,000 year period. Thus, overall the uncertainties relating to infiltration are mainly either pre-existing, due to excavation of the repository, or are associated with the transient high temperature phase. New sources of uncertainty at long timescales would be limited. One possibility is seismically induced changes to fracture aperture, but as the system is considered to be geologically stable, this should be of limited concern.

Once radionuclides have been leached from the waste packages, they will be transported through the underlying unsaturated zone to the water table. As S Cohen & Associates (2005, page 2-11 and 2-12) has commented, sensitivity studies with the TSPA-SR three-dimensional unsaturated zone flow and transport model showed that 'insignificant changes in transport behavior are found for large changes in fracture aperture...Breakthrough is found to be at most only about 1 order of magnitude earlier than for the base case...for an extremely conservative 10-fold increase in fracture aperture applied over the entire unsaturated zone domain.'

Given the above observation and the geological stability of the system, there is no reason to consider that uncertainties in flow and transport through the unsaturated zone would be significantly increased by seismic effects beyond 10,000 years.

S Cohen & Associates (2005, page 3-13) draw a somewhat different conclusion. They comment that 'as the shields and packages begin to fail, the integrity of the natural barrier system will begin to play a larger role in the overall performance of the repository. Under these conditions, the results may be more sensitive to changes in rock properties caused by seismic activity.' However, this comment neglects the consideration that, as the waste packages begin to fail, uncertainties in the performance of the engineered system decrease, as there is increased confidence in the source term. As seismically induced changes in fracture aperture are not certain to occur and are likely to have only limited effects on flow and transport, it seems likely that the effects of decreasing uncertainties in the source term will dominate.

In respect of near-field chemistry, S Cohen & Associates (2005, page 4-2) have commented that the 'major changes to water and gas compositions that would affect the performance of the geologic system can be represented by fairly coarse periods of constant compositions that have step changes between them. These time periods correspond to the preclosure period, a boiling period, a transitional cooldown period and the extended cooldown period.' However, all these periods are over relatively quickly and in the SSPA, S Cohen & Associates (2005, page 4-5) report that for the ambient period (post-100,000 years), the chemical composition results were based on averages from 2,000 to 100,000 years. Thus, no strong distinctions in near-field chemistry due to thermal effects were identified beyond 2,000 years. S Cohen & Associates (2005, page 4-9) noted the result from the SSPA that 'the long-term composition of fluids around the drift appeared to be controlled primarily by the initial composition of the infiltrating water.' For the TSPA-LA, S Cohen & Associates (2005, page 4-9) commented that 'the initial water compositions and infiltration scenarios are most likely to vary over long time periods.' However, as pointed out above, taking anthropogenically induced climate change into account, variations in infiltration are most uncertain in the period before 10,000 years. Variations in initial water composition are likely also to be correlated with climate change and the degree of infiltration.

In respect to integrity of the waste packages, the main consideration is whether Alloy 22 will behave as anticipated. Here the issue is not primarily about a difference in potential performance before and after 10,000 years, but about performance at any time beyond the periods of a few years over which tests on this material have been conducted. As S Cohen & Associates (2005, page 5-15) comment 'uncertainty also exists in the pessimistic direction. The failure, to date, to identify clear natural or archeological analogs for long term passive metallic behavior seriously limits confidence regarding the stability of passive films in providing extremely long term corrosion resistance.' S Cohen & Associates (2005, page 5-16) further conclude that 'as time progresses, the extrapolation of present knowledge on the decrease of general corrosion rate or establishment of a slow steady state in the optimistic scenarios becomes increasingly less reliable. Likewise, many of the pessimistic scenario processes could require long periods to incubate and their strength and consequences would be increasingly uncertain as time progresses.' These comments are undoubtedly true, but they can be read either as resulting in increased uncertainty with time or as implying decreasing confidence that the waste package will perform as designed and hence the need to place increased weight on assessment calculations in which there have been multiple failures of waste packages. In any event, the decreasing confidence in waste package performance relates to timescales of beyond a few decades. Thus, for example, in the context of localized corrosion, S Cohen & Associates (2005, page 5-17) comment that 'open circuit potential evolution information on Alloy 22 is limited to only a few years and analysis of the responsible factors is only beginning to be studied in some detail…at higher temperatures. As a result, the likelihood of unexpected modes of WP [waste package] corrosion deterioration developing during or around the heat pulse is an important source of uncertainty over shorter time periods.'

As to waste form corrosion, similar considerations apply. That is to say, confidence in the integrity of both the waste package and waste form decrease with time. Thus, uncertainty is initially small, as radionuclides are considered to be isolated from the groundwater environment, increases as waste packages and waste forms fail, and then decreases again when a substantial part of the waste has become accessible. What is at issue is the timescale over which this process occurs. If, it takes hundreds of thousands of years or longer, then uncertainties will still be increasing toward the end of the assumed period of geological stability. Conversely, if it is completed on a timescale of a few thousand years then uncertainties will not increase beyond 10,000 years. There is no general argument that uncertainties in the performance of the engineered barriers must increase beyond 10,000 years. Rather this is a matter to be determined through experiment, modeling and safety assessment.

Following release of radionuclides from the waste, consideration has to be given to their transport in groundwater to the point of abstraction. In terms of water flow, downward percolation from the drifts to the water table is likely to be relatively rapid and determined mainly by variations in infiltration, which is associated with larger uncertainties in the first 10,000 years, because of anthropogenic effects, than beyond that time. As noted by S Cohen & Associates (2005, page 8-1), 'transport time through the SZ [saturated zone] for dissolved, nonsorbing, nonreactive radionuclides can be less than 100 years'. As the DOE considers that the water table is 'now at a low point in the 150,000-300,000 years climate cycle' (S Cohen & Associates, 2005, page 8-16), it seems more likely that transit times will decrease in future rather than increase. Such decreases could occur in the next 10,000 years in the event of increased infiltration.

However, the main uncertainties in transport in the unsaturated and saturated zones are related to the degree of sorption of radionuclides to solids, the extent of diffusion into the rock matrix and the degree of binding to, and transport with, colloids. These uncertainties relate primarily to limitations in data and process understanding that are equally applicable before and after 10,000 years.

Finally, there are uncertainties relating to the biosphere. However, in the context of Yucca Mountain, groundwater abstraction rates are prescribed and the characteristics of the RMEI are to be based on present day characteristics of residents of Amargosa Valley. Thus, there are no distinctions in uncertainty before and after 10,000 years.

In summary, performance assessment calculations undertaken by DOE to date do not provide any evidence for substantial increases in uncertainties beyond 10,000 years and no increases in to degree of caution in assessments beyond 10,000 years have been identified. Indeed, in some contexts, caution can be said to be reduced. For example, the model used for waste-package degradation assumes an idealized geometry (dripping onto the center of the upper surface) that will tend to enhance corrosion rates (other factors being held constant). In the short term this is cautious, as it overestimates the degree of corrosive penetration. However, in the long-term, corrosive penetration of a substantial number of packages would occur both in this geometry and in less ideal geometries, so the degree of caution is reduced. Also, a review of the uncertainties that need to be taken into account in assessments showed that there are some, such as those that relate to infiltration that can be argued to be larger in the next 10,000 years than beyond that time. It is concluded that the variation in uncertainty with time is a matter to be determined by assessment modeling and that it cannot be determined *a priori* to increase with time. In view of this conclusion, it seems inappropriate to base a change in the rigor of the standard of protection on the assumption that uncertainty increases with time beyond 10,000 years.

Conclusions

Overall, the following conclusions are drawn.

- Use of the median rather than the arithmetic mean dose beyond 10,000 years as a compliance measure has no significant advantages and several substantial drawbacks. The median does not necessarily converge more readily than the arithmetic mean, does not give appropriate weight to high dose realizations and is not directly linked to health detriment.
- It is appropriate for DOE and other interested parties to examine the results from assessment calculations to determine whether the individual realizations and the overall sets of realizations are appropriate for use for compliance purposes. Such an examination might result in the exclusion of individual realizations or the requirement to rerun the calculations with modified models or altered sampling of the input parameter values, e.g. to reflect accurately any dependencies between the various parameters. However, once this iterative evaluation of the quality of the assessment has been completed, there should be no reason to give preference to one realization over another in the final evaluation of compliance.
- High dose outliers are such potentially important indicators of performance. It is important to emphasize that the safety of the proposed Yucca Mountain facility needs to be evaluated against the full range of assessment results obtained and not just against some central tendency in those results, irrespective of how that central tendency is defined.
- Performance assessment calculations undertaken by DOE to date do not provide any evidence for substantial increases in uncertainties beyond 10,000 years and no increases in to degree of caution in assessments beyond 10,000 years have been identified. Indeed, in some contexts, caution can be said to be reduced.

- The variation in uncertainty with time is a matter to be determined by assessment modeling and that it cannot be determined *a priori* to increase with time. In view of this conclusion, it seems inappropriate to base a change in the rigor of the standard of protection on the assumption that uncertainty increases with time beyond 10,000 years.

References

S Cohen & Associates, Assumptions, Conservatisms, and Uncertainties in Yucca Mountain Performance Assessments, Revised Final Draft, Contract No. EP-D-05-002, Work Assignment No. 1-08, Subtask 2, August 8, 2005.

SSPA (2001). FY01 Supplemental Science and Performance Analyses, Volume 2: Performance Analyses, US Department of Energy, Office of Civilian Radioactive Waste Management.

Mike Thorne and Associates Limited

Michael Thorne

Qualifications PhD FSRP
Year of birth [redacted]
Nationality [redacted]

KEY SKILLS

- Radiological protection
- Assessing the radiological safety of disposal of radioactive wastes
- Distribution and transport of radionuclides in the environment
- Expert elicitation procedures
- Probabilistic safety studies
- Development of safety criteria
- Pharmacodynamics

CAREER HISTORY

2001- <u>Mike Thorne and Associates Limited</u>

Development of Models for Radionuclide Transfers to Sewage Sludge and for Evaluating the Radiological Impact of Sludge applied to Agricultural Land
Client – Food Standards Agency

Includes a review of literature and the development and implementation of probabilistic models for such transfers.

Development of Biokinetic Models for radionuclides in Animals
Client – Serco Assurance

Development of updated biokinetic models for use by the Food Standards Agency in their SPADE and PRISM modelling systems

Review Studies for the Proposed Australian National Radioactive Waste Repository
Client – RWE NUKEM

Reviews of reports on animal transfer factors and of the potential effects of climate change on the repository plus development of a model for the biokinetics of the ^{226}Ra decay chain in grazing animals.

Development and Application of a Model for Assessing the Radiological Impacts of ^{3}H and ^{14}C in Sewage Sludge
Client – NNC Ltd

Development of a model based on physical, chemical and biochemical principles for the uptake of 3H and 14C into sewage sludge and their subsequent distribution and transport after application of the sludge to agricultural land.

Support for development of the Drigg Post-closure Radiological Safety Assessment
Client - BNFL

Support in the areas of FEP analysis, biosphere characterisation, human intrusion assessment and the effects of natural disruptive events. In addition, provision of advice of future research initiatives that should be pursued by BNFL.

Co-ordination of biosphere research and participation in BIOCLIM
Client – UK Nirex Ltd

Co-ordination of research on climate change, ice-sheet development, near-surface hydrology and radionuclide transport, as well as participation in an international programme on the implications of climate change for radioactive waste disposal.

Review of Parameter Values
Client – AEA Technology/Serco Assurance

Review of biosphere parameter values for use in the ANDRA assessment model AQUABIOS.

Effects of Radiation on Organisms Other Than Man
Client – AEA Technology/Serco Assurance

Study for ANDRA to identify appropriate indicator organisms and develop appropriate dosimetry and effects models for those organisms.

Development of a Database related to Emergency Planning
Client – AEA Technology (Rail)

Identification of relevant international, overseas and national legislation, regulations and guidance, and production of brief summaries of the documents.

Dose Reconstruction for Workers on a Uranium Plant
Client - McMurry and Talbot

Dose reconstruction for the plaintiffs in a case relating to the Paducah Gaseous Diffusion Plant.

Dose Reconstruction for a Worker Exposed to Pu and Am
Client – Pattinson and Brewer

Dose reconstruction for a worker exposed by a puncture wound in the finger while working at a glove box.

1998-2001 <u>AEA Technology</u>

Assessment of Remediation Options for Uranium Liabilities in Eastern Europe
Client - European Commission

Studies of remediation requirements relating to mines, waste heaps and hydrometallurgical plant in Bulgaria, Slovakia and Albania.

Evaluation of Unusual Pathways for Radionuclide Transport from Nuclear Installations
Client – Environment Agency

Review of literature and conduct of formal elicitation meetings to determine potential pathways and evaluate their radiological significance.

Revision of Exemption Orders Made Under the Radioactive Substances Act
Client – DETR

Review of requirements for revision and preparation of a draft text for the purposes of consultation.

Support Studies on the Drigg Post-closure Performance Assessment
Client - BNFL

Support in the areas of FEP analysis, biosphere characterisation, human intrusion assessment and the effects of natural disruptive events. In addition, provision of advice of future research initiatives that should be pursued by BNFL.

Development of Models for the Biokinetics of H-3, C-14 and S-35 in Farm Animals
Client - FSA

Review of relevant literature, development of appropriate biokinetic models and implementation in stand-alone software.

Integration of Aerial and Ground-based Monitoring in the Event of a Nuclear Accident
Client - FSA

Desk-based review and simulation study designed to determine optimum monitoring strategies for different types of accidents.

Elicitation of Parameter Values for use in Radiological Impact Assessment Models
Client - FSA

Expert elicitation study to provide distributions of parameter values for use in the suite of assessment models currently used by the FSA for routine and accidental releases.

Biosphere Research Co-ordination and Assessment Studies
Client - United Kingdom Nirex Ltd

Continuation of a programme of work originally undertaken at Electrowatt Engineering (UK) Ltd

Site Investigation and Risk Assessment - Hilsea Lines
Client - Portsmouth City Council

Radiological assessment of a radium-contaminated site.

1987-1998 Electrowatt Engineering (UK) Ltd

Evaluation of Inhalation Doses from Uranium
Client - Baron & Budd

Provision of expert witness support in a class action relating to environmental exposure from a uranium plant.

Biosphere Studies Relating to Drigg
Client - BNFL

Provision of advice on time-dependent biosphere modelling for the Drigg low-level radioactive waste disposal facility.

Development of a Siting Policy for Nuclear Installations: Harbinger Project and Follow-up Study
Client - HSE/NSD

Review of existing policy and development of alternatives as a precursor to application to a wide range of installations, not restricted to commercial reactors.

Support to the Rock Characterisation Facility Public Enquiry
Client - UK Nirex Ltd

Preparation of position papers and rebuttals of evidence.

Radiation Doses to an Individual as a Consequence of Working on the San Onofre Nuclear Power Plant
Client - Howarth & Smith

Interpretation of personal and area monitoring data for legal purposes.

Interpretation of Uranium in Urine Data for the Fernald, Ohio Feed Materials Processing Center
Client - Institute for Energy and Environmental Research

Interpretation of urinalysis and lung counting data, and appearance as an expert witness in the associated trial.

Determination of Failure Probabilities for use in PRA
Client - Nuclear Installations Inspectorate

Development of new approaches to the use of Bayes Theorem in defining component failure probabilities for use in PRA when statistics on actual failures are limited.

Review of Inventory Information
Client - UK Nirex Ltd

Review of uncertainties in inventories of individual radionuclides.

ALARP Study of Options for the Treatment, Packaging, Transport and Disposal of Plutonium Contaminated Material
Client - UK Nirex Ltd

Use of multi-attribute utility analysis to establish which option is preferred.

Expert Judgement Estimation of Intrusion Model Parameters
Client - British Nuclear Fuels plc

Project Manager of a study assessing the risks of human intrusion into Drigg radioactive disposal site using expert judgement techniques.

Brainstorming Study of Risks Associated with Building Structures
Client - Building Research Establishment

Participation in a classification study of the health risks associated with buildings including both injuries and disease.

Rongelap Resettlement Project
Client - Marshall Islands Government

Participation in an oversight committee evaluating the radiological safety of Rongelap in the context of resettlement by its evacuated community.

Radiological Consequences of Deferred Decommissioning of Hunterston A
Client - Scottish Nuclear Ltd

Project Manager of a study of the radiological impacts of groundwater transport of radionuclides, releases to atmosphere and intrusion.

Reviews of Safety Documentation
Client - UK Nirex Ltd

Review of safety related documentation for Packaging and Transport Branch.

The Sheltering Effectiveness of Buildings in Hong Kong
Client - Ove Arup & Partners

Project Manager of a study evaluating the shielding effectiveness of all types of building in Hong Kong for volume sources of photons in air and surface deposition sources.

Assessment of the Radiological Impact of Releases of Radionuclides from Premises other than Licensed Nuclear Sites
Client - Ministry of Agriculture, Fisheries and Food

Project Manager of a study to identify representative premises, obtain data on their releases of radionuclides and assess radiological impacts using a new methodology developed for the project.

Assessment of the Radiological Implications of Uranium and its Radioactive Daughters in Foodstuffs
Client - Ministry of Agriculture, Fisheries and Food

Project Manager of a review study of concentrations of uranium and its daughters in foodstuffs, taking local and regional variations in uranium concentrations in soils, sediments and waters into account.

Radionuclides in Sewage
Client - Her Majesty's Inspectorate of Pollution

Project Manager of a study including a desk review on alternative methods of disposal of sewage sludges, interpretation of monitoring data relating to radionuclide discharges from Amersham International to the public sewer system, development of a model for radionuclide transport in sewers, and collection and analysis of effluent, foul water, sediment, sludge and other samples suitable for use in model validation studies.

Accident Consequence Calculations
Client - Nuclear Installations Inspectorate

Project Manager of a study to assess the radiological consequences of various atmospheric releases using the MARC code.

Definition of Threshold Recording Levels for Drums of ILW
Client - UK Nirex Ltd

Project Manager of a study of the implications of post-closure radiological impacts of radioactive waste disposal in defining Threshold Recording Levels for radionuclides in individual waste drums.

Definition of Expert Judgment Exercises Relating to Nuclear Safety
Client - Commission of the European Communities

Project Manager for a study defining expert judgment exercises relating to conceptualisation, representation and input data specification. Included a comprehensive review of available formal expert judgment procedures, and mathematical and behavioural aggregation techniques.

Definition of Research Requirements Relating to the Use of Expert Judgment in Parameter Value Elicitation for Reactor Safety Studies in a UK Context
Client - Nuclear Safety Research Management Unit, HSE

Development of proposals for using combined behavioural and mathematical aggregation procedures in formal elicitations of expert judgment.

Development Priorities for the Drigg Technical Development Programme
Client - British Nuclear Fuels plc

Provision of detailed advice to BNFL on future design options, and research and development priorities, in relation to radioactive waste disposal at Drigg.

Channel Tunnel Safety Studies
Client - Channel Tunnel Safety Authority

Provision of advice and guidance on safety criteria appropriate to the Fixed Link, on the classes of Dangerous Goods that may properly be carried and on the overall characteristics of the proposed Safety Case.

Development of Societal Risk Criteria
Client - Marathon Oil

Interpretation of F-N curves in the context of the offshore oil/gas industry, taking risk aversion into account.

Impacts of Salt Dispersal on Plant Communities
Client - Sir William Halcrow

Evaluation of salt dispersal from a major road in winter in relation to adjacent Sites of Special Scientific Interest.

Offsite Consequence Assessments
Client - Nuclear Electric

Studies of the offsite radiological impacts of atmospheric and liquid releases of radioactive materials from Magnox stations.

Dry Run 3
Client - Her Majesty's Inspectorate of Pollution

Uncertainty and bias studies involving formal expert judgment procedures to develop a conceptual model of those factors and interrelationships which are of significance in determining the post-closure radiological impact of a deep geological repository for radioactive wastes. This project also included advice on data and models to be used for post-closure radiological assessments.

Radiological Assessments of Drigg
Client - British Nuclear Fuels plc

Project Manager for post-closure radiological impact assessments of the Drigg LLW disposal site. Also included specification and development of computer codes relating to the radiological impact of fires, releases of radioactive gases produced by microbial action and metal corrosion, and human intrusion.

Biosphere Co-ordination
Client - UK Nirex Ltd

Co-ordination of the UK Nirex Ltd Biosphere Research Programme from its inception, including requirements definition, technical management of all projects and QA surveillance as the Client's Representative.

Biosphere Support for the Nirex Disposal Safety Assessment Team
Client - AEA Technology

Development of approaches for assessing the radiological impact of releases of radionuclides to the biosphere, plus advice on radiological protection criteria, definition of individual risk, implications of conventionally toxic chemicals in wastes and a variety of other matters.

Evaluation and Radiological Assessment of Liquid Effluent Releases from Various Premises
Client - Her Majesty's Inspectorate of Pollution

Reviews of monitoring data and evaluations of radiological impact, primarily related to Harwell, Aldermaston, Capenhurst and Amersham International.

Evaluation of the Radiological Impact of Overseas Nuclear Accidents
Client - Her Majesty's Inspectorate of Pollution

Studies of the impact of potential overseas nuclear accidents on the UK, with emphasis on survey and monitoring requirements, and the selection of appropriate radiation detection equipment for monitoring.

Bilsthorpe Power Station
Client - British Coal/East Midlands Electricity

Preparation of an Environmental Statement with emphasis on atmospheric dispersion of SO_2 and NO_x.

Gas Generation in Radioactive Waste Disposal Facilities
Client - AEA Technology

Development of a coupled microbial degradation and corrosion model for gas generation in repositories for LLW and ILW.

Effects of Chernobyl on Drinking Water Supplies
Client - Her Majesty's Inspectorate of Pollution

Evaluation of the radiological implications of enhanced concentrations of radionuclides in water supplies in England and Wales subsequent to the Chernobyl accident.

Sea Disposal of Radioactive Wastes
Client - UK Nirex Ltd

Participation in an Environmental Impact Assessment of the proposed resumption of sea-dumping of radioactive wastes.

UK Research Related to Radioactive Waste Management
Client - Her Majesty's Inspectorate of Pollution

Identification of gaps in the UK national research effort related to radioactive waste management.

Research Requirements for Repository Design and Site Investigations
Client - UK Nirex Ltd

Review of research requirements for repository design and site investigations in relation to LLW and ILW disposal in near-surface and deep repositories.

1985 - 1986 **International Commission on Radiological Protection, Sutton, Surrey, England**

Scientific Secretary responsible for arranging and minuting meetings, administrative arrangements, technical review of reports, editing of the Commission's journal, liaison with other international organisations and public relations.

1979 - 1985 **ANS Consultants Ltd, Epsom, Surrey, England**

Reviews of data on the distribution at transport of radionuclides in terrestrial and aquatic ecosystems (see publications list).

Development of a dynamic model for radionuclide transport in agricultural ecosystems and implementation of the model on various microcomputer systems.

Photon and neutron shielding studies of radiochemical plant, together with area classification and ALARA studies.

A review of UK use of the criticality code MONK and other approaches to criticality safety assessment.

Radiological and conventional safety aspects of Magnox reactor decommissioning.

Development of metabolic models for inclusion in ICRP Publication 30.

Development of pharmacodynamic models for toxic chemicals.

Review of neutron activation analysis in studies of radionuclide transport in soils and plants.

Experimental studies on radionuclide transport in soils and plants using various photon-emitting radionuclides.

Support for DoE work on probabilistic risk assessment of LLW and ILW disposal.

Review of UK research requirements for HLW disposal.

Post-closure radiological impact assessment of the proposed LLW and ILW facility at Elstow, Bedfordshire.

Development of a generalised biosphere model for use in probabilistic risk assessments of solid radioactive waste disposal.

Initial development of a mathematical model for use in assessing the radiological impact of contaminated groundwater.

Development, computer implementation and comprehensive documentation of a model to calculate the radiological impact of intrusion into radioactive waste repositories.

Development of a general-purpose computer code for solving first-order differential equations using a hybrid Predictor-Corrector/Runge-Kutta method.

Studies on the potential radiological consequences of Magnox reactor accidents.

1974 - 1979 **Medical Research Council Radiobiology Unit, Chilton, Didcot, Oxon, England**

Development of dosimetric and metabolic models for use in ICRP Publication 30.

Studies on the metabolism of plutonium in bone and relationships to blood flow.

Theoretical studies on radionuclide metabolism and dosimetry.

Development of techniques in neutron-induced autoradiography and alpha imaging.

Image analysis studies of plutonium in bone, uranium in lungs, lysosomal inclusions in cells and heterochromatin.

Studies on the clearance of inhaled UO_2.

Alpha spectroscopy in support of toxicity studies with Ra-224.

Data analysis in connection with experimental animal studies on the potential efficacy of neutron therapy using 42 MeV neutrons.

1971 - 1974 **University of Sheffield**

Experimental studies on the reaction $\gamma + p \rightarrow \pi^0 + p$ at photon energies between 1 and 3 GeV, using a linearly polarised photon beam.

PROFESSIONAL ACTIVITIES AND MEMBERSHIP

- Fellow of the Society for Radiological Protection and Immediate Past President
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SELECTION OF PUBLICATIONS

A measurement of the beam asymmetry parameter for neutral pion photoproduction in the energy range 1.2 - 2.8 GeV. P.J.Bussey, C. Raine, J.G. Rutherglen, P.S.L. Booth, L. Carroll, G.R. Court, A.W. Edwards, R. Gamet, C.J. Hardwick, P.J. Hayman, J.R. Holt, J.N. Jackson, J. Norem, W.H. Range, F.H. Combley, W. Galbraith, V.H. Rajaratnam, C. Sutton and M.C. Thorne. London Conference (1974) Abstract 997.

The measurement of the polarisation parameters S, P and T for positive pion photoproduction between 500 and 1700 MeV. P.J. Bussey, C. Raine, J.G. Rutherglen, P.S.L. Booth, L.J. Carroll, P.R. Daniel, C.J. Hardwick, J.R. Holt, J.N. Jackson, J.H. Norem, W.H. Range, F.H. Combley, W. Galbraith, V.H. Rajaratnam, C. Sutton, M.C. Thorne and P. Waller. Nuclear Physics, B104, (1976) 253-276.

The polarised beam asymmetry in photoproduction of eta mesons from protons 2.5 GeV and 3.0 GeV. P.J. Bussey, C. Raine, J.G. Rutherglen, P.S.L. Booth, L.J. Carroll, P.R. Daniel, A.W. Edwards, C.J. Hardwick, J.R. Holt, J.N. Jackson, J. Norem, W.H. Range, W. Galbraith, V.H. Rajaratnam, C. Sutton, M.C. Thorne and P. Waller. Physics Letters, 61B, (1976) 479-482.

Aspects of the dosimetry of plutonium in bone. M.C. Thorne. Nature, 259, (1976) 539-541.

The toxicity of Sr-90, Ra-226 and Pu-239. M.C. Thorne and J. Vennart. Nature 263, (1976) 555-558.

Radiation dose to mouse testes from Pu-239. D. Green, G.R. Howells, E.H. Humphreys and J. Vennart with Appendix by M.C. Thorne. Published in "The Health Effects of Plutonium and Radium", Ed. W.S.S. Jee, (J.W. Press, Salt Lake City, Utah, 1976).

The distribution and clearance of inhaled uranium dioxide particles in the repository tract of the rat. Donna J. Gore and M.C. Thorne. In "Inhaled particles IV", Ed. W.H. Walton, (Pergamon Press, Oxford, 1977) pp. 275-284.

Theoretical aspects of the distribution and retention of radionuclides in biological systems. M.C. Thorne. J. Theor. Biol., 65, (1977) 743-754.

Aspects of the dosimetry of emitting radionuclides in bone with particular emphasis on Ra-226 and Pu-239. M.C. Thorne. Phys. Med. Biol., 22, (1977) 36-46.

A new method for the accurate localisation of Pu-239 in bone. D. Green, G. Howells and M.C. Thorne. Phys. Med. Biol., 22, (1977) 284-297.

The measurement of blood flow in mouse femur and its correlation with Pu-239 deposition. E.R. Humphreys, G. Fisher and M.C. Thorne. Calcif. Tiss. Res., 23, (1977) 141-145.

The distribution of plutonium-239 in the skeleton of the mouse. D. Green, G.R. Howells, M.C. Thorne and J. Vennart. In "Proceedings of the IVth International Congress of the International Radiation Protection Association Vol. 2 (Paris 1977).

The visualisation of fissionable radionuclides in rat lung using neutron induced autoradiography. D.J. Gore, M.C. Thorne and R.H. Watts. Phys. Med. Biol., 23 (1978) 149-153.

Lymphoid tumours and leukaemia induced in mice by bone-seeking radionuclides. J.F. Loutit and T.E.F. Carr with an appendix by M.C. Thorne. Int. J. Radiat. Biol., 33, (1978) 245-263.

Plutonium-239 deposition in the skeleton of the mouse. D. Green, G.R. Howells and M.C. Thorne. Int. J. Radiat. Biol., 34, (1978) 27-36.

Imaging of tissue sections on Lexan by alpha-particles and thermal neutrons; an aid in fissionable radionuclide distribution studies. D. Green, G.R. Howells, M.C. Thorne and R.H. Watts. Int. J. Appl. Radiat. Isotopes, 29, 285-295 (1978).

Analytical techniques for the analysis of multi-compartment systems. M.C. Thorne. Phys. Med. Biol., 24, 815-817 (1979).

The initial deposition and redistribution of Pu-239 in the mouse skeleton: implications for rodent studies in Pu-239 toxicology. D. Green, G.R. Howells and M.C. Thorne. Br. J. Radiol., 52, 426-427 (1979).

Bran and experimental colon cancer. M.C. Thorne. Lancet, ii, 13 January 1979, p.108.

Quantitative microscopic studies of the distribution and retention of Pu-239 in the ilium of the female CBA mouse. D. Green, G.R. Howells and M.C. Thorne. Int. J. Radiat. Biol., 36, 499-511 (1979).

Techniques for studying the distribution of alpha emitting and fissionable radionuclides in histological lung sections. T. Jenner and M.C. Thorne. Phys. Med. Biol., 25, 357-364 (1980).

Morphometric studies of mouse bone using a computer-based image analysis system. D. Green, G.R. Howells and M.C. Thorne. J. Microscopy, 122, 49-58 (1981).

A semi-automated technique for assessing the microdistribution of ^{239}Pu deposited in bone. D. Green, G.R. Howells and M.C. Thorne. Phys. Med. Biol., 26, 379-387 (1981).

Radionuclide distribution and transport in terrestial and aquatic ecosystems, Volumes 1 to 6. P.J. Coughtrey, M.C. Thorne et al. A.A. Balkema, Rotterdam 1983-1985.

Dynamic models for radionuclide transport in soils, plants and domestic animals. M. C. Thorne and P. J. Coughtrey. In: Ecological Aspects of Radionuclide Release (Ed. P. J. Coughtrey). British Ecological Society Special Publication No. 3, Blackwell, Oxford, 1983.

Studies on the mobility of radioisotopes of Ce, Te, Ru, Sr and Cs in soils and plants. P.J. Coughtrey, M.C. Thorne, D. Jackson and G.F. Meekings. In: CEC Symposium on the Transfer of Radioactive Materials in the Terrestial Environment Subsequent to an Accidental Release to Atmosphere. Dublin, April 1983.

A study of the sensitivity of a dynamic soil-plant-animal model to changes in selected parameter values. M.C. Thorne, P.J. Coughtrey and G.F. Meekings. In: CEC Symposium on the Transfer of Radioactive Materials in the Terrestial Environment Subsequent to an Accidental Release to Atmosphere. Dublin, April 1983.

Microdosimetry of bone: implications in radiological protection. M.C. Thorne. In: Metals in Bone, N.D. Priest (Ed.) MTP Press, Lancaster (1985), pp. 249-268.

Non-stochastic effects resulting from internal emitters: dosimetric considerations. M.C. Thorne. J. Soc. Rad. Prot., 6 (1986).

Pharmacodynamic models of selected toxic chemicals in man. Vol. 1. Review of metabolic data. M.C. Thorne, D. Jackson and A.D. Smith. MTP Press, Lancaster, 1986.

Pharmacodynamic models of selected toxic chemicals in man. Vol. 2. Routes of intake and implementation of pharmacodynamic models. A.D. Smith and M.C. Thorne. MTP Press. Lancaster 1986.

Generalised computer routines for the simulation of linear multi-compartment systems. D.Jackson, A.D. Smith, M.C. Thorne and P.J. Coughtrey. Environmental Software, 2 (1987), 94-102.

The demonstration of a proposed methodology for the verification and validation of near field models. J-M. Laurens and M.C. Thorne. In: Proceedings of an NEA Workshop "Near-field Assessment of Repositories for Low and Medium Level Radioactive Waste". pp. 297-310. NEA/OECD, Paris, 1987.

Principles of the International Commission on Radiological Protection System of Dose Limitation. Br. J. Radiol., 60 (1987), 32-38.

The origins and work of the International Commission on Radiological Protection. H. Smith and M.C. Thorne. Invest. Radiol., 22 (1987), 918-921.

The potential for irradiation of the lens and cataract induction by incorporated alpha-emitting radionuclides. D.M. Taylor and M.C. Thorne. Health Phys., 54 (1988), 171-179.

Forum on alpha-emitters in bone and leukaemia: introduction and commentary. M.C. Thorne. Int. J. Radiat. Biol., 53 (1988), 521-539.

Radiological protection and the lymphatic system: The induction of leukaemia consequent upon the internal irradiation of the tracheo-bronchial lymph nodes and the gastrointestinal tract wall. K.F. Baverstock and M.C. Thorne. Int. J. Radiat. Biol., 55 (1989), 129-140.

The Biosphere: Current Status. NSS/G106. M.C. Thorne. Available from UK Nirex Ltd, Curie Avenue, Harwell, 1989.

The development of an overall assessment procedure incorporating an uncertainty and bias audit. M. C. Thorne and J-M. Laurens. Proceedings of an International Symposium on Safety Assessment of Radioactive Waste Repositories. OECD Paris (1990), 673-681.

Implications of environmental change for biosphere modelling: work for UK Nirex Ltd. M.C. Thorne. Proceedings of an International Symposium on Safety Assessment of Radioactive Waste Repositories. OECD Paris (1990), 860-865.

The Biosphere: Current Status, December 1989. NSS/G114. M.C. Thorne. Available from UK Nirex Ltd, Curie Avenue, Harwell, 1990.

The Nirex Overview. M.C. Thorne and D. George. In: Future Climate Change and Radioactive Waste Disposal: Proceedings of an International Workshop. C.M. Goodess and J.P. Palutikof (Eds). NSS/R257. Available from UK Nirex Ltd, Curie Avenue, Harwell, 1991.

A review of expert judgment techniques with reference to nuclear safety. M. C. Thorne and M. M. R. Williams, Progress in Nuclear Energy, 27 (1992), 83-254.

NSARP Reference Document: The Biosphere, January 1992. Nirex Report No. NSS/G119 M.C. Thorne. 1993.

The use of expert opinion in formulating conceptual models of underground disposal systems and the treatment of associated bias. M.C.Thorne, Journal of Reliability Engineering and Systems Safety, 42 (1993), 161-180.

UK Nirex Ltd Science Report No S/95/003, Nirex Biosphere Research: Report on Current Status in 1994, M C Thorne (Ed.), UK Nirex Ltd, July 1995.

UK Nirex Ltd. Science Report No S/95/012, Vol 3, A J Baker, C P Jackson, J E Sinclair, M C Thorne and S J Wisbey, Nirex 95: A Preliminary Analysis of the Groundwater Pathway for a Deep Repository at Sellafield: Volume 3 - Calculations of Risk, UK Nirex Ltd, July 1995.

Nirex 95: An Assessment of a deep repository at Sellafield, A J Baker, G E Hickford, C P Jackson, J E Sinclair, M C Thorne and S J Wisbey, TOPSEAL 96, Demonstrating the Practical Achievements of Nuclear Waste Management and Disposal, European Nuclear Society, pp. 125-132, 1996.

Consideration of post-closure controls for a near surface low level waste disposal site, Clegg, R, Pinner, A, Smith, A, Quartermaine, J and Thorne, M C, In: Planning and Operation of Low Level Waste Disposal Facilities, IAEA, Vienna, 1997.

The estimation of failure rates for low probability events, M M R Williams and M C Thorne, Progress in Nuclear Energy, 31 (1997), 373-476.

A comparison of independently conducted dose assessments to determine compliance and resettlement options for the people of Rongelap Atoll, S L Simon, W L Robison, M C Thorne, L H Toburen, B Franke, K F Baverstock and H J Pettingill, Health Physics, 73(1), 133 - 151, 1997.

A Guide to the Use and Technical Basis of the Gas Evolution Program MICROX: A Coupled Model of Cellulosic Waste Degradation and Metal Corrosion, R Colosante, J E Pearson, S Y R Pugh, A Van Santen, R G Gregory, M C Thorne, M M R Williams and R S Billington, Nirex Safety Studies Report NSS/R167, July 1997.

UK Nirex approach to the protection of the natural environment, M J Egan, M C Thorne and M A Broderick, Stockholm Symposium.

Post-closure performance assessment: treatment of the biosphere, M A Broderick, M J Egan, M C Thorne and J A Williams, Winnipeg Symposium.

The application of constraint curves in limiting risk, M C Thorne, J. Radiol. Prot., Vol. 17, 275-280, 1997.

The biosphere in post-closure radiological safety assessments of solid radioactive waste disposal, M C Thorne, Interdisciplinary Science Reviews, Vol. 23, 258-268, 1998.

An illustrative comparison of the event-size distributions for γ-rays and α-particles in the whole mammalian cell nucleus, K Baverstock and M C Thorne, Int. J. Radiat. Biol., 74, 799-804, 1998.

Southport '99, Achievements and Challenges: Advancing Radiation Protection into the 21st Century, Proceedings of an International Symposium, M C Thorne (Ed.) Society for Radiological Protection, London, 1999.

Modelling radionuclide distribution and transport in the environment, K M Thiessen, M C Thorne, P R Maul, G Prohl and H S Wheater, Environmental Pollution, 100, 151-177, 1999.

Use of a systematic approach for the Drigg post-closure radiological safety assessment, G Thomson, M Egan, P Kane, M Thorne, L Clements and P Humphreys, DisTec 2000, Disposal Technologies and Concepts 2000, Kontec Gesellschaft für technische Kommunication mbH, Tarpenring 6, D-22419, Hamburg, 413-417, 2000.

Validation of a physically based catchment model for application in post-closure radiological safety assessments of deep geological repositories for solid radioactive wastes, M C Thorne, P Degnan, J Ewen and G Parkin, Journal of Radiological Protection, 20(4), 403-421, 2000.

An approach to multi-attribute utility analysis under parametric uncertainty, M Kelly and M C Thorne, Annals of Nuclear Energy, 28, 875-893, 2001.

Radiobiological theory and radiation protection, M C Thorne, British Nuclear Energy Society International Conference on Radiation Dose Management in the Nuclear Industry, May 2001.

Development of a solution method for the differential equations arising in the biosphere module of the BNFL suite of codes MONDRIAN, M M R Williams, M C Thorne, J G Thomson and A Paulley, Annals of Nuclear Energy, 29, 1019-1039, 2002.

A model for evaluating radiological impacts on organisms other than man for use in post-closure assessments of geological repositories for radioactive wastes, M C Thorne, M Kelly, J H Rees, P Sànchez-Friera and M Calvez, J. Radiol. Prot., **22**, 249-277, 2002.

Background Radiation: Natural and Man-made, M C Thorne, BNES 4th International Conference on Health Eeffects of Low-level Radiation, 22-24 September 2002, Keble College, Oxford, UK, CD Available from BNES.

Background Radiation: Natural and Man Made, M C Thorne, Journal of Radiological Protection, 23, 29-42, 2003.

Comments from the Society for Radiological Protection on ICRP Reference 02/305/02 – Protection of Non-Human Species From Ionising Radiation, M C Thorne, Journal of Radiological Protection, 23, 107-115, 2003.

Estimation of animal transfer factors for radioactive isotopes of iodine, technetium, selenium and uranium, M C Thorne, J. Environ. Radioact., in the press.

Appendix D

White Paper
Intergenerational Equity as it applies to 40 C.F.R. Part 197

Patricia Ann Fleming, Ph.D.

My charge as an Independent Consulting Expert for the State of Nevada:

I have been asked by the State of Nevada to write a white paper on the ethical issues which present themselves in the August 22, 2005 EPA proposal for radiation protection standards at Yucca Mountain. In particular, I have been asked to comment on intergenerational equity as it applies to these standards. I confine myself to this task and introduce other issues in 40 C.F.R. Part 197 which are related to this task.

Format of my response to my charge:

I have some familiarity with the processes by which an entity (federal agency, national committee, etc.) elicits responses during a comment period to the concerns it has undertaken. Hence, I have chosen the style below of posing questions/statements and providing comments (rather than the more didactic style familiar in my own profession of philosophical scholarship) on the issues relevant to my task at hand. My objective is to ease the task of understanding what I take to be the most significant issues regarding intergenerational equity (and associated topics) raised by 40 C.F.R. Part 197.

1. **What is *ethically significant* about EPA issuance of a new guidance at 40 C.F.R. Part 197?**

The NAS Committee on Technical Bases for Yucca Mountain Standards of the National Academy of Sciences rejected two technical reasons commonly given for not providing guidance beyond 10,000 years--that uncertainty exists in compliance assessment and that there is a likelihood of no significant health effects after a specified time. However, they point out that a time-related regulatory concern remains. "This is based on ethical principles, and is the issue of intergenerational equity." (NAS 1995, p. 56) They say

> *Whether and how best to be fair to future generations is a societal concern...In drafting standards, EPA should as a matter of policy address whether future generations should have **less, greater, or equivalent protection.**" (NAS, 1995, p.56, emphasis added).*

EPA is making an ethically significant judgment about the issue intergenerational equity, i.e. fair and just treatment toward future generations in their proposed rule at 40 C.F.R. Part 197.

2. Did the EPA ignore the NAS Committee's recommendation on the matter of intergenerational equity?

In its *Technical Basis for Yucca Mountain* report, the National Academy of Science committee cites responsible institutions on the question of the protection standard. They remind us of a societal pledge to future generations made by Margaret Federline, USNRC to "provide societies with the same protection from radiation we would expect ourselves" (NAS, 1995, p.56) and an international document from IAEA which asserts that " the degree of isolation of high-level radioactive waste shall be such so there are no predictable future risks to human health or effects on the environment that would not be acceptable today" (NAS, 1995, p. 56) and that "the level of protection to be afforded to future individuals should not be less than that provided today." (NAS, 1995, p. 56) The committee notes that such a standard "could be specified to apply uniformly over time and generation. Such an approach would be consistent with the principle of intergenerational equity that requires that the risks to future generations be no greater than the risks that would be accepted today." (NAS, 1995, p 57). The Committee also cites the following reason that is often given by ethicists in support of a greater level of protection in order to compensate for risks imposed on non-consenting populations:

> *Although current generations are assumed to have benefited from activities, such as electricity production or national defense programs that have caused radioactive wastes to accumulate, far future generations will not benefit directly, but might be exposed to risks when any radioactive materials eventually escape the proposed repository (NAS, 1995, p.56).*

Based on these comments, one might conclude that the NAS committee favors an equivalent or even a greater protection standard for individuals living beyond 10,000 year to peak dose and that EPA, in its proposed rule, ignored the committee's guidance. The committee is clear, however, that how the principle of intergenerational equity is best expressed is a matter of social, not scientific, judgment. As a scientific body, the NAS Committee did not (and would not) explicitly recommend an equivalent or greater protection standard. Committees will lean heavily in one direction on social judgment issues and this august body seems to have leaned *away* from a lesser protection standard for future generations. Nothing that it says in their report supports less protection. Nevertheless, they were clear in articulating that the burden falls to the EPA to ascertain the judgment of society regarding an acceptable expression of the principle of intergenerational equity.

3. How does EPA ascertain the judgment of society regarding an acceptable expression of the principle of intergenerational equity?

Unlike other countries (e.g. Sweden), the United States does not have national referendums. Moreover, EPA is not proposing legislation to specify a societal judgment. This is why the comment period for 40 C.F.R. 197 is so important. It is the mechanism EPA uses to hear the judgments of individual members of society as well as stakeholder groups. In fact, the NAS committee says, "The rulemaking process, directly involving public comment to which an agency must respond, is an appropriate method of addressing the questions of an appropriate level of protection." (NAS, p.49). After the comment period ends, in its response, the EPA assumes the extremely important ethical duty of deciding what is the socially acceptable expression of the principle of intergenerational equity.

4. Does the EPA conceive of future generations as NAS describes them in their 1995 report?

No. NAS did not make a distinction between near future and far future generations. NAS accepted the common distinction found in the scholarship on intergenerational equity, i.e. a distinction between present generations and all future generations taken together. The distinction drawn by EPA is between 1) present and near future generations up to 10, 000 and 2) far future generations from 10,000 years to 1 million years, regardless of when peak dose occurs. EPA cites references from the nuclear waste community which establish several distinctions (but different than its own) among future generations. EPA's distinction seems to be a vestige of the standard rejected by the Court of Appeals.

5. What does EPA say about the present generation's duty toward future generations?

In 40 C.F.R. 197, EPA effectively claims that present generations are entitled and duty-bound to hold near future generations in the same regard but far future generations in less regard than present generations This is expressed in the recommendation that it is permissible to provide far future generations with less protection than present and near future generations.

6. Where does the EPA advance the ethical claim that less protection is required for the far future (from 10,001 to peak dose)?

The first place in EPA's Proposed Rules where the subject of providing less protection to far future generations *as an ethical claim* is discussed is in on page 49035 (Vol. 70, No 161). EPA says, "We have also considered the potential impacts to future generations that would be represented by a dose standard applied to periods up to 1 million years. Impacts on future generations could come in the form of economic cost, health impacts or a reduction in the options available to make decisions to address the problems faced by those generations. A number of regulatory and scientific bodies suggest that it is appropriate to relate longer-term standards to background radiation levels." This is the first indication (other than in the summary section) that the EPA regards it socially acceptable to provide less protection to far future generations by raising the dose standard from 15mrem/a to a higher level (i.e. something *related to* background radiation levels—350mrem/a).

7. How does the EPA support what they say?

They provide underlying ethical arguments, drawn primarily from scholarship by individuals either funded by DOE (NAPA) or involved internationally in regulatory bodies (NAGRA, KASAM). This scholarship focuses on the claim that we might have weaker obligations to future generations than to present persons and near-term generations.

For example, the EPA cites a National Academy of Public Administration (NAPA) 1997 report "Deciding for the Future: Balancing Risks, Costs, and Benefits Fairly Across Generations." They point out that NAPA "recognizes that each generation must consider not only how its actions will affect future generations, but also the extent to which inaction will compromise its own interests and negatively affect those same generations." (EPA, p. 49035)

After listing four basic principles from the NAPA document (three of which some version is generally recognized among environmental ethics scholars as relevant to environmental concerns) and by appealing to the concept of a "rolling present", the EPA concludes that application of these principles would "lead each generation to an approach that would best address the problem without unduly limiting the options available to succeeding generations to modify that approach or to take other actions to address their needs."

This scholarship is a valiant attempt to make sense of a difficult and thorny issue facing nations with nuclear waste sitting in cooling ponds at reactor sites. The authors of these studies or the agency contracting for the study are all involved with this concern (McCombie-Switzerland, Chapman-UK, KASAM-Sweden, NAPA-U.S. DOE).

8. Are there problems with this support?

Although they provide background documents of the an annotated bibliography of scholarship on intergenerational equity from 1992 backwards, the conclusions NAPA draws has not been vetted or reviewed among the *larger* community of scholars working on intergenerational equity. This is evidenced by the fact, despite the report being in existence for the last 13 years, major scholarship in this field today does not cite the NAPA sources. The sources used by EPA tend, instead, to cite each other. Consequently, the scholarship lacks balance, contains logical errors, (McCombie and Chapman), and, in some instances, is a misapplication to cases (NAPA, EPA, KASAM). It almost appears as if the EPA searched for and found scholarship which exclusively supports (or they interpret to support) the "less protection" expression of intergenerational equity, rather than openly asked what would be the most rationally defensible and socially acceptable protection standard for future generations

9. Is there better support for a different conclusion?

The bulk of scholarship on intergenerational equity is done by professional philosophers/ethicists. Associated scholarship exists in the fields of environmental economics and international law. This scholarship, while it looks far more deeply at the profound issues surrounding the question of our duties to future generations, does not always apply its results to high level nuclear waste disposal. Nevertheless, considerable scholarship exists from this professional community of scholars on the important issue of intergenerational equity facing the EPA and should be taken into account. It has been vetted through peer review and does not commit the errors made by the EPA. This scholarship does not (or would not) support the "less protection" expression of intergenerational equity as it is applied to the standards proposed by EPA

Instead, this scholarship shows either we have no duties to future generations or, if we do, our duties are the same as those to present generations, assuming the duty is to leave the future is no worse shape than the present finds itself. For example, the author of a leading and standard textbook in the field of environmental ethics states, "Future people should have the same opportunity that we have had to live healthy, happy, and satisfactory lives. The basic interests of future people are no more, and no less, importantly ethically than our own." (DesJardins, p. 82).

10. Does it matter that there are different viewpoints in the scholarship on intergenerational equity? Hasn't the EPA acted properly in choosing the sources which best support its position on a controversial issue?

This is not simply a matter of there being controversy in the field; rather, what is disconcerting about the scholarship chosen by the EPA to defend its choice of a "lesser protection standard" for the human health of future generations is that their sources or, more often, their *use* of the sources are:

1) misapplied

2) not rationally defensibility

3) fail to avoid logical and other errors.

11. How has the EPA misapplied their sources?

The EPA has misapplied one of their sources, the NAPA document, in two key ways.

12. What is the first way in which EPA misapplied the NAPA document findings?

First, the NAPA report clearly states that the four principles it elicits from its background studies of literature (from December, 1993 backward) and its workshop in phase two of the project supported by the DOE, are very preliminary. They "represent only the first step toward improving public decision making in a broad range of activities that affects future generations. Obvious next steps are elaborating a set of working guidelines showing how to apply them in specific situations;..." (NAPA, p. 3) Later in Chapter 3 of the report, the NAPA panel develops some initial guidance for applying each principle but warns that much more work remains to be done. They say "In the best of circumstances, with all of the necessary guidance, the application of the principles presented here would be a daunting task." (NAPA, p. 13) They construct a simple matrix that is intended to provide a way to prioritize a public administrator's obligations, or to give him/her a sense of which issues he/she should tackle first (the priority is given to issues presenting risks affecting both the present and future generations.) They add that the matrix is inadequate for addressing complex issues and further work is needed to develop it into a useful decision making tool. They say "For example, the idea of addressing the highest near term risk first will not help in deciding between a certain risk now versus an uncertain risk either now or many generations in the future." (NAPA, p. 13) Throughout their report, this panel stresses that what they have provided is just a start, should not be used "off the shelf", and must include the public in determining risk and evaluating the risk's relative importance.

Related to this first problem of misapplication of the NAPA report is the context in which it is used, i.e. for a comment period in which the public has no more that 60 days (extended to 90 days by petition of the State of Nevada) to respond to their use. Figure 4-1 of the panel's report would require more that 90 days for the principles to be processed (including public participation and public judgment), and for the outcomes to be realized, i.e. 1) public agreement on the principles, 2) public agreement on processes, 3) a politically acceptable decision, and 4) enhanced public trust.

Given all these cautions and caveats, it is clearly inconsistent with the panel's report for EPA to cite the four principles and apply them indirectly through reference and subtle inference. Doing this supports, at best, a vacuous conclusion that, through a "rolling present", each generation should address the problem with an approach that does not unduly limit the succeeding generations to modify that approach. Appealing to the concept of a rolling present in a general discussion document is speculative, idealistic, and perhaps even hopeful. But the Proposed Rules, presented as a response on August 22, 2005 to the Court's earlier July, 2004 decision, is not this kind of document. Hence, the conclusion EPA draws has no real meaning for the provisions of the current Nuclear Waste Policy Act under which the EPA has control. This is because, among other things, taking seriously a "rolling present" would effectively obligate future generations to review the individual protection standards (if not all the standards and the entire Nuclear Waste Policy Act) every 20 years. Nowhere does the EPA make this recommendation. In addition, the EPA cannot rely on any concrete provisions in the Nuclear Waste Policy Act for the *institutional constancy* needed to give real meaning to a "rolling present." Neither do they propose any such provisions. Hence, in using the NAPA report results as it does, the EPA oversimplifies and contradicts what NAPA tried to achieve.

13. What should EPA do to rectify this misapplication?

To be consistent with the NAPA panel report recommendations, the EPA should have "(sought) out and utilize (d) public participation early enough in the process to have a meaningful effect on its outcome." Now, when they are at the end-period of producing individual protection standards for peak dose (and only as a result of the Court's decision), they would need to extend the time period and institute a mechanism other than merely a comment period and reactive hearings to insure that the NAPA's expected outcomes are realized. There are ample models being used today by nations and international groups to effect such outcomes but these models take time, patience, and better communication with stakeholders and the general public (see, for example, the results of the NEA/OECD Stakeholder Conference Workshops). In addition, if we accept EPA's understanding of "the rolling present", EPA would need to seek revision of the Nuclear Waste Policy Act in order to create a process that is "continuous and adopts a rolling present responsibility flowing from one generation to the next without interruption." (NAPA, p. 8). They should also ensure that a revised act provides 1) in general, continued research and education about risks associated with nuclear waste disposal and 2) in particular, regularly reexamined and revised individual protection standards. Since "the rolling present" is meant to *substitute* for geological and biospheric stability in the face of uncertainty, such institutional stability, as its substitute, needs to be guaranteed for future generations. (see No. 20 below for further comments on this point which point out that EPA has misapplied the concept of a "rolling present.").

Without such changes, it is questionable as to whether the concept of a "rolling present" is much more than an idealistic vision of how we might *implement* our duties to future obligations. Alternatively, they should abandon such a simplistic and contradictory appeal to the NAPA panel report. The fact that other entities (KASAM and Chapman and McCombie) also appeal to this report does not alter the fact that the EPA has misapplied the report findings by including it as support for their Proposed Rules. In using the NAPA panel report as they do in their Proposed Rules, EPA runs the risk of "put (ting) themselves in the position of advocating policies or programs that are unrealistic and will not be supported by a reasonable public consensus and acceptance." (NAPA, p. 27) It is necessary to avoid this "because intergenerational obligations must ultimately be borne by our society as a whole and not just by the bureaucratic apparatus of government." (NAPA, p. 27)

14. What is the second way in which EPA has misapplied the NAPA report findings?

The second misapplication of the NAPA report is derived from thinking that NAPA's own self-admittedly "simplified illustration" supports the EPA proposal to provide lesser protection to future generations than the present. This illustration concerns a matter close to but not identical with EPA's task at hand. The NAPA panel illustrated how the principles can be used *as a set* in decision making and priority setting. The issue they apply the set of principles to is "How should risk to populations in the near future (e.g. 2 or 4 generations) be compared to risks to populations in the distant future (e.g. 500 or 1000 years)" which is taken from Appendix A, III. Q1. (NAPA, p. 22).

The panel argues that the Trustee Principle is trumped by the Chain of Obligation Principle because of our limitations in addressing the very long-term. It presumes that a probable difference between the risks to present and future populations cannot be detected and so the risks cannot be compared. Because of this difficulty in comparison of real risks, the Chain of Obligation principle requires us to attend to our duties to present and near-future generations.

The Chain of Obligation Principle also trumps the Sustainability Principle. While the Sustainability Principle "admonishes us not to deprive future generations of a quality of life like ours" (NAPA, p. 12), the Chain of Obligation principle trumps sustainability because it "accommodates a natural tendency to prefer near-term over the long-term" and it acknowledges the uncertainty and low probability of future events. The only sense we get that the Chain of Obligation Principle might not top a hierarchy of principles is in the Precautionary Principle's requirement to limit any preference for the near term if there is any plausible threat of irreversible harm or catastrophic damage.

The example used to illustrate this is an accident in 1957 in Chelyabinsk, Russia where surface storage of radioactive waste blew up, contaminating surrounding areas for hundreds of years. The NAPA panel concluded that in making a decision to continue surface storage of liquid waste rather than solidifying it and disposing it in a geological repository, even if such storage were less expensive, "any plausible threat of such an event occurring in the far future should be given additional weight." (NAPA, p.13)

There are several features about this (truly) simplified illustration that commit errors mentioned in No. 10 above. Below, (a) through (c) describe some internal problems with the NAPA report, which should have encouraged EPA to be cautious about its use. The vetting of this report among the peer-review community of ethicists may have caught these errors. Further below (d) describes a misapplication of the NAPA report by the EPA.

a. NAPA's application of the set of principles in this case is not rationally defensible. The Chain of Obligation Principle would *almost always* trump our trusteeship obligation and any sustainability obligation whenever uncertainty exists. This is because, according to the NAPA panel, uncertainty is a morally relevant characteristic in determining our duties. It can only be trumped by catastrophic harm. This would be strangely precedent-setting. One can always argue uncertainty exists. In almost all areas of environmental concern there will always be uncertainty. Does it have that much power to derail duties we have to persons living in the future? While we might think that uncertainty affects our moral duties, do we really want to say that uncertainty dissolves or reduces moral responsibility? If the NAPA committee did not intend this result, they needed to have stated this clearly.

b. It is illogical and ethically irrelevant as to whether any principle, and in particular the Chain of Obligation Principle, accommodates a natural tendency. This is a statement about our moral psychology at best. It is not a normative claim. It attempts to derive "ought" from "is." Assuming this is a correct, empirically verified statement about our natural moral disposition, nevertheless professional ethicists generally reject attempts to base our moral obligations on our natural tendencies. The consequences of doing so are quite problematic because we know that our natural tendencies are not, by virtue of being natural, necessarily morally praiseworthy. Additionally, economists will be the first to argue that, when engaged in economic planning, we should not follow any "natural inclination" to favor the present. We should be concerned with what is most "rational" (i.e. stands up to scrutiny by rational actors), not what is most "natural."

c. The Precautionary Principle may lead to the claim that our obligations to future generations are **greater** than those to present generations. The example is meant to illustrate this. But, in fact, it is miscast. In the example given, the probability of harm from a nuclear accident potentially endangers both the present as well as the future. To keep liquid waste in an unmonitored state, allowing the loss of cooling, is not defensible under any version of the principles above. It is simply irresponsible to both present persons and the future generations. It is not an apt illustration of a case in which the present is rationally preferred over the future.. At best, if cost was the prime consideration, the example should be characterized as one in which present regulators (in 1957) miscalculated the risks over costs to both present and future generations, not one in which the well-calculated risks to future generations outweighed any well-calculated risks to present persons (on some utilitarian calculus that is assumed to have intentionally occurred in 1957). It's a bad example.

d. Most significantly, if the Chain of Obligation Principle is applied to the issue at hand (as the EPA Proposed Rules infer), then near-term concrete hazards have priority over long-term hypothetical hazards. What is the near-term concrete hazard at issue? EPA does not identify or evaluate it, so it is impossible to comment on EPA's application of the Principle. I will return to this point shortly.

What is the long-term hypothetical hazard? Here, things become more complex. If by this expression, the EPA, Chapman and McCombie, KASAM and others in the nuclear community define 'hypothetical hazard' to mean 'the uncertainty associated with the geological structure or with the way in which a repository will perform in the distant future', then this is a misconstruction of the term. The ethical framework under discussion is designed to evaluate the acceptability of risks, not to specify the limits of uncertainty in doing a performance assessment. The hazard being addressed by the individual protection standard under consideration is the hazard to human health, in the far-future, associated with exposures to 350 mrem . Are these health affects hypothetical? The answer the EPA must give to this question is "No. These health affects are no more hypothetical in the future than they are in the present. Radiation sciences, including radiation epidemiology, provide us with an understanding of the health affects of exposure to radiation. We base our protection standards in part on this work. This knowledge is frozen in time by other parts of the EPA rule (40 C.F.R. 197.15). The EPA presumes that the human living in the far future is similar to the human living in the present and near-future. Without this assumption, the EPA task of establishing individual protection standards would be impossible to accomplish beyond a few generations.

15. If the far-term hazards from radiation exposure to human health are no more hypothetical than those to the present and near-term generations, what other meaning could be given to near-term hazards so that the idea that the Chain of Obligation Principle supports the creation of a multiple dose standard in which far future generations would receive less protection?

It is possible that what the nuclear waste community means by near-term hazard is the hazards to human enterprises if a repository were not licensed, opened, filled, and closed within the next 30 years. In other words, a near-term hazard would be the risks associated with not being able to license and operate a nuclear waste repository in the very near future. But there are multiple problems with such an approach in this rule making. First, it would be a pure guess to say this is the near term hazard EPA has in mind in applying the principle. Second, even assuming it is, EPA offers us no specific estimate of what the magnitude of this hazard might be, let alone any supporting evaluation, on which one could comment. Third, it is certainly not a given in any event that the near term hazards from failure to have a repository in the next thirty years or so would counterbalance the hazards from Yucca, considering that large quantities of spent fuel will be stored on reactor sites for many decades to come even if Yucca is licensed tomorrow, and that the duration of exposures to 350 mrem could be many hundreds of years, a much greater time that thirty years or so. Finally, we cannot assume 350 mrem is necessary to avoid a failure in the repository program unless we assume the program consists only of Yucca mountain and Yucca Mountain will fail if there is a stricter standard. But this would mean the whole EPA rule begs the question of the safety of Yucca.

In any event, the Chain of Obligation Principle used by EPA would not apply in this analysis because we are not comparing hypothetical and non-hypothetical (or concrete) hazards.

16. Since the hazards to future as well as present generations are not hypothetical, how would ethics justify the preference of the present over the future?

What we are being asked to consider is this question: Is it ever fair or just to act differently toward far- future generations than we do toward present and near-future generations?

There are at least two traditions in ethics which provide answers to this question: the egalitarian tradition (related to a deontological approach to right/wrong, wherein some feature of the act itself and not its consequences, determines right and wrong actions or just and unjust policies; and the 2) the consequentialist tradition (related to a utilitarian approach and often reduced to RCBAs, wherein the consequences of the act or policy, such a risks, benefits, and costs, determine right and wrong action or just and unjust policies.

For egalitarians, equity or fairness is a moral concept of right proportionality. Equity does not simply involve treating persons equally, but rather *treating like persons alike. Equity allows us to treat persons differently if there are relevant differences between them, but it enjoins us not to discriminate where there are no such differences.* Hence, equity requires consistency of treatment. We would be charged with discrimination if we had no good moral grounds for doing otherwise. We must look to certain features of the persons or generations in question to determine if those features change the nature or strength of our moral duties.

Future generations are not yet living; they do not exist. Specific persons may never come into existence since our present actions affect the future. We do not know what they will be like. Some ethicists (egalitarians and consequentialists alike) have argued that all these features, i.e. the non- existence of future humans, which specific humans will exist, their DNA structure, and their abilities to withstand disease, affect our obligations to future persons. They, in fact, establish that future persons have NO moral worth. These time-dependent features of future humans are exactly the reasons why ethicists in both traditions have sometimes argued strongly *against* the position that we have obligations to future generations. A quite large and serious scholarship exists which asserts we have NO duties to the future. For these thinkers, our duties to present humans *always and in every case* trump any duty we think we might have to future generations. These time-dependent features of future persons do not merely weaken any belief we have in obligations, they erase them. It is extremely important to point out that, as explained above, this position is not a viable one for the EPA to hold in defending its multiple-dose individual protection standard

17. Does this mean that if we assert we have duties to future generations, they will always be of the same strength as our duties to present persons or near-future generations?

No. The strength of our duties can differ. Unfortunately, the EPA's gloss of the scholarship in this field fails to allow them to understand the depth and complexity of the issues at hand.

To begin, the EPA asserts that "...there is no clear consensus regarding the extent of the claims held by the future on current generation (i.e. how many generations should be considered, how to compare their interests to those of the current generation, or what it means to 'compromise' their ability to take action.)" (EPA, p. 49036). This is an exaggeration and come close to building one's position on the *ad ignorantium* fallacy.

Instead, what one finds in the scholarship on intergenerational equity is agreement over some important distinctions that are not introduced by the scholarship in the NAPA report, the KASAM report and Chapman and McCombie. Those distinctions concern the difference between basic needs and welfare interests. It is this distinction that is used by both egalitarian and the consequentialist tradition. (In the scholarship, this distinction is often cast as basic human rights and welfare rights; however, the EPA Proposed Rules avoids language about the rights of future generations. I infer that they adopt the non-correlativity thesis regarding rights and duties, i.e. while legitimate rights beget legitimate moral (and legal) duties, legitimate duties exist without having to assert legitimate corresponding rights claims of non-existent persons. This lack of correlativity, by the way, is another reason why some ethicists assert we have no duties in the present to future generations).

Basic needs concern human survival (life) and health. Welfare interests are associated with the quality of life. Much of the concerns taking up in environmental ethics about intergenerational equity are related to welfare interests, i.e. in insuring a biodiverse world, in protecting environmental resources from depletion so that they may also be used by future persons, degrees of robust sustainability, etc. This is why the evolution in thinking in the received, peer-reviewed scholarship has turned to the provision of future opportunities and compensation for the lost of opportunities rather than the provision of specific resources. (DesJardins, p. 82) The emphasis on sustainability of resource utilization and trusteeship of the environment represents these concerns.

But, in the issue at hand, the EPA's proposed rules affect basic needs—preservation of life and protection of human health. It is sometimes the case that a present basic need will conflict with a future welfare interest. There is some agreement that basic needs of persons in the present trump future welfare interests if there are no alternative ways in which the basic need can be met. This fact of insuring that no alternatives are available is another moral trumping card even when basic needs in the present and the future are in conflict.

In applying this carefully to the issue at hand, the ethicist would want to know if the conflict is between 1) a present basic human need and a future human need; if so, this presents us with a moral dilemma , a truly thorny and complex ethical situation to confront, 2) a present welfare interest (often termed "wants") and a future basic human need, 3) a present basic human need and a future welfare interest, or 4) a present welfare interest and a future welfare interest. The nature of the interest will determine the how best to resolve the conflict. A determination must be made about the viability of alternative courses of action.

The grid below displays this conflict-resolution scheme:

Grid 1

Present Persons have:	Future Generations have:	Resolution
Present basic human need (need)	Future basic human need (need)	A moral dilemma which needs dissolution; dilemmas are, in principle, irresolvable
Present welfare interest (want)	Future basic human need (need)	Future trumps present
Present basic human need (need)	Future welfare interest (want)	Present trumps future
Present welfare interest (want)	Future welfare interest (want)	Present may trump future in some hierarchy of wants.

18. Using Grid 1, what must the EPA prove in order to better establish their ethical claim that it is morally permissible to require multiple dose standards in which less protection is given to future generations?

In the analysis above, the EPA must show that there are only welfare interests at stake to the future generations and that future generations' basic needs are not threatened; at the same time, they must show that basic human needs are at stake for present persons. However, if basic human needs are also at stake for future generations, we have a moral dilemma. A moral dilemma presents us with an apparent conflict between our moral duties, whereby following one transgresses on the other. A common way of handling a moral dilemma is to show that it doesn't really exist by dissolving one of the "horns of the dilemma." This is how some ethicist would handle the problem at hand, i.e. by denying that we have moral duties to future generations or by pointing out that perceived needs are really only wants. Another approach is to show that a proposed resolution, although not ideal is the greater of two goods or the lesser of two evils. In this instance, assuming present the present basic need for life and health conflicts with the far future basic need for the same, minimally, the EPA must clearly demonstrate that there is no feasible alternative to Yucca Mountain in order to override the basic needs of future generations to meet the basic needs of persons living in the present.

Finally, if only welfare interest are at stake for present persons, i.e. their life and health is not threatened but their interest in providing renewed energy resources is in jeopardy, the EPA would need to demonstrate that no life or health of far future generations are threatened. Grid 2 below represents the application of Grid 1 above:

Grid 2

Present Persons have:	Future Generations have:	Resolution
Basic human need to ensure equal protection of life and health from radiation exposure from HLNW at reactor and other sites	Basic human need to ensure equal protection of life and health from radiation exposure from breached nuclear repository	If there is no viable alternative to Yucca Mountain (if it cannot provide protection for both present and future generations), we have some hard choices to make for which there are no easy "principled" or "trumping" resolutions.
A welfare interest in promoting nuclear energy as a viable energy source for present persons.	Basic human need to ensure equal protection of life and health from radiation exposure from breached nuclear repository.	A multiple dose standard for the far-future generation **is not morally permissible.** Current welfare interests do not trump future basic needs.
Basic human need to ensure equal protection of life and health from radiation exposure from HLNW at reactor and other sites	A welfare interest only in promoting optimization of energy resources	A multiple dose standard that weakens the standard for the far-future generation **is permissible.**
A welfare interest in promoting nuclear energy as a viable energy source for present persons.	A welfare interest only, in promoting optimization of energy resources in the future	Present may trump future

A moral dilemma is represented by Row 1 above. Which "row" best describes the issue at hand is not merely a matter of interpretation or "words." Empirical evidence needs to be offered in support of the claims made in the relevant cells.

19. **The EPA appeals to the KASAM State of the Art Report (1998) in which the assertion is made that because of increasing uncertainties "...our capacity to assume responsibility changes with time. In other words our moral responsibilities diminish on a sliding scale over the course of time." Chapman and McCombie also argue that time and uncertainties reduce our duties. What is wrong with this approach of coupling time with uncertainty to establish a reduction in duties?**

No argument has been given by the EPA for why time alone weakens our duties to future generations. Chapman and McCombie, borrowing from economics, give credence to the use of discounting future interests in favor of present interests. (Chapman and McCombie, p. 53). Discounting takes account of the effect of time on the economy; analogically, the moral argument is to allow time to have its effect on our moral duties to future generations, thereby reducing or weakening them over time. However, there is widespread agreement among environmental economists and ethicists that discounting future generations interests, merely because they will live at a different time, is severely limited. . In fact, even the NAPA panel report (NAPA, Appendix B, p. 33) points this out. (Here, EPA has used sources which conflict with each other on this issue.)

The work of John Rawls, cited in some of the scholarship used by the EPA to support their Proposed Rules, would also deny the moral relevance of time in weakening our duties to future generations. For Rawls, the Original Position is not limited in time. Rawls says, "Now the contract doctrine looks at the problem from the standpoint of the original position. The parties do not know to which generation they belong or, what comes to the same thing, the stage of civilization of their society. They have no way of telling whether it is a poor or relatively wealthy, largely agricultural or already industrialized, and so on. The veil of ignorance is complete in these respects." (Rawls, p. 287). No future generation is more important than another as justice has no time preference. "The life of a people is conceived as a scheme of cooperation spread out in historical time. It is to be governed by the same conception of justice that regulates the cooperation of contemporaries. No generation has stronger claims than any other" (Rawls, p. 289). Each generation is obligated to save for the next (in terms of welfare) and each generation is obligated to maintain the same democratic institutions over time. Rawls points out, "We can now see that persons in different generations have duties and obligations to one another just as contemporaries do. The present generation cannot do as it pleases but is bound by the principles that would be chosen in the original position to define justice between persons at different moments of time. In addition, men have a natural duty to uphold and to further just institutions and for this the improvement of civilization up to a certain level is required...The original position is so defined that it leads to the correct principle in this respect...In the case of society, pure time preference is unjust: it means (in the more common instance when the future is discounted) that the living take advantage of their position in time to favor their own interests." (Rawls, p. 293 - 295)

We have seen above (13d) that uncertainties about the future that may be associated with time do not apply in this case and, therefore, do not provide a firm moral basis for weakening or reducing our duties to future generations.

20. Shouldn't uncertainty play some role in the moral life, in being ethical, and in creating ethical public policies?

Yes, it should. The authors of the KASAM report may, in fact, be correct in claiming that "increasing uncertainties means that our capacity to assume responsibilities changes with time." (KASAM, 1998, p. 27) However, a reduced capacity does not lead to the conclusion that "our moral responsibility diminishes on a sliding scale over the course of time." (ibid.) This distinction between ***capacity to assume or perform a duty*** and ***the strength of the duty itself*** is a significant distinction, overlooked by KASAM. The strength of duty itself remains the same, but the capacity to fulfill the duty may justify the shifting of the duty, in this case, from present generations to future generations if capacity increases by virtue of certain uncertainties decreasing with time.

In this case, uncertainties in repository performance are relevant to the question: *Who* has these responsibilities to future generations if current persons lack capacity? In other words, if uncertainties over time affect our *capacity* to ensure that an equivalent level of protection is met by a repository at a given site, and we have no alternative but this site (e.g. no other rock body can give us the assurances we need for the entire period from post-closure to peak dose period), then how can this responsibility to future generations be met?

Our *capacity* to assume those duties may, indeed, differ over time. Near and far future generations may be able to perform the duties better than we can in the present. They may have new technologies, reduced uncertainties, and expanded knowledge that time affords. Hence they may be able to do a better job of protecting human health in the future. The concept of the "rolling present" represents the fact that we transfer our duties over time; it does not represent the fact that we reduce them or weaken them because of uncertainty associated with time.

The concept of the "rolling present" emerged in the nuclear waste community as they were dealing with concerns that permanent reposition of nuclear waste did not leave open the ability to act on the solutions that the future might hold. If we cannot construct repositories now that will provide the same standard of protection to future generations as we provide present persons, then the rolling present allows us to transfer duties, along with resources and knowledge, without disenabling present persons or harming future generations.

A similar concept was introduced by John Rawls in order to help understand that our duties to future generations will need continuity over time. Others have introduced this concept of ensuring continuity in fulfilling our obligations, including the work cited in the KASAM report by Lars Ingelstram which calls for *an institutional constancy.* (KASAM, 1998, p. 25) KASAM states, "The question, Ingelstram argues, then becomes one of whether or not it is possible to bridge the time interval, or discover a link between the present and the future so that the comprehensibility and credibility can be preserved even for complex socio-technical systems designed to function for an extended period of time where we have no possibility to demonstrate that they will function as planned on the basis of the demands we make for long-term safety. Ingelstram claims that this link is *institutional constancy* by which he means the necessity to build in control mechanisms in society's institutions to continuously test to see if promised results are achieved." (p. 26).

KASAM points out that geologic disposal has been thought to provide the stability needed to protect human health from radiation exposure due to a repository breach. Not too long ago the nuclear waste community found this appeal to obligations to future generations both morally praiseworthy and politically effective. However, as we come closer to realizing the complexities and uncertainties associated with repository performance, unless alternative sites and alternative engineering is available to restore such stability, we have shifted to a concept of "the rolling present" that is thought to displace some of our obligations onto the future. As I pointed out in No. 13 above, the EPA is not empowered to respond to the demands for institutional constancy required by a rolling present.

In an earlier report by the Alternative Group in Sweden, this idea of a rolling present surfaced but it was coupled with a warning that this would require a new way of approaching the regulatory requirements for nuclear waste disposal. In this same publication, the question of how long the present rolls is raised. The response points out that it is a phenomenon which, in practice, began when the first reactor was created and ends when an irrevocable decision is made, most likely when the repository closes and the waste becomes difficult to retrieve. Swedish citizens are asked to contemplate "which decisions can with a rolling present be left to future generations and which decisions are they qualified to make in the near future." (Nilsson, p. 32.) This demonstrates the lack of fit of this concept for the EPA's task at hand. The EPA is not authorized to delay the decision on protection standards and the multiple dose standard they propose does not reflect the need for a rolling present.

To be clear, were a shift in the locus of moral responsibility needed, it does not change the strength of the moral duty we have to provide equal protection to individuals from harm (no matter how "negligible") to their basic need for health. As Richard Howarth points out in his article "Intergenerational Justice and the Chain of Obligation," the links made among succeeding generations are equally strong. Our link to the children of today, a presently living but nevertheless different generation than our own, is just as strong as the subsequent links made between our children and theirs, and their children's children and the children of these children's children and so forth. The strength of the link doesn't weaken merely because they live later in time from us. They bear the same strength in the link between the succeeding generation and theirs. Our place in the chain doesn't weaken their link (i.e. their duties).

If we believe *our* children should be exposed to no more that 15mrem/a, there is no reason for us to think and act in such a way that our distantly-related generations should not also be exposed to no more than 15mrem/a. Why would the child who lives on January 1, 10,001 be entitled to less protection than our children today? What we believe to be just in our relations to our contemporaries should be extended to define standards of just distribution between generations. "To the extent that principles of justice require equal treatment for contemporaries, they require equal treatment for future generations as well" (Howarth, p. 135). The chain of obligations does not weaken our duties to future generations; it does just the opposite: it establishes those duties as equally strong across generations

Understanding this comes from untangling the distinction between our **capacity to fully assume our duties** and **the strength of the duties themselves**. These two aspects of the moral life must not be confused with each other.

21. The EPA Proposed Rules lists three gradations of principles of justice: strong, weak, and minimal. What is wrong with thinking that we can apply a "Strong Principle of Justice" a "Weak Principle of Justice" and a "Minimal Principle of Justice" to the various time periods from post closure to peak dose and associate differing standards of protection to such time periods?

These principles of justice are relatively unfamiliar. They are not found in the scholarship of American ethicists or scholars of social justice. Nor are they found in the reference cited by EPA. A document search of Philosopher's Index, which indexes all the major and minor journals from the present backward, revealed no scholarship with titles or abstracts using these three principles. A "Google" search also came up with no results for this combination of strings. The expression 'minimal principle of justice' is common in justice scholarship but it only refers to the principle "Treat like cases alike." After considerable search, this distinction was finally found buried in the third chapter of Mikael Stenmark's *Environmental Ethics and Policymaking* (Studentlitteratur, 2000) originally published in Swedish and recently translated into English (by Ashgate Press, 2002).

The EPA adopts these principles from a later KASAM report (2004). In Chapter 9 of this report, which is coauthored by Stenmark, his four principles are introduced. His purpose, in Chapter 3 of the earlier work, is to explain just sustainability.

> Static Principle of Justice: *We have a moral obligation to pass on to subsequent generations the same quantities and type of natural resources that our own generation inherited from previous generations.*
>
> Strong Principle of Justice: *We have an obligation to use or consume natural resources in such a way that subsequent generations can be expected to achieve a quality of life equivalent to ours.*
>
> Weak Principle of Justice: *We have a moral obligation to exploit natural resources in such a manner that not only the present generation but also future generations can satisfy their basic needs (i.e. need for food and water, protection against weather and wind, and access to work, health care, and education.*
>
> Minimal Principle of Justice: *Intrusion into the natural order of things is a human right. However, we have a moral obligation to exploit or consume natural resources in such a way that we do not jeopardize future generations' possibilities for life.*

These principles of justice are placed on a spectrum, which "is based on a scale which deals with the consequences of the present generations' patterns of consumption and use of natural resources. Certain principles of justice would – if applied consistently – result in radical changes in our consumption patterns and use of natural resources." (KASAM, 2004, p. 433)

Arguing that we have a diminishing moral responsibility, the authors clarify this to mean the following: "Our main thesis is that we should have a more extensive duty towards generations in our immediate future – and apply the strong principle of justice – and a more limited duty toward distant generations – and apply the weak principle of justice" (p. 436). Then, they ask, why in the very far future do we need only apply a minimal principle of justice? Changing over from one principle to another on this spectrum is justified by the "lack of ability to assess or influence, in a reliable manner, the needs that those generations will have in terms of energy, transport, housing, education, etc." (436).

These principles are mapped onto a timeline and in turn applied to the disposal of nuclear waste. The static principle, rejected by the authors, would not allow any disposal to take place—and would most likely not have allowed the intrusion into nature in the first place to extract uranium for the production of nuclear energy, which ultimately produced the waste. At the other end of the spectrum, the minimal principle of justice is mapped to the very far future.

Whether this "spectrum approach" to just sustainability and its mapping onto time is defensible is a matter for scholars of environmental ethics and other scholars to explore. However, whether its subsequent application to the nuclear waste issue ***in the way used by the EPA*** holds up under critical scrutiny is highly doubtful, given the discussion above. The EPA states "In the case of spent fuel disposal, these considerations lead to the idea that a repository must provide reasonable protection and security for the very far future, but this may not necessarily be at levels deemed protective (and controllable) for the current or succeeding generations."(EPA, p. 49036) This statement does not follow from any one of these principles. We must conclude that the principles in the KASAM Report (2004) do not support the creation of the multiple dose protection standard proposed by EPA. This is because, as we have said above,:

1. We do not lack the ability to assess the needs of future generations regarding protection from radiation (unless we want to stipulate either ignorance of or changes in human physiology, genetic structure, etc. which EPA is unwilling to make).

2. EPA protection standards are not about welfare interests in energy, transport, housing, education. They are about the most basic, fundamental interest a human has--in his/her preservation of life.

3. The multiple dose protection standard proposed by the EPA jeopardizes future humans' possibilities for life. We know that 350 millirems will provide less protection and greater risk of deaths in the future than 15 millirems will in the present. Hence, the multiple dose standards are not even justified by the minimal principle of justice.

4. The multiple dose protection standard proposed by the EPA is, in fact, "off the map" or one that lies outside the spectrum of these 4 principles.

5. The multiple dose protection standard proposed by the EPA is supported, instead, only by the very position rejected by the KASAM Report (2004), i.e. Andrew Kadak's view that "we have an obligation to protect future generations provided the interests of the present and its immediate offspring are not jeopardized." (KASAM, p. 432). The KASAM authors point out that "even the weak principle of justice does not allow us to prioritize all our interests without further ado. According to the weak principle of justice, the basic needs of future generations take precedence over the current generation's interest, which extend beyond our basic need for work, food, energy, housing, health care, and education. (ibid.). This comparison of basic needs and interests is provided above.

22. Do these principles, in their original formulation, support the EPA's Proposed Rule?

First, it is important to point out that these principles are intended to apply to the ethics of sustainability and, in particular, the just allocation of resources across generations. The EPA Proposed Rule is not about sustainability, except in the very narrow sense of sustaining the life and health of future generations. Work by ethicists on sustainability concern much broader issues, such as increased population and increased consumption. Stenmark's principles attempt to justify the different duties we have to provide these resources to differently situated generations in time.

Second, if pressed to apply these principles to the question of radiation standards of protection of human health and life, one must conclude that these principles would not support a multiple dose standard that would put far future generations at greater risk than present ones. This is simply because the most minimal of principles can be interpreted, as Stenmark himself does in the concluding paragraph of his original work, as follows:

> 'Without compromising the ability of future generations to meet their own needs' can imply that they should be so equipped...that at least they can ensure their survival: in other words, we do not expose them to radioactive radiation or radioactive waste, dramatic natural catastrophes, or severe alterations of climate (Stenmark, p. 56)

From this, it is doubtful that any of these principles, even the one that provides the barest standard of sustainability (Stenmark's minimal principle of justice), would actually support different standards of protection of life and health, i.e. allow greater risk to the far future than to the present and near future.

23. What should the EPA have provided in 40 C.F.R. 197 in its discussion of intergenerational equity?

In order to gauge the social acceptability of a particular expression of intergenerational equity through its comment period, the EPA **needed to have followed the NAS Committee's recommendation more closely and *also* addressed whether future generations should have *greater* or *equivalent* protection.** The reader is only able to *infer* from the 40 C.F.R. 197 that society does not have a greater or equivalent duty to future generations but he or she has not be offered good reasons to accept this inference.. Unfortunately and without intending it , in 40 C.F.R. 197, the EPA's examination of this matter comes perilously close to "cherry picking", i.e. mustering only those arguments to support the lesser duty, albeit from scholarship provided by entities with vested interests in solving one of this nation's most challenging environmental issues. This approach does not tell the reader *why* the duties are not greater or equivalent. A more balanced approach to the EPA's proposed rule-making and one clearly recommended by NAS (NAS, 1995, p. 56) , would have been to also muster arguments in support of the other two positions and then explain why the "lesser duty position" is morally preferable.

Again, this is especially important not because there is controversy about this matter. The two unexamined positions of equivalent or greater protection are more strongly held by members of society. The moral intuition of most persons (and replete in the literature) is that if uncertainty surrounds a situation of potential risk to something as basic as life and health from radiation exposure or if future persons must bear risks with only indirect benefits, it is best to provide greater or equivalent protection, *not less protection*. These more commonly accepted societal expressions of intergenerational equity were not addressed. The EPA proposal is lacking in this regard in 40 C.F.R. 197.

24. What are the ethical problems with using Chapman and McCombie's approach that we should return to nature for standards in the long term?

EPA refers to these authors to support the view that natural background radiation levels should be normative for determining standards in the long term. These authors support their position with the following reasons:

1. "...there is a strong case, based on the parallel with nature, on society's real expectations and on sensible use of resources for saying that we have done enough." (p. 114)

2. "There is no logical or ethical reason for trying to provide more protection than the population already has from Earth's natural radiation environment in which it lives and evolves." (p. 114)

3. "It is a scientifically tenuous position to argue that additional protection (e.g. down to a few microsieverts of exposure) can be provided so far into the future and that this can be ensured by regulations." (p. 114)

Having listened to the nuclear waste community for decades, I know full well how difficult it is for some of its members to see that the appeal to nature is, first and foremost, logically problematic because it commits a fallacy. This fallacy rests on the fact that, (as I mentioned above in connection with an appeal to a "natural tendency" in moral psychology), it illicitly attempts to derive "ought" from "is." What is missing is a defense of the enthymatic (suppressed) premise "Nature is good" (or in this case, 'Exposure to radiation from natural background is good.')

But the argument presented by Chapman and McCombie has further problems. The first reason above is nothing more than *ad populum* or an appeal to popular beliefs, assuming that this belief is indeed true, i.e. that society does not expect regulations to provide greater protection from radiation than what we receive from the natural background. There is, of course, very good reason to believe that society has not assented to this level of radiation. Numerous radiological protection standards which set limits below natural background exist. Additionally, there is considerable difference between measuring society's expectations by what it lives with out of ignorance, unintentionally, or passively, and measuring society's expectations by its intentional, active acceptance, through referendum, or some other means for assessing its expectations.

This argument is similar to the one discarded by environmental ethicists, that persons actively assent to certain beliefs over others through the market place and therefore, we have no obligations to our environment other than those reflected in purchasing patterns. This collapses an important distinction between person as consumers, acting from certain desires and persons as citizens, operating on certain beliefs. (Sagoff, 1990)

The second reason is simply false. As I've already pointed out there are both logical and ethical reasons for trying to provide more protection than we already have from Earth's natural radiation environment. Not only is the argument fallacious (and therefore, illogical) but also humans' interest in protecting their health and improving it are supported by the principles of non-malfeasance and beneficence.

The third reason introduces a straw man. The regulation proposed (15 mrem/a) does not place undue burden on science for at least up to 10,000 years. Whether it does so for the repository at Yucca Mountain beyond 10,000 years does not mean that it would do so for all potential repository sites.

25. Notwithstanding the above comments on problems with setting a multiple dose standard that differs for present, near future and far future persons, the EPA set the individual protection standard for far-future generations at 350m/rem/a. How would it know if this expression of intergenerational equity is socially acceptable?

The EPA assumes a responsibility of significant proportions by trying to set a radiation protection standard that reflects the judgment of society regarding intergenerational equity. In doing so, not only does it have the attendant responsibility to consider whether future generations should receive more, less, or equivalent protection, but it also must have some **clear criteria** (absent a national referendum) for determining which expression of intergenerational equity is socially acceptable and it must translate that expression into a radiation protection standard. "Societal acceptability means that decisions are justified by agreed criteria and procedures for decision making." (NAS/BRWM Committee on Disposition of High-Level Radioactive Waste through Geological Isolation, "Disposition of High-Level Waste and Spent Nuclear Fuel", 2001)

* * * * * * * * *

In conclusion, justice and fairness requires that we begin with the presumption that present, near and far future generations all deserve equal protection to a basic need such as health and life; our duties to them are equally strong; equality establishes equity in this case. If we want to claim differently, i.e. that they are stronger to some generations than to others it must be because of a morally relevant difference to secure equity. For example, NAS suggests that direct benefit accrual is one such difference. Even that has to be justified with good argument—it should not be simply asserted. Moreover, if one's duties are weak to some generations but not to others, then a morally relevant difference must be identified and justified. It is the well-reasoned view that will ultimately win social acceptability. Despite the valiant attempts to use the scholarship in ethics found within the nuclear waste community, for the many reason cited above, we haven't been presented with a well-reasoned position in the EPA Proposed Rules of August 22, 2005.

Bibliography

Barry, Brian. "Intergenerational Justice in Energy Policy" in MacLean And Brown, eds., *Energy and the Future*, pp. 15-30.

DesJardins, Joseph R. *Environmental Ethics: An Introduction to Environmental Philosophy*. Belmont, CA: Thomson Wadsworth. 4th Edition, 2006.

Disposition of High-Level Waste and Spent Nuclear Fuel, NAS/BRWM Committee on Disposition of High-Level Radioactive Waste through Geological Isolation, National Academy Press, 2001.

Environmental Protection Agency. 40 C.F.R. PART 197 [OAR-2005-0083; FRI] [RIN 2060-AN15] PUBLIC HEALTH AND ENVIRONMENTAL RADIATION PROTECTION STANDARDS FOR YUCCA MOUNTAIN, NEVADA. AGENCY: Environmental Protection Agency. ACTION: Proposed Rule. August 19, 2005; August 21, 2005. Washington, D.C.: Government Printing Office.

Deciding for the Future: Balancing Risks, Costs, and Benefits Fairly Across Generations. A Report by a Panel of the National Academy of Public Administration [NAPA] for the U. S. Department of Energy. Washington, D.C.: NAPA, June 1997

Chapman, Neil, and McCombie, Charles. *Principles and Standards for the Disposal of Long-lived Radioactive Wastes*. Waste Management Series, Vol. 3. Amsterdam: Pergamon, 2003

Howarth, Richard B. "Intergenerational Justice and the Chain of Obligation", *Environmental Values* I, #2 (7/1992), 133-139.

KASAM. Nuclear Waste: state-of-the-arts report. Stockholm, Sweden, 1998.

KASAM. Nuclear Waste: state-of-the-arts report. Stockholm, Sweden, 2004.

Nilsson, Annika. Responsibility, equity and credibility: ethical dilemmas relating to nuclear waste. Stockholm, Sweden: Kommentus, 2001.

Rawls, John. *A Theory of Justice* . Cambridge, MA.: Belknap Press of Harvard University Press, 1971.

Sagoff, Mark. The Economy of the Earth. New York: Cambridge University Press, 1990.

Stenmark, Mikael. *Environmental Ethics and Policy-making*, Stockholm, SE: Studentlitteratur, 2000, translated by Ashgate Press, 2002.

Technical Bases for Yucca Mountain Standards. Committee on Technical Bases for Yucca Mountain Standards, Board on Radioactive Waste Management, National

Research Council. Washington, D.C.: National Academy Press, 1995.

Weiss, Edith Brown. *In Fairness to Future Generations.* Tokyo: The United Nations University, 1988, and Dobbs Ferry: Transnational Publishers, 1989.

Biographical Information

Dr. Patricia Ann Fleming is a professional philosopher by training with a specialization in applied ethics and philosophy of science. (M.A. and Ph.D. from Washington University, St. Louis). She teaches Environmental Ethics regularly at Creighton University and is the Senior Associate Dean of the College of Arts and Sciences. Dr. Fleming publishes and lectures nationally and internationally on the ethical and epistemological issues associate with high level nuclear waste disposal. Her familiarity with the many ethical and epistemological issues of HLNW disposal spans the period from approximately 1979 – 2005. She has participated in VALDOR and is a board member of VALDOC and has been performed the functions of a thematic rappatouer for the NEA/OECD Forum on Stakeholder Confidence in Ottawa, Canada. This familiarity with ethical concerns regarding the health effects from radiation exposure led to her appointment on the NAS Committee to Assess the Scientific Information for the Radiation Exposure Screening and Education Program. She has recently been nominated to serve on the national Veteran's Board on Dose Reconstruction, established by Congress

Dr. Fleming has friendly acquaintances with individuals from "both sides of the aisle". These connections, necessary to accomplish her scholarship as an applied ethicist, do not prevent her from examining the issue below with impartiality. Dr. Fleming does not have a conflict of interest with either the State of Nevada or the Environmental Protection Agency.

Appendix E

Mike Thorne and Associates Limited

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External Memorandum

Date: 10 November 2005
From: M C Thorne
Subject: Climatic Considerations relevant to the Draft EPA Rule

The draft EPA Rule (page 49058 *et seq.*) gives consideration to how climate change should be represented beyond 10,000 years. EPA is 'concerned about the possibility of over-speculation of climatic change over such extremely long time periods, possibly out to the next 1 million years.' In support of its position, it cites the NAS Report (page 77) as stating:

'Although the typical nature of past climate changes is well known, it is obviously impossible to predict in detail either the nature or the timing of future climate change. This fact adds to the uncertainty of the model predictions.'

This is the beginning of a more extended commentary on the influence of climate provided in the NAS Report (pages 77 and 78). The paragraph immediately following that cited above is given in full below. The references cited are given in full in the NAS Report.

'During the past 150,000 years, the climate has fluctuated between glacial and interglacial status. Although the range of climatic conditions has been wide, paleoclimatic research shows that the bounding conditions, the envelope encompassing the total climatic range have been fairly stable (Jannik et al., 1991; Winograd et al., 1992; Dansgaard et al., 1993). Recent research has indicated that the past 10,000 years are probably the only sustained period of stable climate in the past 80,000 years (Dansgaard et al., 1993). Based on this record, it seems plausible that the climate will fluctuate between glacial and interglacial states during the period suggested for the performance assessment calculations. Thus, the specified upper boundary, or the physical top boundary of the modeled system, should be able to reflect these variations (especially in terms of ground water recharge).'

The NAS Report provides further discussion of the role of climate change at Yucca Mountain at pages 91 to 92. Three main potential effects of climate change on repository performance are identified. 'The first of these is that increases in erosion might significantly decrease the burial depth of the repository. Site-specific studies of erosion rates at Yucca Mountain (DOE, 1993b) indicate that an increase in erosion to the extent necessary to expose the repository (even over a million-year time scale) is extremely unlikely.' The third type of change that might result from climate change is a shift in the distribution and activities of human populations. However, this matter is addressed through the specified definition of the exposed group and is not considered further here. The second type of change relates to the flux of water through the unsaturated zone. The comments from the NAS Report on this matter are reproduced in full below.

'Change to a cooler, wetter climate at Yucca Mountain would likely result in greater fluxes of water through the unsaturated zone, which could affect rates of radionuclide release from waste-forms and transport to the water table. Little effort has been put into quantifying the magnitude of this response, but a doubling of the effective wetness, defined as the ratio of precipitation to potential evapotranspiration, might cause a significant increase in recharge. An increase in recharge could raise the water table, increasing saturated zone fluxes. There is a reasonable data base from which to infer past changes in the water table at Yucca Mountain. Although past increases under wetter climates are evidenced, a water-table rise to the point that the repository would be flooded appears unlikely (Winograd and Szabo, 1988; NRC, 1992; Szabo et al., 1994). Additional site characterization activities and studies of infiltration at Yucca Mountain should help improve estimates of the bounds of potential hydrologic responses to climate change. It should also be noted that the subsurface location of the repository would provide a temporal filter for climate change effects on hydrologic processes. The time required for unsaturated zone flux changes to propagate down to the repository and then to the water table is probably in the range of hundreds to thousands of years. The time required for saturated flow-system responses is probably even longer. For this reason, climate changes on the time scale of hundreds of years would probably have little if any effect on repository performance, and the effects of climate changes on the deep hydrogeology can be assessed over much longer time scales.'

The EPA Draft Rule (pages 49058-49059) reiterates and endorses the above comments and also includes a brief summary of the infiltration modeling undertaken by the DOE. It then states that the EPA believes that 'an approach should be developed to answer several basic questions about how climatological effects realistically will impact the proposed repository until the time to peak dose. The questions that concern us are:

1. How much total water will infiltrate into the repository over this large amount of time?
2. Will more water infiltrate the repository over time when modelled as a wave function (current DOE modelling) or as total average?'

The conclusions drawn by the EPA as to how these questions should be addressed are reproduced, in full, below from pages 49059-49060 of the Draft Rule.

'The answers to these questions assist in identifying conservative, yet reasonable, conditions the repository may encounter over the period of geologic stability. The amount of net infiltration into Yucca Mountain has an effect on the disposal system performance because higher net infiltration leads to the possibility that a greater proportion of the repository will experience ground-water seepage. For solubility-limited radionuclides in the waste, an increase in net infiltration could lead to a higher release rate of radionuclides from the disposal system, thereby affecting the potential dose to the RMEI in the accessible environment. We do not believe that it is important to know or predict with certainty precisely when the climate states with peak precipitation occur during the modeling. There are too many uncertainties and permutations available in trying to project a future set of climate conditions, and it is difficult to place specific times on when discrete pulses of precipitation should be injected into the modeling (NAS Report p. 77). Instead, we believe that it is reasonable to assume an average increase in precipitation over the entire time from 10,000 years through the period of geologic stability, and to model those consequences. An increase in average precipitation throughout the period of geologic stability is a more reasonable approach because it assumes a constant source of precipitation, creating more downward flow that will eventually reach the repository. This scenario need not be dominated by highs or lows in precipitation over the time period and does not require speculation about the exact timing or transient effects of shifts in climate. Rather, setting a constant value somewhat higher than today's average annual rainfall and extending it out to the time of peak dose would account for the greater potential for available fluids at the time of the failure of the waste packages. We believe that this approach provides a reasonable test of the repository conditions out to the time of peak dose, and will give a more conservative idea of potential fluid flow, as well as potential for migration of radionuclides out of the repository.'

'We are proposing today that DOE, based on past climate conditions in the Yucca Mountain area, should determine how the disposal system responds to the effects of increased water flow through the repository as a result of climate change. We believe that the nature and extent of climate change can be reasonably represented by constant conditions taking effect after 10,000 years out to the time of geologic stability. We are proposing to explicitly require that DOE assume water flow will increase as a result of climate change. We leave it to NRC as the licensing authority to specify the values to be used to represent climate change. However, we expect that a doubling of today's average annual precipitation beginning at 10,000 years and continuing through the period of geologic stability would provide a reasonable scenario, given NAS's statements regarding potential effects on recharge (NAS Report p. 92). NRC could also use the range of projected precipitation values for different climate states and specify a reasonable long-term average precipitation based on the duration of each climate state over the period of geologic stability. We believe that either approach will allow for a reasonable estimate of how water will impact the site without subjecting the assessments to speculative assumptions that may well be unresolvable, while providing a reasonable indicator of disposal system compliance. NRC might choose to express the ground-water flow effects directly as infiltration rates or other representative parameters, avoiding the necessity of translating precipitation and other climate-related parameters (e.g., temperature or evapotranspiration rates) into infiltration.'

The EPA comments reproduced above make two very broad assumptions about climatic and hydrologic behavior at Yucca Mountain. These are that:

1. Future climatic conditions at Yucca Mountain can be bounded by the observed range of conditions over past glacial-interglacial cycles;
2. Only long-term average responses of the system to changes in infiltration are of relevance.

We contend that neither of these conclusions has been adequately substantiated, but that both can be investigated using current and developing techniques that would command substantial support in the scientific community.

This memorandum does not address the response of the system to changes in infiltration rate in any detail. However, it is a characteristic of arid zone hydrological systems that hydrological response is highly non-linear. For frequent events, almost all of the precipitation that falls is subsequently lost to evaporation, so runoff and groundwater recharge are very limited. Extreme storm events occur infrequently, but tend to dominate runoff production and groundwater recharge. Therefore, inter-annual variability of precipitation leads to much greater inter-annual variability of runoff and recharge, and annual runoff and recharge can be dominated by a single large event.

The dominant effects of extreme events have been widely noted in the historical literature. For example, Drissel and Osborn (1968) reported for Alamogordo Creek in

New Mexico that 60% of a decade's runoff was produced in a single year. Osborn and Renard (1969) observed for Walnut Gulch, Arizona, that runoff from a single storm in 1967 accounted for more than 80% of the runoff for the year and 50% of the total runoff from a three year period. They noted that 'the exceptional events are extremely important in studies of water yield....'

For Yucca Mountain, Woolhiser *et al.* (1998), reporting to NRC, simulated runoff and channel infiltration for Solitario Canyon based on a generated 100 year precipitation series. They concluded that, depending on the parameters selected, between 16 and 24 events in the 100 years accounted for 75% of the runoff, and between 31 and 35 events accounted for 75% of the infiltration. Stothoff (1999) used a simpler modeling approach (a 1-dimensional soil model; see also Stothoff *et al.* (1996)), but also observed a highly nonlinear response of net infiltration to climate: 'The exponential response of net infiltration to climate change suggests that cumulative net infiltration may be underestimated unless perturbations in the climate cycle are considered.' The 1997 Unsaturated Zone Flow Modeling Expert Elicitation Panel (CRWMS M&O (1997)) felt that events occurring once in 10 or 20 years would dominate net infiltration.

Clearly, extreme events dominate hydrological response and any changes in extremes will have disproportionate effects on runoff and net infiltration.

By the use of appropriate hydrogeological modeling techniques, it is possible to evaluate the flow of water through both the unsaturated and saturated zones at Yucca Mountain under time-varying boundary conditions. Therefore, the issue of timescales of response of the system to changes in boundary conditions can be investigated directly and should not be considered to be either a matter of speculation or requiring prior prescription. Furthermore, it should be noted that the radiological impact of hydrological changes is not simply determined by the cumulative influx of water through the system, but by the influx on timescales comparable with those for water flow through the system. In a recent report to the EPA, S Cohen & Associates (2005, pages 2-8 and 2-9) has stated that:

> 'The percolation flux in the UZ [Unsaturated Zone] is not expected to be constant with time, but may increase episodically as a result of high-infiltration events, seasonal variations, and climate changes.
>
> Episodic flow events may affect seepage in two ways:
> (1) Episodic flow events lead to periods when percolation fluxes (and thus seepage rates) are greater than the corresponding average values.
> (2) Episodic flow events lead to transient effects (such as storage and hysteresis).
>
> UZ modeling handles temporally increased percolation fluxes by applying episodic-flow factors in a way similar to the flow-focusing factors (CRWMS M&O 2000e, Section 6.3.4). Currently, no evidence shows that high-frequency fluctuations (a few years or shorter) penetrate to the depth of the potential repository. Flow simulations have shown that the nonwelded PTn rock unit effectively damps out flow transients. The TSPA-SR analysis explicitly accounts for increased percolation from long-term transients (climate change).'

This citation does not rule out the potential significance of transient effects on groundwater flow through the unsaturated zone on timescales of more than a few years. Also, as noted by S Cohen & Associates (2005, page 8-1), 'transport time through the SZ

[Saturated Zone] for dissolved, nonsorbing, nonreactive radionuclides can be less than 100 years'. As the DOE considers that the water table is 'now at a low point in the 150,000-300,000 years climate cycle' (S Cohen & Associates, 2005, page 8-16), it seems more likely that transit times will decrease in future rather than increase.

Finally, on this point, we note that Figure 3.2.1-1 from Volume 2 of the SSPA (2001) (reproduced below as Figure 1) demonstrates that annual doses assessed using the TSPA can respond very rapidly to changes in climate. In a study in which the times of climate transitions were fixed for every realization, the changes in response arose almost instantaneously in nearly all those realizations. As a basis for interpreting this figure, it should be noted that, in the Extended Climate Model, there is no change in climate state from 2,000 years to 38,000 years, which is when the first glacial period (increased infiltration) is estimated to occur. The next glacial periods occurs at 106,000 years and 200,000 years. Glacial periods are 8,000 to 40,000 years in duration and recur approximately every 90,000 years, on average.

(a)

(b)

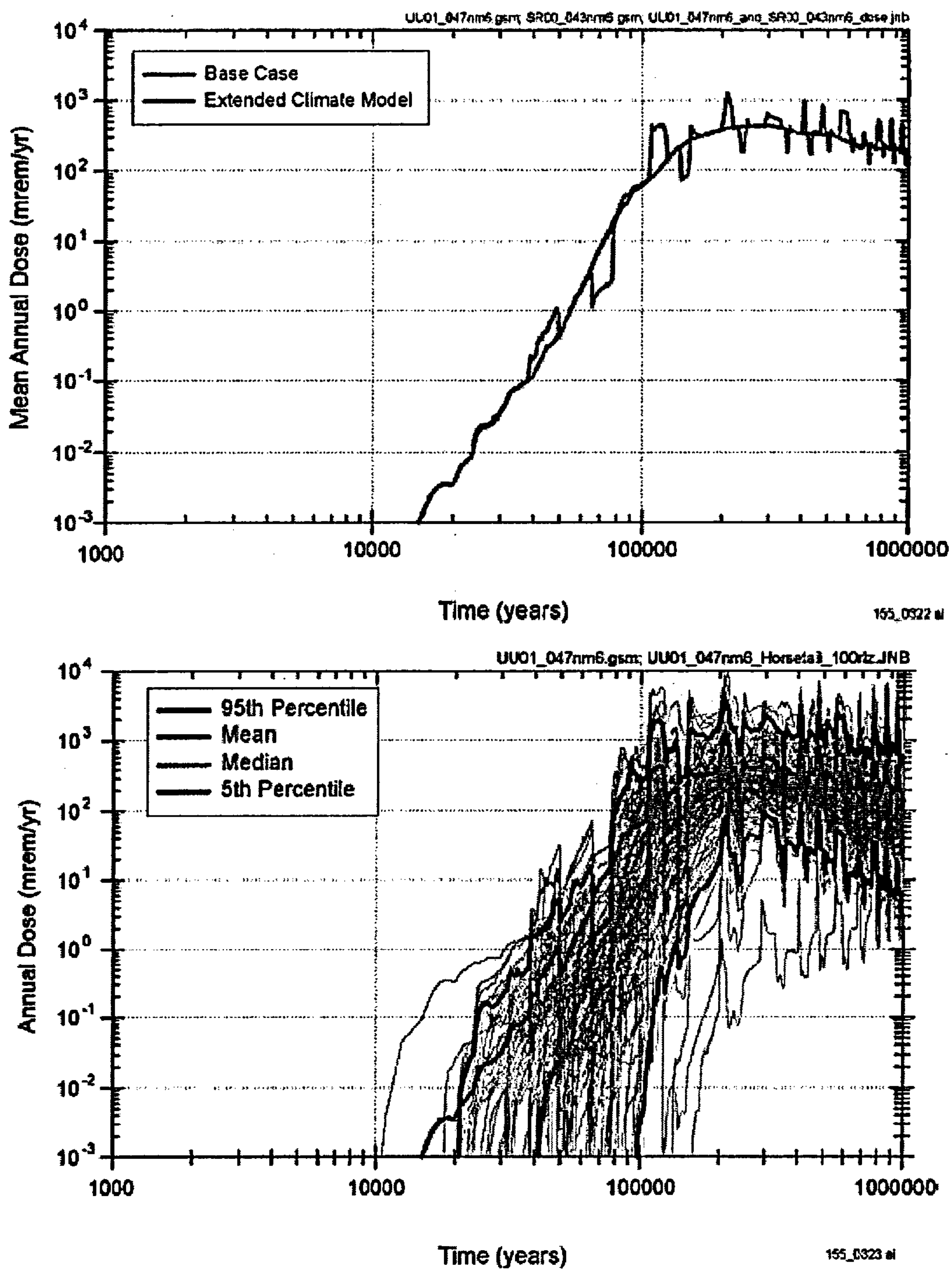

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Figure 1: Figure 3.2.1-1 from Volume 2 of the SSPA, illustrating Annual Dose Histories from the Extended Climate Model and the Base Case (The Base Case Model exhibits a constant climate state beyond 10,000 years, whereas the Extended Model exhibits climate transitions at specific times, as described in the text.)

Thus, the consideration arises as to whether the EPA Draft Rule has given adequate consideration to the range of future climate changes that could occur. The main issue that has to be addressed is the total lack of consideration of the potential for anthropogenically induced climate change due mainly to the carbon dioxide released as a consequence of the burning of fossil fuels.

Anthropogenic releases of carbon dioxide are generally considered likely to have long-lasting consequences for the carbon cycle of the Earth. Though other greenhouse gases, like methane or nitrous oxide, may have some influence on climate over the coming decades or centuries, only carbon dioxide has a lifetime in the atmosphere of many millennia. This is why understanding the evolution of atmospheric carbon dioxide concentrations is a top priority in climate change studies.

Systematic atmospheric measurements performed since the 1950s have demonstrated a very rapid increase in carbon dioxide concentrations, from about 320 ppm in the 1950s to nearly 380 ppm nowadays. This additional carbon has been unambiguously traced to arise from fossil fuel sources (Houghton *et al.*, 2001), and the now available long carbon dioxide history from Antarctic ice cores tells us that pre-industrial levels were approximately around 280 ppm, already a maximum value for natural carbon dioxide levels during the Quaternary (Petit *et al.*, 1999). There is now wide acceptance that these increased greenhouse concentration levels will significantly warm our planet during the 21st century and also almost certainly during the 22nd, depending on the availability of fossil fuels, on the economic choices made and on possible future technological breakthroughs in the production of cheap energy that does not rely on fossil fuel combustion (Houghton *et al.*, 2001). Currently, the focus of climate change research is on the future decadal or century scale, and more limited work has been performed on possible longer-term consequences. Furthermore, the available resources of fossil fuel are limited and, under most economic scenarios, would result in declining use in, at most, a few centuries. Is this anthropogenic carbon of significance when considering a very long-term future perspective? It is, because even though a large part of the fossil fuel carbon will, within centuries, be absorbed by the ocean, a non-negligible fraction, between 5 and 10% of the total amount, will remain in the atmosphere for a period measured in hundreds of thousands of years (e.g. see Archer *et al.*, 1997; Archer, 2005). Depending on the size of the anthropogenic perturbation, this remaining fraction could have a direct influence on the occurrence of future glacial-interglacial cycles.

The potential evolution of atmospheric carbon dioxide concentrations over the long-term and the associated implications for climate change have been investigated in the context of deep geological disposal of radioactive wastes in Europe in the BIOCLIM program (funded by the European Union and involving radioactive waste management organizations from the UK, France, Spain, Germany and the Czech Republic, as well as the UK Environment Agency and academic climate research centers from various countries).

In BIOCLIM, future variations in natural carbon dioxide concentrations in the atmosphere, i.e. excluding anthropogenic influences, were estimated using statistical regression techniques or a simple threshold model (BIOCLIM, 2001). This work was based on the extensive knowledge that has been developed over the last few decades on variations in atmospheric carbon dioxide concentrations that have occurred over the last few hundred thousand years.

Imposed upon these natural variations are the changes in carbon dioxide concentrations that arise from human activities, primarily the burning of fossil fuels. Future increases were estimated in BIOCLIM (2001) for two emissions scenarios (low and high), based on different projections of future fossil fuel use, combined with a model-based relationship between the amount of carbon introduced into the atmosphere as carbon dioxide and the time-dependent concentration of carbon dioxide in the atmosphere arising in consequence. The relationship used had components with atmospheric mean residence times of 3.65×10^2, 5.5×10^3, 8.2×10^3 and 2.0×10^5 years, so the long-term effects of fossil fuel combustion on atmospheric carbon dioxide concentrations were projected to persist for timescales corresponding to several glacial-interglacial cycles.

Finally, to define overall scenarios for future variations in concentrations of atmospheric carbon dioxide, the contribution from fossil fuel combustion had to be combined with the projected natural variations. As it was unclear whether the fossil fuel component would be subject to temporal modulation in the same way as the natural component, two different approaches to combination were used. However, comparison of the results obtained showed no strong distinction between the two approaches. Furthermore, there was also no strong distinction between the scenarios generated using the statistical regression and threshold models for variations in natural carbon dioxide concentrations (BIOCLIM, 2001). Therefore, only three scenarios were carried forward for detailed consideration. These all used the threshold model for variations in natural carbon dioxide concentrations and did not modulate the fossil fuel contribution according to variations in the natural concentration. These three scenarios were:

- Scenario A4: Natural variations only with no post-industrial, i.e. after 1850 a.d., contribution from fossil fuel combustion;
- Scenario B3: Natural variations plus a contribution from the fossil fuel scenario with low future utilization of fossil fuels;
- Scenario B4: Natural variations plus a contribution from the fossil fuel scenario with high future utilization of fossil fuels.

Both low and high utilization scenarios were consistent within known, economic resources of fossil fuels.

Results from this analysis for Scenarios B3 and B4 using both the summing and scaling approaches to natural carbon dioxide concentrations are shown in Figure 2. Although there is room for considerable variation in the choice of emissions scenario selected for study, as well as the approach adopted for combining natural and anthropogenically induced variations, the general conclusions from this work are thought to be reasonably robust. Specifically, atmospheric concentrations of carbon dioxide are projected to peak at 1000 to 2000 ppm, compared with a pre-industrial value of 280 ppm and a present-day value of 380 ppm, at about 300 years After Present (AP). They are then expected to decrease gradually, but not to fall to pre-industrial levels, on a long-term basis, until more than 300,000 years AP.

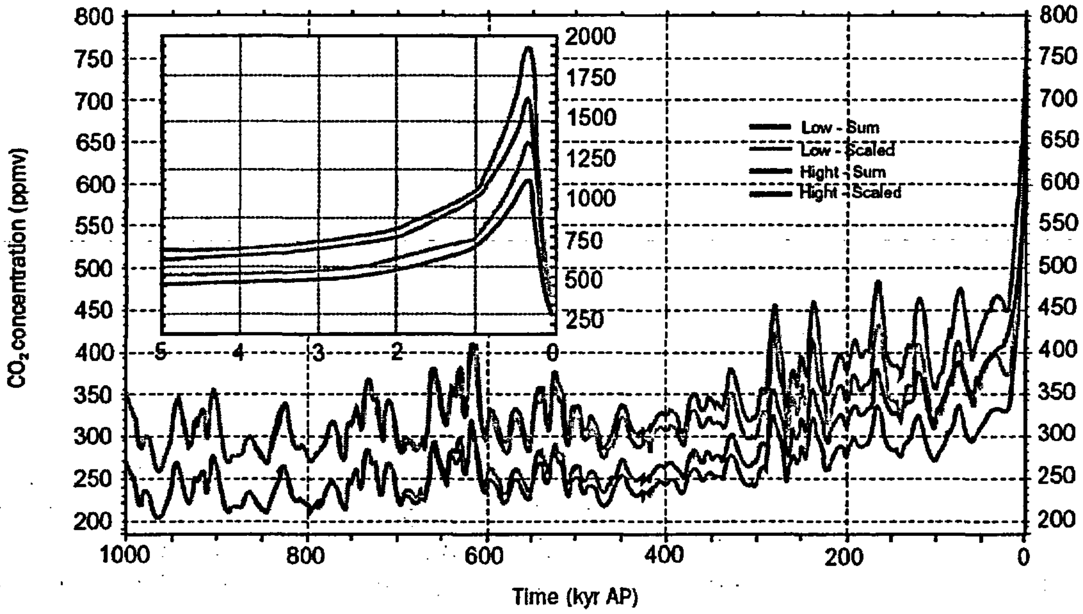

Figure 2: Atmospheric Carbon Dioxide Concentrations simulated in BIOCLIM. Reproduced from BIOCLIM (2001). Note that the time axis runs unconventionally from right to left and that kyr AP is thousands of years after present. The inset shows details of atmospheric concentrations over the next 5000 years.

In BIOCLIM, these scenarios were then used to investigate the potential range of long-term climatic conditions that could occur over Europe driven by both the changes in carbon dioxide concentrations and variations in insolation arising from changes in the orbital characteristics of the Earth (see, for example, Figure 3). The approach used involved the application of various types of climate model. Long-term transient simulations were undertaken, for timescales of either 200,000 years or one million years, using three different Earth Models of Intermediate Complexity (EMICs) (for a review see Claussen *et al.*, 2002). These were LLN 2D NH and MoBidiC, developed by the Institut d'Astronomie et de Géophysique Georges Lemaître, Université catholique de Louvain, Belgium (Gallée *et al.*, 1991; 1992; Crucifix *et al.*, 2001), and CLIMBER-GREMLINS, developed by the Commissariat à l'Energie Atomique/Laboratoire des Sciences du Climat et de l'Environnment (CEA/LSCE), France (Petoukhov *et al.*, 2000). In addition, snapshot simulations of climatic conditions at various times were undertaken with an Atmosphere-Ocean General Circulation Model (AOGCM), IPSL_CM4_D, also from

CEA/LSCE (Li, 1998; Madec *et al.*, 1999; Krinner *et al.*, submitted). Downscaling of the results obtained from these various models was undertaken using rule-based and statistical approaches, as well as by running a Regional Climate Model (MAR, see Gallée and Schayes, 1994) using boundary conditions prescribed from the AOGCM (BIOCLIM, 2004).

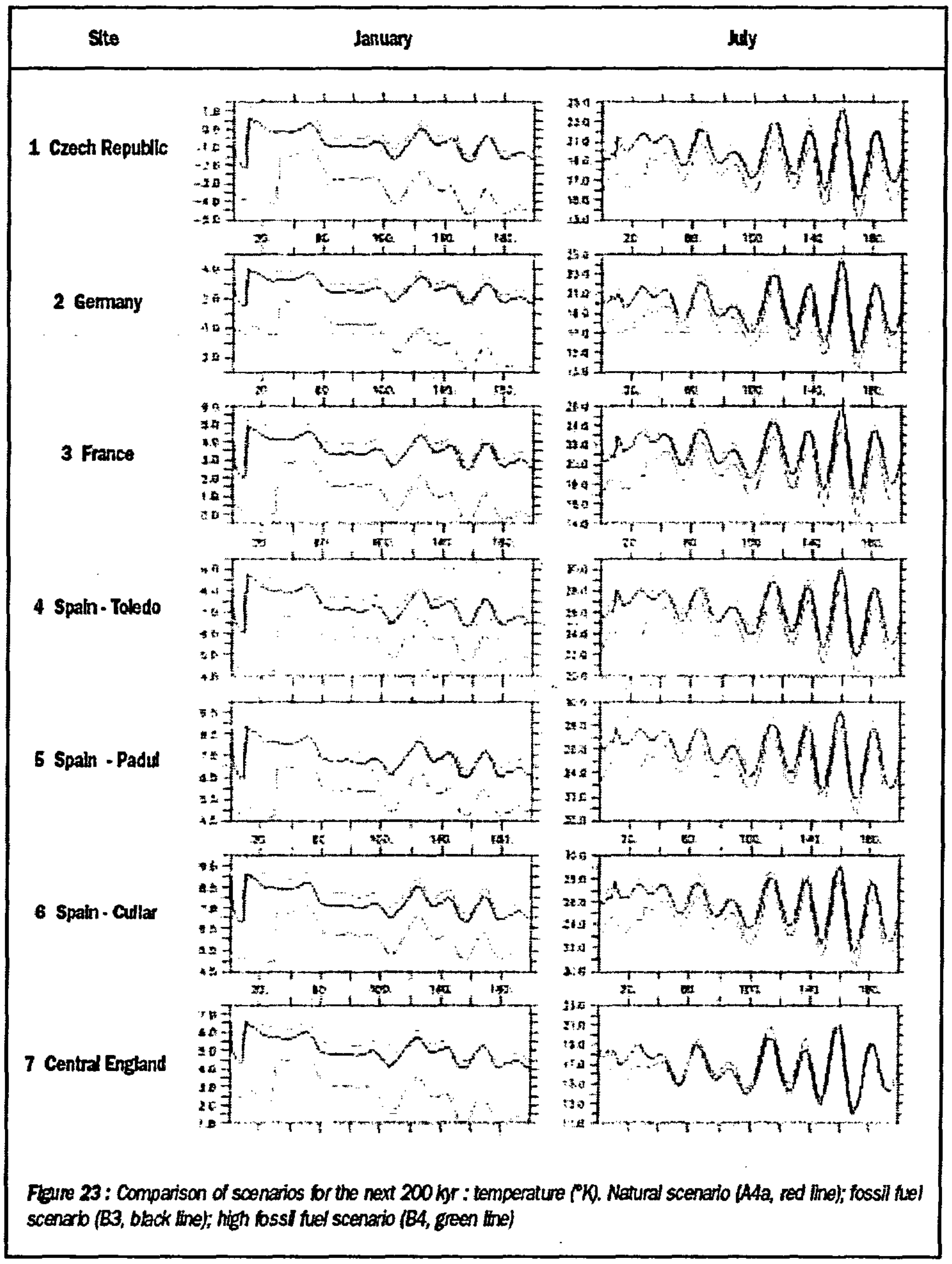

Figure 3: Illustrative Climate Change Results for the next 200,000 Years (BIOCLIM, 2003)

The detailed results from these studies are all for the European region and demonstrate that the pattern of climate change follows the pattern of carbon dioxide concentration changes in the atmosphere closely, with lags measured in decades to centuries (BIOCLIM, 2004).

Overall, the studies undertaken in BIOCLIM serve to illustrate the following points of direct relevance to Yucca Mountain:

- Anthropogenically induced climate change is projected to be considerable, is likely to reach a maximum over the next few hundred years and is then likely to persist throughout the next few hundred thousand years, i.e. through to when peak doses are projected to occur at Yucca Mountain;
- The possibility of substantial anthropogenically induced climate change is taken seriously by European waste management organizations, is included by them in their research programs, and is included in assessment studies through the application of quantitative models;
- Although the global carbon cycle is not fully understood and alternative scenarios for future carbon dioxide emissions need to be considered, it is possible, with sufficient research effort, to construct an envelope of future concentrations of carbon dioxide in the atmosphere that can be used as a basis for assessment studies;
- Various EMICs are now available (see Claussen *et al.*, 2002) that allow transient projections of future global climate to be made on time scales of several hundred thousand years, these studies can be complemented with snapshot studies of key periods using AOGCMs;
- These same models have proven capable of simulating many aspects of climate change observed in the paleoclimatic record;
- Various techniques are available for downscaling EMIC and AOGCM results to smaller spatial scales.

It is further noted that transient climate modeling on long time scales is a rapidly developing field and that capabilities in this area will increase very substantially in the next few years. In particular, a wider ensemble of models is likely to become available, and the spatial and temporal resolution of those models is likely to be enhanced. Thus, no issues of principle arise in applying climate modeling to Yucca Mountain out to the time of peak dose. Specifically, there is no reason to exclude *a priori*, as EPA has done potential future anthropogenic influences on climate.

It might be argued that although the modeling of future climates is possible, it would not contribute significantly to evaluation of the safety of the facility. The basis for such an argument would be that the main concern is with increased precipitation and infiltration, and that such increases are likely to occur in glacial conditions, as these are likely to be cooler and wetter than at the present day. Although it is indeed the case that glacial conditions are likely to be cooler and wetter, those conditions do not necessarily bound conditions prejudicial to repository performance that could occur in future warm world conditions. Specifically, global warming is associated with increased evaporation and a strengthening of the hydrological cycle, with delivery of increased energy and moisture to the atmosphere. In these circumstances, substantial reorganization of atmospheric systems can occur and these have the potential to increase precipitation significantly at the site. In particular, there could be an increase in the number and intensity of storm events. The range of current climate model simulations available suggests that the Yucca Mountain region could be wetter or drier in a human-warmed world. Although it is clear that it will be hotter, there is substantial uncertainty whether it will be drier or wetter. However, if the likely increases in hurricane intensity and rainfall amounts take place due to global warming, we must consider the possibility that there will be more intense hurricanes capable of reaching Yucca Mountain. Given that Hurricane Nora reached southern Nevada in 1997, and resulted in up to 300 mm of precipitation in some Southwest U.S. locations, it is safe to say that precipitation totals of this amount, superimposed on the current range are possible. Moreover, if there is an anthropogenically induced increase in mean precipitation during the hurricane season, the number could be larger, as the largest rainfall events in the Southwest U.S. tend to be those associated with coincident/colliding tropical and frontal storms. Furthermore, hurricane-related rainfall is intense and concentrated in just a couple days of rainfall at any location. As noted above, the susceptibility of arid environments to event-driven infiltration and the highly non-linear relationships involved mean that such events may have a disproportionate effect on infiltration and repository performance.

A further consideration relevant to the Draft EPA Rule is that uncertainties in climate projections do not increase beyond 10,000 years after present, at least in terms of the range of climate conditions that could occur, rather than their detailed timing. As illustrated in Figure 2, atmospheric carbon dioxide levels are likely to peak within the next few hundred years and the maximum of global warming is likely to occur soon after that peak. The projected peak concentration of carbon dioxide is in the range 1000 to 2000 ppm, i.e. a factor of 3.6 to 7.1 times larger than the pre-industrial concentration. In these circumstances, partial or complete removal of the Greenland ice sheet is very likely to occur (Gregory *et al.*, 2004; Houghton *et al.*, 2001), resulting in potential large-scale reorganization of the global circulation. In addition, there may be substantial changes in ice-cover in West Antarctica (Oppenheimer and Alley, 2004; Thorne *et al.*, 2000) and the possibility of a positive feedback effect due to methane release from clathrates cannot be discounted (Archer and Buffett, 2005). As ice-sheet collapse has a characteristic timescale of a few hundred to a few thousand years (Oppenheimer and Alley, 2004; Houghton *et al.*, 2001; Thorne *et al.*, 2000) and feedbacks from clathrate releases would be expected to occur on similar or shorter timescales, the next few thousand years are considered likely to be a period of unusually large changes and instabilities of climate. In contrast, beyond a few thousand years, atmospheric carbon dioxide levels are envisaged as slowly declining, but still sufficiently high that renucleation of the Greenland ice sheet is unlikely for up to 500,000 years (Archer and Ganopolski, 2005), so boundary conditions on the global climate system will change much more gradually and climatic modeling will be more readily justified. As a combination of EMICs and AOGCMs is required to model climate over the next 10,000 years and the same combination of models has to be used beyond that time, the fact that climate conditions are assessed as becoming more stable after the next few thousand years suggests that we can have more confidence in climate modeling results beyond 10,000 years than over the next few thousand years. More particularly, there is no step change in our capability to project climate change, given a particular emissions scenario, at around 10,000 years.

References

Archer, D (2005). The fate of fossil fuel CO_2 in geologic time. *Journal of Geophysical Research*, doi:10.1029/2004JC002625.

Archer, D and Buffett, B (2005). Time-dependent response of the global ocean clathrate reservoir to climatic and anthropogenic forcing. *Geochem. Geophys. Geosystems*, **6**, Q03002, doi:10.1029/2004GC000854.

Archer, D and Ganopolski, A (2005). A movable trigger: fossil fuel CO_2 and the onset of the next glaciation. *Geochem., Geophys., Geosystems*, **6**, Q05003, doi:10.1029/2004GC000891.

Archer, D, Kheshgi, H and Maier-Raimer, E (1997). Multiple timescales for neutralization of fossil fuel CO_2. *Geophysical Research Letters*, **24**, 405-408.

BIOCLIM (2001). Deliverable D3: Global climatic features over the next million years and recommendation for specific situations to be considered. Available from www.andra.fr/bioclim.

BIOCLIM (2003). Deliverable D8b: Development of the Physical/Statistical Downscaling Methodology and Application to Climate Model CLIMBER for BIOCLIM Workpackage 3. Available from www.andra.fr/bioclim.

BIOCLIM (2004). Deliverable D10-12: Development and application of a methodology for taking climate-driven environmental change into account in Performance Assessments. Available from www.andra.fr/bioclim.

Claussen, M, Mysak, L A, Weaver, A, Crucifix, M, Fichefet, T, Loutre, M F, Weber, S L, Alcamo, J, Alexeev, V A, Berger, A, Calov, R, Ganopolski, A, Goosse, H, Lohmann, G, Lunkeit, F, Mokhov, I I, Petoukhov, V, Stone, P and Wang, Z (2002). Earth system models of intermediate complexity: closing the gap in the spectrum of climate system models. *Climate Dynamics* **18**, 579-586.

Cohen, S & Associates (2005). Assumptions, Conservatisms, and Uncertainties in Yucca Mountain Performance Assessments, Revised Final Draft, Contract No. EP-D-05-002, Work Assignment No. 1-08, Subtask 2, August 8, 2005.

CNWRA (2004). System-level performance assessment of the proposed repository at Yucca Mountain using the TPA version 4.1 code. Revised March.

CRWMS M&O (1997). Unsaturated Zone Flow Model Expert Elicitation Project.

Crucifix, M, Tulkens, P and Berger, A (2001). Modelling abrupt climatic change during the last glaciation. *The Oceans and Rapid Climate Changes: Past, Present and Future*, Eds. Seidov, D, Haupt, B J and Maslin, M. AGU Monograph series **126** pp.117-134.

Drissel, J C and Osborn, H (1968). Variability in rainfall producing runoff from a semiarid rangeland watershed, Alamogordo Creek, New Mexico. J. Hydrol., **6**, 194-201

Gallée, H, van Ypersele, J P, Fichefet, Th, Tricot, C and Berger, A (1991). Simulation of the last glacial cycle by a coupled sectorially averaged climate – ice-sheet model. I. The climate model. *J. Geophys. Res.*, **96**, 13139-161.

Gallée, H, van Ypersele, J P, Fichefet, Th, Marsiat, I, Tricot, C and Berger, A (1992). Simulation of the last glacial cycle by a coupled sectorially averaged climate – ice-sheet model. II. Response to insolation and CO_2 variation. *J. Geophys. Res.*, **97(D14)**, 15713-740.

Gallée, H and Schayes, G (1994). Development of a three-dimensional meso-gamma primitive equations model. *Mon. Wea. Rev.*, **122**, 671-685.

Gregory, J M, Huybrechts, P and Raper, S C B (2004). Climatology - Threatened loss of the Greenland ice-sheet. *Nature*, **428**, 616.

Houghton, J T, Ding, Y, Griggs, D J, Noguer, M, Linden, P J v. d, Dai, X, Maskell, K, and Johnson, C A (2001). Climate Change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Krinner, G, Viovy, N, de Noblet-Ducoudré, N, Ogée, J, Polcher, J, Friedlingstein, P, Ciais, P, Sitch, S and Prentice, C (Submitted). A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system. Submitted to Global Biochemical Cycle.

Li, Z L (1998). Description algorythmique d'un ensemble de parameterisation physique - phylmd. Available from: http://www.lmd.jussieu.fr/~lmdz/doc.html.

Madec, G, Delecluse, P, Imbard, M and Levy C (1999). OPA 8.1 Ocean General Circulation Model reference manual Note du Pole de Modélisation, Institut Pierre-Simon Laplace, No XX, pp. 91.

Oppenheimer, M and Alley, R B (2004). The West Antarctic ice sheet and long term climate policy - An editorial comment. *Climatic Change*, **64**, 1-10.

Osborn, H B and Renard, K G (1969). Analysis of two major runoff-producing southwest thunderstorms. J.Hydrol., **8**, 282-302.

Petit, J R, Jouzel, J, Raynaud, D, Barkov, N I, Barnola, J-M, Basile, I, Bender, M, Chapellaz, J, Davis, M, Delaygue, G, Delmotte, M, Kotlyakov, V M, Legrand, M, Lipenkov, V Y, Lorius, C, Pépin, L, Ritz, C, Saltzman, E and Stievenard, M (1999). Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* **399**, 429-436.

Petoukhov, V, Ganopolski, A, Brovkin, V, Claussen, M, Eliseev, A, Kubatzki, C and Rahmstorf, S (2000). CLIMBER-2: A climate system model of intermediate complexity. *Climate Dynamics*, **16**, 1-17.

SSPA (2001). FY01 Supplemental Science and Performance Analyses, Volume 2: Performance Analyses, US Department of Energy, Office of Civilian Radioactive Waste Management.

Stothoff, S A (1999) Infiltration Abstractions for Shallow Soil over Fractured Bedrock in a Semiarid Climate. CNWRA Report to NRC.

Stothoff, S A, Castellaw, H M and Bagtzoglou, A C (1996) Simulating the Spatial Distribution of Infiltration at Yucca Mountain, Nevada. CNWRA Report to NRC.

Thorne, M C, Watkins, S J, Goodess, C M and Palutikof, J P (2000). The Role of the Antarctic Ice Sheets in Determinining Global Sea Levels, AEA Technology Report AEAT/R/ENV/0170 to United Kingdom Nirex Limited.

Woolhiser, D A, Stothoff, S A and Wittmeyer, G W (1998). Estimating Channel Infiltration from Surface Runoff in the Solitario Canyon Watershed, Yucca Mountain. CNWRA report to NRC.

Mike Thorne and Associates Limited

Michael Thorne

Qualifications PhD FSRP
Year of birth [redacted]
Nationality [redacted]

KEY SKILLS

- Radiological protection
- Assessing the radiological safety of disposal of radioactive wastes
- Distribution and transport of radionuclides in the environment
- Expert elicitation procedures
- Probabilistic safety studies
- Development of safety criteria
- Pharmacodynamics

CAREER HISTORY

2001- Mike Thorne and Associates Limited

Development of Models for Radionuclide Transfers to Sewage Sludge and for Evaluating the Radiological Impact of Sludge applied to Agricultural Land
Client – Food Standards Agency

Includes a review of literature and the development and implementation of probabilistic models for such transfers.

Development of Biokinetic Models for radionuclides in Animals
Client – Serco Assurance

Development of updated biokinetic models for use by the Food Standards Agency in their SPADE and PRISM modelling systems

Review Studies for the Proposed Australian National Radioactive Waste Repository
Client – RWE NUKEM

Reviews of reports on animal transfer factors and of the potential effects of climate change on the repository plus development of a model for the biokinetics of the ^{226}Ra decay chain in grazing animals.

Development and Application of a Model for Assessing the Radiological Impacts of ^{3}H and ^{14}C in Sewage Sludge
Client – NNC Ltd

Development of a model based on physical, chemical and biochemical principles for the uptake of 3H and 14C into sewage sludge and their subsequent distribution and transport after application of the sludge to agricultural land.

Support for development of the Drigg Post-closure Radiological Safety Assessment
Client - BNFL

Support in the areas of FEP analysis, biosphere characterisation, human intrusion assessment and the effects of natural disruptive events. In addition, provision of advice of future research initiatives that should be pursued by BNFL.

Co-ordination of biosphere research and participation in BIOCLIM
Client – UK Nirex Ltd

Co-ordination of research on climate change, ice-sheet development, near-surface hydrology and radionuclide transport, as well as participation in an international programme on the implications of climate change for radioactive waste disposal.

Review of Parameter Values
Client – AEA Technology/Serco Assurance

Review of biosphere parameter values for use in the ANDRA assessment model AQUABIOS.

Effects of Radiation on Organisms Other Than Man
Client – AEA Technology/Serco Assurance

Study for ANDRA to identify appropriate indicator organisms and develop appropriate dosimetry and effects models for those organisms.

Development of a Database related to Emergency Planning
Client – AEA Technology (Rail)

Identification of relevant international, overseas and national legislation, regulations and guidance, and production of brief summaries of the documents.

Dose Reconstruction for Workers on a Uranium Plant
Client - McMurry and Talbot

Dose reconstruction for the plaintiffs in a case relating to the Paducah Gaseous Diffusion Plant.

Dose Reconstruction for a Worker Exposed to Pu and Am
Client – Pattinson and Brewer

Dose reconstruction for a worker exposed by a puncture wound in the finger while working at a glove box.

1998-2001 <u>AEA Technology</u>

Assessment of Remediation Options for Uranium Liabilities in Eastern Europe
Client - European Commission

Studies of remediation requirements relating to mines, waste heaps and hydrometallurgical plant in Bulgaria, Slovakia and Albania.

Evaluation of Unusual Pathways for Radionuclide Transport from Nuclear Installations
Client – Environment Agency

Review of literature and conduct of formal elicitation meetings to determine potential pathways and evaluate their radiological significance.

Revision of Exemption Orders Made Under the Radioactive Substances Act
Client – DETR

Review of requirements for revision and preparation of a draft text for the purposes of consultation.

Support Studies on the Drigg Post-closure Performance Assessment
Client - BNFL

Support in the areas of FEP analysis, biosphere characterisation, human intrusion assessment and the effects of natural disruptive events. In addition, provision of advice of future research initiatives that should be pursued by BNFL.

Development of Models for the Biokinetics of H-3, C-14 and S-35 in Farm Animals
Client - FSA

Review of relevant literature, development of appropriate biokinetic models and implementation in stand-alone software.

Integration of Aerial and Ground-based Monitoring in the Event of a Nuclear Accident
Client - FSA

Desk-based review and simulation study designed to determine optimum monitoring strategies for different types of accidents.

Elicitation of Parameter Values for use in Radiological Impact Assessment Models
Client - FSA

Expert elicitation study to provide distributions of parameter values for use in the suite of assessment models currently used by the FSA for routine and accidental releases.

Biosphere Research Co-ordination and Assessment Studies
Client - United Kingdom Nirex Ltd

Continuation of a programme of work originally undertaken at Electrowatt Engineering (UK) Ltd

Site Investigation and Risk Assessment - Hilsea Lines
Client - Portsmouth City Council

Radiological assessment of a radium-contaminated site.

1987-1998 Electrowatt Engineering (UK) Ltd

Evaluation of Inhalation Doses from Uranium
Client - Baron & Budd

Provision of expert witness support in a class action relating to environmental exposure from a uranium plant.

Biosphere Studies Relating to Drigg
Client - BNFL

Provision of advice on time-dependent biosphere modelling for the Drigg low-level radioactive waste disposal facility.

Development of a Siting Policy for Nuclear Installations: Harbinger Project and Follow-up Study
Client - HSE/NSD

Review of existing policy and development of alternatives as a precursor to application to a wide range of installations, not restricted to commercial reactors.

Support to the Rock Characterisation Facility Public Enquiry
Client - UK Nirex Ltd

Preparation of position papers and rebuttals of evidence.

Radiation Doses to an Individual as a Consequence of Working on the San Onofre Nuclear Power Plant
Client - Howarth & Smith

Interpretation of personal and area monitoring data for legal purposes.

Interpretation of Uranium in Urine Data for the Fernald, Ohio Feed Materials Processing Center
Client - Institute for Energy and Environmental Research

Interpretation of urinalysis and lung counting data, and appearance as an expert witness in the associated trial.

Determination of Failure Probabilities for use in PRA
Client - Nuclear Installations Inspectorate

Development of new approaches to the use of Bayes Theorem in defining component failure probabilities for use in PRA when statistics on actual failures are limited.

Review of Inventory Information
Client - UK Nirex Ltd

Review of uncertainties in inventories of individual radionuclides.

ALARP Study of Options for the Treatment, Packaging, Transport and Disposal of Plutonium Contaminated Material
Client - UK Nirex Ltd

Use of multi-attribute utility analysis to establish which option is preferred.

Expert Judgement Estimation of Intrusion Model Parameters
Client - British Nuclear Fuels plc

Project Manager of a study assessing the risks of human intrusion into Drigg radioactive disposal site using expert judgement techniques.

Brainstorming Study of Risks Associated with Building Structures
Client - Building Research Establishment

Participation in a classification study of the health risks associated with buildings including both injuries and disease.

Rongelap Resettlement Project
Client - Marshall Islands Government

Participation in an oversight committee evaluating the radiological safety of Rongelap in the context of resettlement by its evacuated community.

Radiological Consequences of Deferred Decommissioning of Hunterston A
Client - Scottish Nuclear Ltd

Project Manager of a study of the radiological impacts of groundwater transport of radionuclides, releases to atmosphere and intrusion.

Reviews of Safety Documentation
Client - UK Nirex Ltd

Review of safety related documentation for Packaging and Transport Branch.

The Sheltering Effectiveness of Buildings in Hong Kong
Client - Ove Arup & Partners

Project Manager of a study evaluating the shielding effectiveness of all types of building in Hong Kong for volume sources of photons in air and surface deposition sources.

Assessment of the Radiological Impact of Releases of Radionuclides from Premises other than Licensed Nuclear Sites
Client - Ministry of Agriculture, Fisheries and Food

Project Manager of a study to identify representative premises, obtain data on their releases of radionuclides and assess radiological impacts using a new methodology developed for the project.

Assessment of the Radiological Implications of Uranium and its Radioactive Daughters in Foodstuffs
Client - Ministry of Agriculture, Fisheries and Food

Project Manager of a review study of concentrations of uranium and its daughters in foodstuffs, taking local and regional variations in uranium concentrations in soils, sediments and waters into account.

Radionuclides in Sewage
Client - Her Majesty's Inspectorate of Pollution

Project Manager of a study including a desk review on alternative methods of disposal of sewage sludges, interpretation of monitoring data relating to radionuclide discharges from Amersham International to the public sewer system, development of a model for radionuclide transport in sewers, and collection and analysis of effluent, foul water, sediment, sludge and other samples suitable for use in model validation studies.

Accident Consequence Calculations
Client - Nuclear Installations Inspectorate

Project Manager of a study to assess the radiological consequences of various atmospheric releases using the MARC code.

Definition of Threshold Recording Levels for Drums of ILW
Client - UK Nirex Ltd

Project Manager of a study of the implications of post-closure radiological impacts of radioactive waste disposal in defining Threshold Recording Levels for radionuclides in individual waste drums.

Definition of Expert Judgment Exercises Relating to Nuclear Safety
Client - Commission of the European Communities

Project Manager for a study defining expert judgment exercises relating to conceptualisation, representation and input data specification. Included a comprehensive review of available formal expert judgment procedures, and mathematical and behavioural aggregation techniques.

Definition of Research Requirements Relating to the Use of Expert Judgment in Parameter Value Elicitation for Reactor Safety Studies in a UK Context
Client - Nuclear Safety Research Management Unit, HSE

Development of proposals for using combined behavioural and mathematical aggregation procedures in formal elicitations of expert judgment.

Development Priorities for the Drigg Technical Development Programme
Client - British Nuclear Fuels plc

Provision of detailed advice to BNFL on future design options, and research and development priorities, in relation to radioactive waste disposal at Drigg.

Channel Tunnel Safety Studies
Client - Channel Tunnel Safety Authority

Provision of advice and guidance on safety criteria appropriate to the Fixed Link, on the classes of Dangerous Goods that may properly be carried and on the overall characteristics of the proposed Safety Case.

Development of Societal Risk Criteria
Client - Marathon Oil

Interpretation of F-N curves in the context of the offshore oil/gas industry, taking risk aversion into account.

Impacts of Salt Dispersal on Plant Communities
Client - Sir William Halcrow

Evaluation of salt dispersal from a major road in winter in relation to adjacent Sites of Special Scientific Interest.

Offsite Consequence Assessments
Client - Nuclear Electric

Studies of the offsite radiological impacts of atmospheric and liquid releases of radioactive materials from Magnox stations.

Dry Run 3
Client - Her Majesty's Inspectorate of Pollution

Uncertainty and bias studies involving formal expert judgment procedures to develop a conceptual model of those factors and interrelationships which are of significance in determining the post-closure radiological impact of a deep geological repository for radioactive wastes. This project also included advice on data and models to be used for post-closure radiological assessments.

Radiological Assessments of Drigg
Client - British Nuclear Fuels plc

Project Manager for post-closure radiological impact assessments of the Drigg LLW disposal site. Also included specification and development of computer codes relating to the radiological impact of fires, releases of radioactive gases produced by microbial action and metal corrosion, and human intrusion.

Biosphere Co-ordination
Client - UK Nirex Ltd

Co-ordination of the UK Nirex Ltd Biosphere Research Programme from its inception, including requirements definition, technical management of all projects and QA surveillance as the Client's Representative.

Biosphere Support for the Nirex Disposal Safety Assessment Team
Client - AEA Technology

Development of approaches for assessing the radiological impact of releases of radionuclides to the biosphere, plus advice on radiological protection criteria, definition of individual risk, implications of conventionally toxic chemicals in wastes and a variety of other matters.

Evaluation and Radiological Assessment of Liquid Effluent Releases from Various Premises
Client - Her Majesty's Inspectorate of Pollution

Reviews of monitoring data and evaluations of radiological impact, primarily related to Harwell, Aldermaston, Capenhurst and Amersham International.

Evaluation of the Radiological Impact of Overseas Nuclear Accidents
Client - Her Majesty's Inspectorate of Pollution

Studies of the impact of potential overseas nuclear accidents on the UK, with emphasis on survey and monitoring requirements, and the selection of appropriate radiation detection equipment for monitoring.

Bilsthorpe Power Station
Client - British Coal/East Midlands Electricity

Preparation of an Environmental Statement with emphasis on atmospheric dispersion of SO_2 and NO_x.

Gas Generation in Radioactive Waste Disposal Facilities
Client - AEA Technology

Development of a coupled microbial degradation and corrosion model for gas generation in repositories for LLW and ILW.

Effects of Chernobyl on Drinking Water Supplies
Client - Her Majesty's Inspectorate of Pollution

Evaluation of the radiological implications of enhanced concentrations of radionuclides in water supplies in England and Wales subsequent to the Chernobyl accident.

Sea Disposal of Radioactive Wastes
Client - UK Nirex Ltd

Participation in an Environmental Impact Assessment of the proposed resumption of sea-dumping of radioactive wastes.

UK Research Related to Radioactive Waste Management
Client - Her Majesty's Inspectorate of Pollution

Identification of gaps in the UK national research effort related to radioactive waste management.

Research Requirements for Repository Design and Site Investigations
Client - UK Nirex Ltd

Review of research requirements for repository design and site investigations in relation to LLW and ILW disposal in near-surface and deep repositories.

1985 - 1986 International Commission on Radiological Protection, Sutton, Surrey, England

Scientific Secretary responsible for arranging and minuting meetings, administrative arrangements, technical review of reports, editing of the Commission's journal, liaison with other international organisations and public relations.

1979 - 1985 ANS Consultants Ltd, Epsom, Surrey, England

Reviews of data on the distribution at transport of radionuclides in terrestrial and aquatic ecosystems (see publications list).

Development of a dynamic model for radionuclide transport in agricultural ecosystems and implementation of the model on various microcomputer systems.

Photon and neutron shielding studies of radiochemical plant, together with area classification and ALARA studies.

A review of UK use of the criticality code MONK and other approaches to criticality safety assessment.

Radiological and conventional safety aspects of Magnox reactor decommissioning.

Development of metabolic models for inclusion in ICRP Publication 30.

Development of pharmacodynamic models for toxic chemicals.

Review of neutron activation analysis in studies of radionuclide transport in soils and plants.

Experimental studies on radionuclide transport in soils and plants using various photon-emitting radionuclides.

Support for DoE work on probabilistic risk assessment of LLW and ILW disposal.

Review of UK research requirements for HLW disposal.

Post-closure radiological impact assessment of the proposed LLW and ILW facility at Elstow, Bedfordshire.

Development of a generalised biosphere model for use in probabilistic risk assessments of solid radioactive waste disposal.

Initial development of a mathematical model for use in assessing the radiological impact of contaminated groundwater.

Development, computer implementation and comprehensive documentation of a model to calculate the radiological impact of intrusion into radioactive waste repositories.

Development of a general-purpose computer code for solving first-order differential equations using a hybrid Predictor-Corrector/Runge-Kutta method.

Studies on the potential radiological consequences of Magnox reactor accidents.

1974 - 1979 **Medical Research Council Radiobiology Unit, Chilton, Didcot, Oxon, England**

Development of dosimetric and metabolic models for use in ICRP Publication 30.

Studies on the metabolism of plutonium in bone and relationships to blood flow.

Theoretical studies on radionuclide metabolism and dosimetry.

Development of techniques in neutron-induced autoradiography and alpha imaging.

Image analysis studies of plutonium in bone, uranium in lungs, lysosomal inclusions in cells and heterochromatin.

Studies on the clearance of inhaled UO_2.

Alpha spectroscopy in support of toxicity studies with Ra-224.

Data analysis in connection with experimental animal studies on the potential efficacy of neutron therapy using 42 MeV neutrons.

1971 - 1974 **University of Sheffield**

Experimental studies on the reaction $\gamma + p \rightarrow \pi^0 + p$ at photon energies between 1 and 3 GeV, using a linearly polarised photon beam.

PROFESSIONAL ACTIVITIES AND MEMBERSHIP

- Fellow of the Society for Radiological Protection and Immediate Past President
- Member of the Eco-ethics International Union
- Visiting Fellow at the Climatic Research Unit, University of East Anglia

SELECTION OF PUBLICATIONS

A measurement of the beam asymmetry parameter for neutral pion photoproduction in the energy range 1.2 - 2.8 GeV. P.J.Bussey, C. Raine, J.G. Rutherglen, P.S.L. Booth, L. Carroll, G.R. Court, A.W. Edwards, R. Gamet, C.J. Hardwick, P.J. Hayman, J.R. Holt, J.N. Jackson, J. Norem, W.H. Range, F.H. Combley, W. Galbraith, V.H. Rajaratnam, C. Sutton and M.C. Thorne. London Conference (1974) Abstract 997.

The measurement of the polarisation parameters S, P and T for positive pion photoproduction between 500 and 1700 MeV. P.J. Bussey, C. Raine, J.G. Rutherglen, P.S.L. Booth, L.J. Carroll, P.R. Daniel, C.J. Hardwick, J.R. Holt, J.N. Jackson, J.H. Norem, W.H. Range, F.H. Combley, W. Galbraith, V.H. Rajaratnam, C. Sutton, M.C. Thorne and P. Waller. Nuclear Physics, B104, (1976) 253-276.

The polarised beam asymmetry in photoproduction of eta mesons from protons 2.5 GeV and 3.0 GeV. P.J. Bussey, C. Raine, J.G. Rutherglen, P.S.L. Booth, L.J. Carroll, P.R. Daniel, A.W. Edwards, C.J. Hardwick, J.R. Holt, J.N. Jackson, J. Norem, W.H. Range, W. Galbraith, V.H. Rajaratnam, C. Sutton, M.C. Thorne and P. Waller. Physics Letters, 61B, (1976) 479-482.

Aspects of the dosimetry of plutonium in bone. M.C. Thorne. Nature, 259, (1976) 539-541.

The toxicity of Sr-90, Ra-226 and Pu-239. M.C. Thorne and J. Vennart. Nature 263, (1976) 555-558.

Radiation dose to mouse testes from Pu-239. D. Green, G.R. Howells, E.H. Humphreys and J. Vennart with Appendix by M.C. Thorne. Published in "The Health Effects of Plutonium and Radium", Ed. W.S.S. Jee, (J.W. Press, Salt Lake City, Utah, 1976).

The distribution and clearance of inhaled uranium dioxide particles in the repository tract of the rat. Donna J. Gore and M.C. Thorne. In "Inhaled particles IV", Ed. W.H. Walton, (Pergamon Press, Oxford, 1977) pp. 275-284.

Theoretical aspects of the distribution and retention of radionuclides in biological systems. M.C. Thorne. J. Theor. Biol., 65, (1977) 743-754.

Aspects of the dosimetry of emitting radionuclides in bone with particular emphasis on Ra-226 and Pu-239. M.C. Thorne. Phys. Med. Biol., 22, (1977) 36-46.

A new method for the accurate localisation of Pu-239 in bone. D. Green, G. Howells and M.C. Thorne. Phys. Med. Biol., 22, (1977) 284-297.

The measurement of blood flow in mouse femur and its correlation with Pu-239 deposition. E.R. Humphreys, G. Fisher and M.C. Thorne. Calcif. Tiss. Res., 23, (1977) 141-145.

The distribution of plutonium-239 in the skeleton of the mouse. D. Green, G.R. Howells, M.C. Thorne and J. Vennart. In "Proceedings of the IVth International Congress of the International Radiation Protection Association Vol. 2 (Paris 1977).

The visualisation of fissionable radionuclides in rat lung using neutron induced autoradiography. D.J. Gore, M.C. Thorne and R.H. Watts. Phys. Med. Biol., 23 (1978) 149-153.

Lymphoid tumours and leukaemia induced in mice by bone-seeking radionuclides. J.F. Loutit and T.E.F. Carr with an appendix by M.C. Thorne. Int. J. Radiat. Biol., 33, (1978) 245-263.

Plutonium-239 deposition in the skeleton of the mouse. D. Green, G.R. Howells and M.C. Thorne. Int. J. Radiat. Biol., 34, (1978) 27-36.

Imaging of tissue sections on Lexan by alpha-particles and thermal neutrons; an aid in fissionable radionuclide distribution studies. D. Green, G.R. Howells, M.C. Thorne and R.H. Watts. Int. J. Appl. Radiat. Isotopes, 29, 285-295 (1978).

Analytical techniques for the analysis of multi-compartment systems. M.C. Thorne. Phys. Med. Biol., 24, 815-817 (1979).

The initial deposition and redistribution of Pu-239 in the mouse skeleton: implications for rodent studies in Pu-239 toxicology. D. Green, G.R. Howells and M.C. Thorne. Br. J. Radiol., 52, 426-427 (1979).

Bran and experimental colon cancer. M.C. Thorne. Lancet, ii, 13 January 1979, p.108.

Quantitative microscopic studies of the distribution and retention of Pu-239 in the ilium of the female CBA mouse. D. Green, G.R. Howells and M.C. Thorne. Int. J. Radiat. Biol., 36, 499-511 (1979).

Techniques for studying the distribution of alpha emitting and fissionable radionuclides in histological lung sections. T. Jenner and M.C. Thorne. Phys. Med. Biol., 25, 357-364 (1980).

Morphometric studies of mouse bone using a computer-based image analysis system. D. Green, G.R. Howells and M.C. Thorne. J. Microscopy, 122, 49-58 (1981).

A semi-automated technique for assessing the microdistribution of ^{239}Pu deposited in bone. D. Green, G.R. Howells and M.C. Thorne. Phys. Med. Biol., 26, 379-387 (1981).

Radionuclide distribution and transport in terrestial and aquatic ecosystems, Volumes 1 to 6. P.J. Coughtrey, M.C. Thorne et al. A.A. Balkema, Rotterdam 1983-1985.

Dynamic models for radionuclide transport in soils, plants and domestic animals. M. C. Thorne and P. J. Coughtrey. In: Ecological Aspects of Radionuclide Release (Ed. P. J. Coughtrey). British Ecological Society Special Publication No. 3, Blackwell, Oxford, 1983.

Studies on the mobility of radioisotopes of Ce, Te, Ru, Sr and Cs in soils and plants. P.J. Coughtrey, M.C. Thorne, D. Jackson and G.F. Meekings. In: CEC Symposium on the Transfer of Radioactive Materials in the Terrestial Environment Subsequent to an Accidental Release to Atmosphere. Dublin, April 1983.

A study of the sensitivity of a dynamic soil-plant-animal model to changes in selected parameter values. M.C. Thorne, P.J. Coughtrey and G.F. Meekings. In: CEC Symposium on the Transfer of Radioactive Materials in the Terrestial Environment Subsequent to an Accidental Release to Atmosphere. Dublin, April 1983.

Microdosimetry of bone: implications in radiological protection. M.C. Thorne. In: Metals in Bone, N.D. Priest (Ed.) MTP Press, Lancaster (1985), pp. 249-268.

Non-stochastic effects resulting from internal emitters: dosimetric considerations. M.C. Thorne. J. Soc. Rad. Prot., 6 (1986).

Pharmacodynamic models of selected toxic chemicals in man. Vol. 1. Review of metabolic data. M.C. Thorne, D. Jackson and A.D. Smith. MTP Press, Lancaster, 1986.

Pharmacodynamic models of selected toxic chemicals in man. Vol. 2. Routes of intake and implementation of pharmacodynamic models. A.D. Smith and M.C. Thorne. MTP Press. Lancaster 1986.

Generalised computer routines for the simulation of linear multi-compartment systems. D.Jackson, A.D. Smith, M.C. Thorne and P.J. Coughtrey. Environmental Software, 2 (1987), 94-102.

The demonstration of a proposed methodology for the verification and validation of near field models. J-M. Laurens and M.C. Thorne. In: Proceedings of an NEA Workshop "Near-field Assessment of Repositories for Low and Medium Level Radioactive Waste". pp. 297-310. NEA/OECD, Paris, 1987.

Principles of the International Commission on Radiological Protection System of Dose Limitation. Br. J. Radiol., 60 (1987), 32-38.

The origins and work of the International Commission on Radiological Protection. H. Smith and M.C. Thorne. Invest. Radiol., 22 (1987), 918-921.

The potential for irradiation of the lens and cataract induction by incorporated alpha-emitting radionuclides. D.M. Taylor and M.C. Thorne. Health Phys., 54 (1988), 171- 179.

Forum on alpha-emitters in bone and leukaemia: introduction and commentary. M.C. Thorne. Int. J. Radiat. Biol., 53 (1988), 521-539.

Radiological protection and the lymphatic system: The induction of leukaemia consequent upon the internal irradiation of the tracheo-bronchial lymph nodes and the gastrointestinal tract wall. K.F. Baverstock and M.C. Thorne. Int. J. Radiat. Biol., 55 (1989), 129-140.

The Biosphere: Current Status. NSS/G106. M.C. Thorne. Available from UK Nirex Ltd, Curie Avenue, Harwell, 1989.

The development of an overall assessment procedure incorporating an uncertainty and bias audit. M. C. Thorne and J-M. Laurens. Proceedings of an International Symposium on Safety Assessment of Radioactive Waste Repositories. OECD Paris (1990), 673-681.

Implications of environmental change for biosphere modelling: work for UK Nirex Ltd. M.C. Thorne. Proceedings of an International Symposium on Safety Assessment of Radioactive Waste Repositories. OECD Paris (1990), 860-865.

The Biosphere: Current Status, December 1989. NSS/G114. M.C. Thorne. Available from UK Nirex Ltd, Curie Avenue, Harwell, 1990.

The Nirex Overview. M.C. Thorne and D. George. In: Future Climate Change and Radioactive Waste Disposal: Proceedings of an International Workshop. C.M. Goodess and J.P. Palutikof (Eds). NSS/R257. Available from UK Nirex Ltd, Curie Avenue, Harwell, 1991.

A review of expert judgment techniques with reference to nuclear safety. M. C. Thorne and M. M. R. Williams, Progress in Nuclear Energy, 27 (1992), 83-254.

NSARP Reference Document: The Biosphere, January 1992. Nirex Report No. NSS/G119 M.C. Thorne. 1993.

The use of expert opinion in formulating conceptual models of underground disposal systems and the treatment of associated bias. M.C.Thorne, Journal of Reliability Engineering and Systems Safety, 42 (1993), 161-180.

UK Nirex Ltd Science Report No S/95/003, Nirex Biosphere Research: Report on Current Status in 1994, M C Thorne (Ed.), UK Nirex Ltd, July 1995.

UK Nirex Ltd. Science Report No S/95/012, Vol 3, A J Baker, C P Jackson, J E Sinclair, M C Thorne and S J Wisbey, Nirex 95: A Preliminary Analysis of the Groundwater Pathway for a Deep Repository at Sellafield: Volume 3 - Calculations of Risk, UK Nirex Ltd, July 1995.

Nirex 95: An Assessment of a deep repository at Sellafield, A J Baker, G E Hickford, C P Jackson, J E Sinclair, M C Thorne and S J Wisbey, TOPSEAL 96, Demonstrating the Practical Achievements of Nuclear Waste Management and Disposal, European Nuclear Society, pp. 125-132, 1996.

Consideration of post-closure controls for a near surface low level waste disposal site, Clegg, R, Pinner, A, Smith, A, Quartermaine, J and Thorne, M C, In: Planning and Operation of Low Level Waste Disposal Facilities, IAEA, Vienna, 1997.

The estimation of failure rates for low probability events, M M R Williams and M C Thorne, Progress in Nuclear Energy, 31 (1997), 373-476.

A comparison of independently conducted dose assessments to determine compliance and resettlement options for the people of Rongelap Atoll, S L Simon, W L Robison, M C Thorne, L H Toburen, B Franke, K F Baverstock and H J Pettingill, Health Physics, 73(1), 133 - 151, 1997.

A Guide to the Use and Technical Basis of the Gas Evolution Program MICROX: A Coupled Model of Cellulosic Waste Degradation and Metal Corrosion, R Colosante, J E Pearson, S Y R Pugh, A Van Santen, R G Gregory, M C Thorne, M M R Williams and R S Billington, Nirex Safety Studies Report NSS/R167, July 1997.

UK Nirex approach to the protection of the natural environment, M J Egan, M C Thorne and M A Broderick, Stockholm Symposium.

Post-closure performance assessment: treatment of the biosphere, M A Broderick, M J Egan, M C Thorne and J A Williams, Winnipeg Symposium.

The application of constraint curves in limiting risk, M C Thorne, J. Radiol. Prot., Vol. 17, 275-280, 1997.

The biosphere in post-closure radiological safety assessments of solid radioactive waste disposal, M C Thorne, Interdisciplinary Science Reviews, Vol. 23, 258-268, 1998.

An illustrative comparison of the event-size distributions for γ-rays and α-particles in the whole mammalian cell nucleus, K Baverstock and M C Thorne, Int. J. Radiat. Biol., 74, 799-804, 1998.

Southport '99, Achievements and Challenges: Advancing Radiation Protection into the 21st Century, Proceedings of an International Symposium, M C Thorne (Ed.) Society for Radiological Protection, London, 1999.

Modelling radionuclide distribution and transport in the environment, K M Thiessen, M C Thorne, P R Maul, G Prohl and H S Wheater, Environmental Pollution, 100, 151-177, 1999.

Use of a systematic approach for the Drigg post-closure radiological safety assessment, G Thomson, M Egan, P Kane, M Thorne, L Clements and P Humphreys, DisTec 2000, Disposal Technologies and Concepts 2000, Kontec Gesellschaft für technische Kommunication mbH, Tarpenring 6, D-22419, Hamburg, 413-417, 2000.

Validation of a physically based catchment model for application in post-closure radiological safety assessments of deep geological repositories for solid radioactive wastes, M C Thorne, P Degnan, J Ewen and G Parkin, Journal of Radiological Protection, 20(4), 403-421, 2000.

An approach to multi-attribute utility analysis under parametric uncertainty, M Kelly and M C Thorne, Annals of Nuclear Energy, 28, 875-893, 2001.

Radiobiological theory and radiation protection, M C Thorne, British Nuclear Energy Society International Conference on Radiation Dose Management in the Nuclear Industry, May 2001.

Development of a solution method for the differential equations arising in the biosphere module of the BNFL suite of codes MONDRIAN, M M R Williams, M C Thorne, J G Thomson and A Paulley, Annals of Nuclear Energy, 29, 1019-1039, 2002.

A model for evaluating radiological impacts on organisms other than man for use in post-closure assessments of geological repositories for radioactive wastes, M C Thorne, M Kelly, J H Rees, P Sânchez-Friera and M Calvez, J. Radiol. Prot., 22, 249-277, 2002.

Background Radiation: Natural and Man-made, M C Thorne, BNES 4th International Conference on Health Eeffects of Low-level Radiation, 22-24 September 2002, Keble College, Oxford, UK, CD Available from BNES.

Background Radiation: Natural and Man Made, M C Thorne, Journal of Radiological Protection, 23, 29-42, 2003.

Comments from the Society for Radiological Protection on ICRP Reference 02/305/02 – Protection of Non-Human Species From Ionising Radiation, M C Thorne, Journal of Radiological Protection, 23, 107-115, 2003.

Estimation of animal transfer factors for radioactive isotopes of iodine, technetium, selenium and uranium, M C Thorne, J. Environ. Radioact., in the press.

BIOGRAPHICAL SKETCH

JONATHAN OVERPECK

EDUCATION

Ph.D. Geological Sciences, Brown University, RI, 1985
M.S. Geological Sciences, Brown University, RI, 1981
AB Geology (Honors), Hamilton College, Clinton, NY, 1979

PROFESSIONAL AND ACADEMIC EXPERIENCE

Director, Institute For The Study of Planet Earth, Univ. of Arizona, Tucson, 1999-present
Professor, Dept. of Geosciences, Univ. of Arizona, Tucson, 1999-present
Adj. Assoc. Professor, Dept. of Geological Sciences, University of Colorado, 1992-2001
Fellow, Institute for Arctic and Alpine Research, Univ. of Colorado, 1992-1999
Director, World Data Center-A for Paleoclimatogy, Boulder, CO, 1992-1999
Head, NOAA Paleoclimatology Program, Nat. Geophysical Data Center, Boulder, 1991-1999
Associate Research Scientist, Lamont-Doherty Geological Observatory, 1986-1990
Post-doctoral Res. Scientist, Lamont-Doherty Geological Observatory, 1985-1986

RESEARCH INTERESTS

My research focuses on using climate and ecosystem records of the past ca. 200,000 years, along with an array of environmental modeling strategies, to understand recent environmental change, and also to constrain what might happen in the next 100 to 200 years. I maintain active paleoenvironmental data generation and modeling labs, and have active field and analysis programs on four continents – mostly focused on those parts of the climate system that are most important to decision-makers in society (e.g., El Niño Southern Oscillation, monsoons and Arctic variability). I have a special interest in "abrupt climate change" (including western North American megadrought, and sea level), particularly of interglacial climates, and have been involved in National Research Council studies related to this issue. Abrupt non-linear change is perhaps the biggest wildcard in the climate change debate. My students and I are also using data and models to understand climate-induced vegetation change, past, present and future, and are particularly interested in implications for future biodiversity conservation. Since coming to the University of Arizona, I have become heavily involved building university-stakeholder partnerships, and in the development of improved scientific decision-support for stakeholders in society.

SELECTED PUBLICATIONS (from over 80 total)

Overpeck, J.T., C. Whitlock, and B. Huntley. 2003. Terrestrial biosphere dynamics in the climate system: past and future. Pages 81-103 in K. Alverson, R. Bradley and T. Pedersen, eds., *Paleoclimate, Global Change and the Future* (IGBP Synthesis Volume).

National Research Council. 2002. *Abrupt Climate Change: Inevitable Surprises*. National Academy Press, Washington, D.C. 182 pp., (Overpeck is a co-author).

Cole, J.E., J.T. Overpeck, and E.R. Cook. 2002. Multiyear La Niña events and persistent drought in the contiguous United States. *Geophysical Research Letters* 29, 10.1029/2001GL013561

Urban, F.E., J.E. Cole, and J.T. Overpeck. 2000. Influence of mean climate change on variability in a 155-year tropical Pacific coral record. *Nature* 407:989-993.

Overpeck, J.T., and R.S. Webb. 2000. Non-glacial rapid climate events: past and future. *Proceedings of the National Academy of Sciences* 97:1335-1338.

ACTIVITIES AND ACCOMPLISHMENTS

HONORS

Sigma Xi, 1979; Hamilton College Senior Fellow, 1978-1979; US Dept. of Commerce Unusually Outstanding Performance Award, 1991; Dept. of Commerce Bronze Medal, 1994; Nat. Geophysical Data Center Director Award, 1995; Dept. of Commerce Gold Medal, 1998; American Meteorological Society's Walter Orr Roberts Award, 2001.

SYNERGISTIC ACTIVITIES

Lead Presenter (Paleoclimate), United Nations Intergovenmental Panel on Climate Change (IPCC) 4th Assessment Scoping Meeting, April 2002 (Morocco).

Member, NOAA Regional Integrated Sciences and Assessments Executive Committee, 2003-present

Co-chair, Science and Technology Working Group, Planned University of Arizona/City of Tucson ca. $60M Science Center," 2002-present.

Chair, NSF Arctic System Science (ARCSS) Committee, 2002-present. Leading the planning and execution of a integrated arctic system synthesis, as well as development of new science plan for the ARCSS Program.

Co-convener, CLIVAR/PAGES/IPCC Workshop "A multi-millennia perspective on drought and implications for the future" Tucson, AZ November, 2003.

Member, NOAA Climate and Global Change Working Group – serves as a primary mechanism for advice to NOAA on climate and global change matters, 2003-present

Member, National Academy of Sciences/NRC Committee (and workshop co-organizer) on "Coping with Increasing Demands on Government Data Centers, 2002-2003

Member, National Academy of Sciences/NRC Committee (and workshop co-organizer) on "Abrupt Climate Change: Science and Policy" 2001-2002.

Co-Chair, IGBP PAGES-WCRP CLIVAR Working Group, 1995-present

Member, American Meteorological Society Board on Higher Education, 2002-2005

Member, U.S. National Research Council National Committee for International Quaternary Association (INQUA), 1997-2003

COLLABORATORS

David Anderson, NOAA, Roger Bales, UA, Warren Beck, UA, Bonnie Colby, UA, Julie Cole, UA, Andrew Comrie, UA, Tim Finan, UA, Konrad Hughen, Woods Hole Oceanographic, Malcolm Hughes, UA, Jeff Kiehl, National center for Atmospheric Research, Steve Jackson, U. of Wyoming, John King, U. of Rhode Island, Christian Koeberl, U. of Vienna, Scott Lehman, U. of Colorado, Maria-Carmen Lemos, U. of Michigan, Diana Liverman, UA, Kam-biu Liu, Louisiana State U., Barbara Morehouse, UA, Dan Osgood, UA, Bette Otto-Bleisner, National Center for Atmospheric Research, Larry Peterson, U. of Miami, Chris Scholz, Syracuse U., Robert Schowengerdt, UA, Soroosh Sorooshian, UA, John Southon, U. of California, Irvine, Tom Swetnam, UA

GRADUATE STUDENTS AND POSTDOCTORAL RESEARCHERS

Graduate students: M.S.: Alex Robertson, Frank Urban (co-advisor), Kathy Likos, Allison Drake (current) Ph.D.: Mike Kerwin, Konrad Hughen, Jennifer Mengan (co-advisor), Carrie Morrill (co-advisor), Tim Shanahan (current), Jessica Conroy (current).

Post-docs: Elsa Cortijo, Teri King, Connie Woodhouse, Nan Schmidt (current).

TOTAL SINCE 1973

4 M.S. students; 6 PhD students; 4 Postdoctoral researchers

5 male, 9 female; 13 US citizens, 1 foreign nationals

GRADUATE ADVISOR

Thompson Webb III, Brown University

POSTGRADUATE ADVISORS

William Ruddiman (Columbia University), James Hansen (NASA Goddard Institute for Space Studies)

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Tom M.L. Wigley

Date and place of birth

[redacted]

Academic Record:

1959 B.Sc. (University of Adelaide)
Major subjects: Pure Mathematics III (Distinction), Applied Mathematics III (Distinction), Physics III (Credit)

1960 B.Sc. Hons (University of Adelaide)
Mathematical Physics (IIA)

1961-2 Commonwealth Bureau of Meteorology Training Course
(standing: first)

1967 Ph.D. (University of Adelaide)
(Mathematical Physics: Dissertation entitled 'Problems in Plasma Dynamics and Fluid Mechanics')

Awards:

1991 Member, Academia Europaea

1992 Sixth Annual Climate Institute Award

1993 *Who's Who in the World*, Eleventh Edition, 1993/1994

1997 Outstanding Scientific Paper Award, National Oceanic and Atmospheric Administration, Environmental Research Laboratories

1998 Norbert Gerbier - MUMM International Award for the paper entitled "A search for human influences on the thermal structure of the atmosphere" by B.D. Santer et.al., published in *Nature*, Vol. 382, July 1996

Biographical details:

Tom Wigley was born and educated in Australia. His undergraduate (honours) degree was in Mathematical Physics, completing three majors (Pure Mathematics, Applied Mathematics and Physics) instead of the normal two. He then trained as a meteorologist at the Bureau of Meteorology Training School (a 15-month course), subsequently working for a year as a research meteorologist before returning to university to do a Ph.D. His doctoral dissertation in the Department of Mathematical Physics, University of Adelaide, dealt with the kinetic theory of plasmas.

After graduating in 1967, he joined the faculty of the Mechanical Engineering Department at the University of Waterloo, Ontario, Canada where he stayed until 1975. Here he taught courses in applied mathematics, statistics, air pollution and meteorology. Apart from completing some work in plasma physics while on leave at the U.K. Atomic Energy Authority in Culham, U.K. during 1969, his main research interests during this period were in air pollution and aqueous geochemistry. The former included important work of the dynamics and dispersion of industrial plumes (particularly moist plumes), while the latter produced highly cited papers on the dissolution kinetics of calcite, chemical modelling and carbon isotope geochemistry.

In 1975, he moved to the U.K. to take up a "soft money" research job in climatology, in the then fledgling Climatic Research Unit in the School of Environmental Sciences at the University of East Anglia, Norwich, U.K. In 1978, on the retirement of Professor H.H. Lamb, he became Director of the Unit. Since then, the Unit has become firmly established as one of the world's leading centres in climatology. In 1993, he resigned as Director of the Climatic Research Unit to take up the position of Director of the Office for Interdisciplinary Earth Studies at the University Corporation for Atmospheric Research, Boulder, CO. He was appointed as an NCAR/UCAR Senior Scientist in 1994.

Wigley has published in diverse aspects of the broad field of climatology; from data analysis, to climate impacts on agriculture and water resources, to climate, sea level and carbon cycle modelling, to paleoclimatology. He has concentrated recently on facets of the greenhouse problem, and contributed as a lead author in each of the six recent major reviews of this problem (US DOE, WMO/UNEP/ICSU-SCOPE, and the 1990, 1992, 1994 and 1995 IPCC Reviews). He is one of the most highly cited scientists in the discipline.

Appointments:

1962-3	Meteorologist, Research Section, Commonwealth Bureau of Meteorology, Melbourne, Australia
1968-72	Assistant Professor, Department of Mechanical Engineering, University of Waterloo, Ontario, Canada
April-December 1969	Vacation Associate, United Kingdom Atomic Energy Authority, Culham Laboratory, Abingdon, Berks, U.K. (on study leave from University of Waterloo)
1972-75	Associate Professor, Department of Mechanical Engineering, University of Waterloo, Ontario, Canada
September 1972-April 1973	Visiting Fellow, Research School of Pacific Studies, Australian National University, Canberra, Australia (on study leave from University of Waterloo)
1975-78	Senior Research Associate, Climatic Research Unit, University of East Anglia, Norwich, U.K.
1978-93	Director, Climatic Research Unit, University of East Anglia, Norwich, U.K.
Jan. 1987-	Professor (personal chair in climatology), School of Environmental Sciences, University of East Anglia
1993-1994	Director, Office for Interdisciplinary Earth Studies (OIES), University Corporation for Atmospheric Research (UCAR), Boulder, CO
July 1994-	Senior Scientist, National Center for Atmospheric Research (NCAR), Boulder, CO.

Professional Consultant for:

United States Atomic Energy Commission
Ontario Hydro-Electric Power Commission
Canada Department of the Environment
Eastman Kodak Company
Tennessee Valley Authority

United Nations Development Programme, Morocco
U.K. Overseas Development Administration
Food and Agriculture Organization of the United Nations
British Petroleum Research Centre
U.S. Environmental Protection Agency
Electric Power Research Institute
U.K. Department of the Environment
United Nations Environment Programme, Nairobi
Center for Nuclear Waste Regulatory Analyses,
Southwest Research Institute
Hagler Bailly Consulting, Inc.
Lawrence Livermore National Laboratory
Science and Policy Associates, Inc.

Other Items:

(*indicates currently active)

National or International Committees

U.K. Department of the Environment Steering Group for Climatic Change
Natural Environment Research Council Stable Isotope Project Coordinating Panel
SCOR/IOC Committee on Climatic Changes and the Ocean (CCCO)
Panel on Paleoclimatology
Royal Meteorological Society Council
UNEP Correspondence Group on the Interface between Climate (Global Circulation) Models and Crop-Climate Models
Meteorology and Atmospheric Physics Subcommittee, British National Committee for Geodesy and Geophysics
International Commission on Climate of the International Association of Meteorology and Atmospheric Physics
Technical Advisory Panel, U.S. Environmental Protection Agency, Global Change Research Program
Chairman, Climate Hazards Coordination Group, Commission of the European Communities, Climatology and Natural Hazards Programme
Atmospheric Sciences Committee, Natural Environment Research Council
Forestry Research Co-ordination Committee, Review Group on Climatic Change and Forestry
Electric Power Research Institute, Global Climate Advisory Committee
Science Review Group, Hadley Centre for Climate Prediction and Research, U.K. Meteorological Office
*Electric Power Research Institute, ACACIA (A Consortium for the Application of Climate Impact Assessment) Planning Committee

*American Geophysical Union, Atmospheric Sciences Section, Climate and Paleoclimate Committee
*United Nations Environment Program (UNEP) Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility (GEF)

Editorial

Editorial Board, *Climatic Change* (Kluwer Academic Publishers)
Editorial Advisory Board member, *Atmospheric Sciences Library* (Kluwer Academic Publishers)
*Editorial Board, *Mitigation and Adaptation Strategies for Global Change* (Kluwer Academic Publishers)
*Editorial Advisory Board member, *Encyclopedia of Climate & Weather* (Robert Ubell Associates)
*Editorial Board, *Global Climate Change Digest* (Elsevier Science Publishing Co., Inc.)
*Editorial Board, *Climatic Dynamics* (Springer-Verlag)
*Referee for numerous journals

Publications (1990-present)

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Page last updated: 21 May 2001

Curriculum Vitae

PROFESSOR H.S. WHEATER

Name:	Howard Simon Wheater
Date of Birth:	[redacted]
Nationality:	[redacted]
Present Appointment:	Professor of Hydrology, Department of Civil & Environmental Engineering, Imperial College, University of London Head, Environmental and Water Resource Engineering Section, Department of Civil & Environmental Engineering, Imperial College Chairman, Centre for Environmental Control and Waste Management, Imperial College Director, MSc in Hydrology for Environmental Management, Imperial College

Degrees:

B.A.	(1st Class Honours) Engineering Science University of Cambridge	1971
M.A.	University of Cambridge	1974
Ph.D.	University of Bristol	1977

Awards:

Rolls-Royce Industrial Scholarship	1968
Entrance Exhibition, Queens' College, Cambridge	1968
Senior Scholarship, Queens' College, Cambridge	1971
Institution of Civil Engineers Overseas Premium	1984
British Hydrological Society President's Prize	1996

Membership of Professional Bodies and Learned Societies:

Fellow, Royal Academy of Engineering (FREng)	2003
Life Member, International Water Academy (Oslo)	1999
Fellow, Institution of Civil Engineers (C.Eng, FICE) (Member 1978)	1999
Member, British Hydrological Society (MBHS)	1983
Fellow, Royal Meteorological Society (F.Roy.Met.Soc)	1985
Member, American Geophysical Union	1983

Appointments:

1978-	**Imperial College of Science, Technology & Medicine**
1993-	Professor of Hydrology
1990-1993	Reader in Engineering Hydrology, Department of Civil Engineering
1987-1990	Senior Lecturer in Engineering Hydrology, Department of Civil Engineering
1978-1987	Lecturer in Engineering Hydrology, Department of Civil Engineering
1972-1978	**University of Bristol, Department of Civil Engineering**
1976-1978	Research Associate Integration of tidal power within the UK electricity generating network (SERC).
1975-1976	Research Assistant Regional analysis of rainfall-runoff relations. Effects of urbanization on flood runoff (Water Research Centre).

1972-1975 Research Assistant
Research into catchment hydrology, physical simulation of hydrological processes, rainfall-runoff simulation techniques for flood management.

1968-1972 **Rolls-Royce Ltd (Aero Engine Division).** Engineering apprenticeship
Fluid Mechanics research.

July 1978 to date Present Appointment

Teaching:

Lecturer to Engineering Hydrology MSc/DIC Course
Lecturer to Environmental Engineering MSc/DIC Course
Lecturer to Environmental Technology MSc/DIC Course
Lecturer to Environmental Diagnosis MSc/DIC Course
Current courses include: Urban Hydrology; Evaporation & Soil Water Processes; Catchment Hydrology; Irrigation
Lecturer to Civil Engineering and Civil and Environmental Engineering, MEng
Courses include: Environmental Engineering, Water Resources

Current Research Group:
8 research students.
5 research assistants.

Current Research Grants & Contracts:

Radionuclide transport in vegetated soils
UK Nirex 1988-2003, £2.8 million
National Infrastructure for Catchment Hydrology Experiments (NICHE)/Lowland Catchment Research (LOCAR)
Joint Infrastructure Fund 1999-2004, £2 million
Hydrogeochemical functioning of lowland permeable catchments: from process understanding to environmental management
NERC/Environment Agency 2002-2005, £500k
Generation of spatially-consistent rainfall data,
DEFRA 2003-2006, £680K

Research training: 32 Ph.D students, 80 MSc projects (past and present).

College Administration: Department of Civil & Environmental Engineering
Head, Water and Environmental Engineering Teaching Division,
Head, Environmental & Water Resource Engineering Section,
Chairman, Departmental Research Committee
Chairman, Centre for Environmental Control and Waste Management
Director, Engineering Hydrology MSc/DIC Course (1984-date)
Member, College ENTRUST Panel

Learned Society Activities, UK and International Scientific Administration:
British Hydrological Society
President 1999-2001
Chairman, Southern Section, 1984-96
Chairman, Research Sub-Committee, 1994-
Chairman, Scientific Programme Committee, Intnl Conf on Hydrology in a Changing Environment, Exeter, 1998
Natural Environment Research Council
Chairman, Land & Water Resources Review Panel, Centre for Ecology and Hydrology, 1996-
Chairman, LOCAR Working Group, 1998-9
Member, Freshwater Sciences Research Grants & Training Awards Committee, 1993-7
Member, HYREX Programme Committee, 1992-6

Member, Environmental Diagnostics Programme Committee, 1995-
Member, LOCAR Programme Committee, 1999-

MAFF Committee
Member, Flood Estimation Handbook Committee, 1994-1999

Environment Agency Flood Warning and Management
R&D Advisory Group, 1999-

DEFRA/EA Broad Scale Modelling Thematic Advisory Group 2000-

Chairman, UNEP-UK Working Group on Protection of the Supply and Quality of Freshwater (1991 Rio Summit prepcon)

Member, UNESCO Panel on Arid Zone Water Resource Development, 1995-

1993-97 Scientific Advisor to the Ministry of Foreign Affairs, Republic of Hungary with respect to the Gabcikovo-Nagymaros Barrage System (GNBS) case and Counsel and Advocate for Hungary, at the International Court of Justice, The Hague.

Editorial Activities:

Editor, Progress in Environmental Science, 1998-2001
Reviewer for: Proc. Roy. Soc., Water Resources Research, J. Hydrology, J. Hydrological Processes, Proc. Instn. Civil Engrs., Hydr. Sci. Jnl., etc.

External Examining & Assessment:

Referee: Stockholm Water Prize
Professorial Appointments: Elector, University of Cambridge; University of Tufts, USA
Academic Appointments/Promotions: University of Edinburgh, University of Khartoum, University of Jordan, University of Riyadh, Institute of Hydrology
DSc: University of Bristol
PhD: Universities of Bradford, Bristol, Birmingham, Lancaster, London, Reading, Salford, Southampton, Woollangong (Australia)
Research Grant Assessment: NERC, EPSRC, MAFF, British Council, Leverhulme Foundation, Royal Society, NOAA (USA), Swiss National Science Foundation, etc.

Overseas Development:

Overseas lecture courses given include:-

1979-1984	University College, Galway, Eire, International Hydrology MSc course
1982	University of Dar-es-Salaam, ANSTI/UNESCO International Hydrology MSc
1984	Catholic University of Chile, Santiago, Hydrology short course
1986	CETESB, Sao Paulo, Brazil, Hydrology & Water Quality short course
1990	Tsinghua University, Beijing, China, Water Quality lectures
1998	UNESCO Workshop, Amman, Jordan, Wadi Hydrology.

Recent Invited Lectures:

UNESCO Arab Region, IHP Workshops, Beirut (1999); American Geophysical Union Fall Meeting, San Francisco (1999); Intnl Water & Energy Conference, Las Vegas (2000); Intnl Arid Zone Hydrology Conference, Cairo (2000); Starker Lecturer, Oregon State University (2000); American Geophysical Union Fall Meeting, San Francisco (2002); Kyoto Water Summit (2003).

Principal Areas of Expertise:

Unsaturated zone and groundwater hydrology
Extensive research is being undertaken into modelling of unsaturated flow and solute transport, and the soil-plant-atmosphere continuum. A major (15 year) research contract with UK Nirex Ltd. involves lysimeter experiments of radionuclide transport in soils and vegetation uptake, and the integrated modelling

of these processes for safety assessment of radioactive waste management. 1, 2 and 3D models have been developed; current research is focussing on redox-dependent geochemical interactions and the representation of uncertainty.

A major (£10million) national initiative (LOCAR) has been developed to study lowland permeable catchments, including a £2million infrastructure grant to Imperial College. Three catchments have been instrumented in detail to monitor hydrological fluxes and water quality, including special instrumentation to investigate aquifer properties and stream-aquifer interactions. See also surface water quality, below.

Research in groundwater contaminant transport has included numerical methods for advectively-dominated contaminant transport, field and modelling studies of saline intrusion, field and laboratory studies of non-aqueous phase liquids in groundwater, laboratory and numerical modelling of microbial de-nitrification processes, and modelling of chemically-reactive contaminant transport. A recent EPSRC/BG project has investiged microbial degradation of organic pollutants at a Gas works site and developing models for coupled flow, transport, geochemical interactions and microbial degradation. Other research is developing a framework for uncertainty analysis for well protection zones and investigating the value of data in risk reduction.

Groundwater recharge studies include UK applications and research into surface water/groundwater interactions in ephemeral flow systems, in Saudi Arabia, Oman, Botswana and the USA.

Recent consultancy includes advice to British Nuclear Fuels Ltd. on hydrological, hydrogeological and groundwater modelling studies at the Drigg nuclear repository, Cumbria and a study of Karst groundwater flooding in the Irish Republic.

Arid zone hydrology and water resource development
Major projects include:- Northern Oman Flood Study (1981) (Principal Investigator) and Five Wadis Study, S.W. Saudi Arabia (1985-88) (Senior Expert) in addition to numerous smaller-scale flood and water resource studies in the Middle East and Africa (Yemen, Jordan, Oman, UAE, Botswana). Published research includes rainfall analysis and simulation, rainfall-runoff modelling, groundwater recharge. Current research includes sustainable development of alluvial groundwater (Botswana), stochastic spatial-temporal rainfall modelling and rainfall-runoff processes (Arizona), NASA-funded University of Arizona real-time hydrological modelling project.

Rainfall modelling
Stochastic models of rainfall have been developed for various applications with support from NERC and DEFRA . Poisson-process based single site models have been developed for UK and US applications, and are currently being extended for regional UK application in conjunction with continuous simulation rainfall-runoff modelling for flood design and management. A suite of models for spatial rainfall analysis and spatial-temporal simulation has been developed, ranging from radar-based continuous space-continuous time methods to Generalised Linear Modelling of daily rainfall including both temporal and spatial non-stationarity. Applications include modelling impacts of climate variability on flooding in W. Ireland and next-generation rainfall-runoff modelling for UK flood practice.

Rainfall-runoff modelling, flood hydrology and urban hydrology
Major flood investigations have been carried out for the Water Research Centre, Severn-Trent Water, Thames Water, the Basque Regional Government, the Oman Government and numerous consultants. Recent UK studies have focussed on urbanisation effects, with respect to a new town development in Hampshire. New point and spatial rainfall modelling methods are being

developed for continuous simulation modelling with NERC and MAFF support. A new suite of rainfall-runoff modelling software has been developed with NERC support for regionalisation of rainfall-runoff models, with application to the UK, USA and Southern Africa. A recent study of Karst flooding problems in W. Ireland has included analysis of non-stationarity in rainfall (Southern Water, on behalf of Irish Govt.). Prof. Wheater is currently developing a national programme of research on land use impacts on flooding as part of a £5million EPSRC research programme.

Surface water quality
Current research funded by NERC and the Environment Agency of England and Wales is focussing on the development of decision support models of nutrients for lowland catchment management, including diffuse and point source loads and in-stream processes. A recent EU contract has developed modelling systems for nutrient response of the Wash catchments in Eastern England, as a pre-pilot study for the EU Water Framework Directive. Research into hydrology and water quality in upland Britain has addressed surface water acidification (Royal Society funding (in collaboration with Norwegian and Swedish Academies of Science) and NERC (Environmental Diagnostics) support). Published research includes field process and model identification studies. Water quality research overseas has included development of integrated river and lake water quality models for decision support for pollution control (EU, in collaboration with Tsinghua University, Beijing and Suez Lyonnaise-des-Eaux).

Large-scale hydrological modelling
Research into improved hydrological modelling for global climate models has included new methods for disaggregation of spatial rainfall and evaluation of SVAT schemes at point and catchment scale, contributing to the NERC TIGER programme and the GCIP study of the Mississippi. Current research in collaboration with the Hadley Centre is focussing on improved modelling of climate change impacts over the Nile.

International Consultancies & Research Contracts:

Royal Oman Police & Diwan of HM Sultan Qaboos of Oman; Ministry of Agriculture & Water, Riyadh (as consultant to Dames & Moore); Royal Commission of Jubail, Saudi Arabia; Dar Al Handasah (flood protection of Medinah & Mecca); Howard Humphries (UAE); Balfour Beatty International (Sri Lanka); Maunsells (Oman); Zambian Cons. Copper Mines; CETESB, Sao Paulo (Brazil); Basque Regional Government (Spain); Dar Al Handasah (Yemen); Shimizu Corporation (Japan); European Community (Nepal); JCE (Jordan); Travers Morgan (Oman); Government of Hungary; Southern Water Global (Eire); DANIDA (Botswana), European Union (China), UNESCO.

UK Consultancies and Research Contracts:

Anglian Water Authority, Severn Trent Water Authority, Thames Water Authority, Royal Society, UK Nirex Ltd., British Nuclear Fuels Ltd., Balfours, W.S. Atkins, Watson Hawksley, Hydro-logic Ltd., Electrowatt, Her Majesty's Inspectorate of Pollution, Eagle Star Property Management, Natural Environment Research Council, Binnie and Partners, Thames Water Utilities Ltd, EPSRC, Halcrow, Environment Agency, Department of Environment, Food and Rural Affairs.

Appendix F

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Bad to the Bone:

Analysis of the Federal Maximum Contaminant Levels for Plutonium-239 and Other Alpha-Emitting Transuranic Radionuclides in Drinking Water

Arjun Makhijani, Ph.D.

Institute for Energy and Environmental Research

June 2005

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Acknowledgements

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This study is part of IEER's technical support project for grassroots groups on nuclear weapons related issues in the United States. We gratefully acknowledge the generous support of John Merck Fund, Ploughshares Fund, Public Welfare Foundation, Stewart R. Mott Charitable Trust, Town Creek Foundation, Colombe Foundation, Education Foundation of America, Ford Foundation, New Cycle Foundation, and the New-Land Foundation, as well as the individual donors who give generous support to our work.

Arjun Makhijani
Takoma Park, Maryland
June 2005

Main findings

The limit for gross-alpha contamination of drinking water is based on science that is over four decades old. It is an unsatisfactory basis for public health protection that is at variance with the content and intent of the safe drinking water regulations for radionuclides that were first promulgated in 1976. Specifically, the scientific understanding of how plutonium and other alpha-emitting, long-lived transuranic radionuclides behave in the human body, and of the magnitude of radiation dose they deliver to various organs, has changed a great deal, beginning with revisions first published by the International Commission on Radiological Protection in the late 1970s. The United States Environmental Protection Agency (EPA) first officially adopted these changes for assessment of radiation doses in its Federal Guidance Report 11, published in 1988. More changes have occurred since that time, which allow estimation of doses to people of various ages including infants.

EPA last reviewed its radionuclide standards in the year 2000 as part of a legally-mandated process. But despite the fact that it had been more than a decade since the publication of Federal Guidance Report 11, the EPA chose not to revise the maximum contaminant levels (MCLs) for alpha-emitting, long-lived transuranic radionuclides in that review. The next scheduled review of radionuclide MCLs in drinking water will occur in 2006.

This report provides an analysis of the changes in the dose estimates to the maximally exposed organ that have occurred since the MCL limits for radionuclides were first set in 1976. It presents the scientific underpinning for tightening the MCL for alpha-emitting, long-lived transuranic radionuclides by a factor of one hundred compared to the present gross alpha MCL of 15 picocuries per liter (pCi/L).

1. Drinking water maximum contaminant limits for plutonium-239 and other alpha-emitting, long-lived transuranic radionuclides are about a hundred times too lax.

The most recent science, as published by the EPA, indicates that the radiation dose to the most exposed organ, the surface of the bone, from drinking water contaminated to the maximum allowable limit is about a hundred times greater than the dose to what in 1976 was regarded as the maximally exposed organ (the marrow-free skeleton). This indicates that the drinking water standards are about a hundred times too lax, as measured by the intent of the regulations when they were first promulgated. The current MCL for each alpha-emitting, long-lived transuranic radionuclide separately is 15 picocuries per liter.

2. Drinking water regulations – when they were first set - explicitly included military sources of radionuclides – specifically, fallout from testing.

3. A much tighter MCL for alpha-emitting, long-lived transuranic radionuclides is needed to prevent lax approaches to cleanup of weapons sites.

Once drinking water is polluted to a few picocuries per liter, which is many times the indicated MCL by current science, it will be essentially impossible to remediate it. A stringent MCL is therefore needed as a guide to the United States Department of Energy (DOE) in its cleanup and as a preventive measure for protecting public water supplies.

4. The vast majority of public water systems will incur no costs from the proposed change and a few would incur a one-time monitoring cost.

Since the vast majority of public water systems have alpha-emitting, long-lived transuranic radionuclide levels orders of magnitude below the proposed MCLs (from weapons testing). They are not at risk for further contamination. No sampling, monitoring, or remediation is needed for these systems.

For public water systems that are hydrologically or hydrogeologically connected to DOE sites, where large amounts of plutonium waste were dumped or were disposed of, a one-time initial sampling and analysis should be done. If found clean, further sampling need not be conducted provided the DOE maintains a thorough water sampling program for surface and ground waters on site and reports the results publicly. It is presently mandated to do that, so no additional expenses would be incurred in this regard.

5. The relaxation of DOE goals in regard to cleanup and the lack of national cleanup standards necessitates an urgent revision of MCLs for alpha-emitting, long-lived transuranic radionuclides, if critical drinking water systems are to be protected for the long-term.

The timing and urgency of the main recommendation of this report, that MCLs for alpha-emitting, long-lived transuranic radionuclides be tightened by one hundred times (see below), derives largely from the very large inventories of alpha-emitting, long-lived transuranic radionuclides at several (DOE) nuclear weapons sites. Some wastes containing these radionuclides (both low-level and transuranic wastes) were dumped in unlined trenches in cardboard boxes and similar non-durable packaging in the early decades of the Cold War. The primary sites are in Idaho, Nevada, New Mexico, South Carolina, Tennessee, and Washington state. Further, the combined plutonium-238, -239, and -240 inventory contained in DOE high-level waste tanks at Savannah River Site is over a million curies. In 2004, Congress gave DOE the latitude to reclassify some of this waste. DOE can now grout high-level waste in place by reclassifying it as waste incidental to reprocessing. Congress set no limit on the total residual radioactivity content of the grouted waste. Since grouting is essentially irreversible, it is imperative the DOE implement the law in a manner that is compatible with the protection of the Savannah River, which is increasingly used by more people as a source of drinking water in South Carolina and Georgia.

Recommendations

The EPA is going to review the radionuclide standards for drinking water as part of a scheduled process in 2006. We urge the EPA to revise the drinking water regulations in regard to alpha-emitting, long-lived transuranic radionuclides. The Department of Energy should evaluate its cleanup and decommissioning efforts with a view to meeting the tighter standard.

1. The EPA should reduce its maximum contaminant levels for all alpha-emitting, long-lived transuranic radionuclides, combined, by one hundred times to an MCL of 0.15 picocuries per liter during its 2006 review of radionuclide standards for drinking water.

EPA should set a combined maximum contaminant level for alpha-emitting, long-lived transuranic radionuclides of 0.15 picocuries per liter. If only one of the radionuclides in question were present, then the limit for that radionuclide would be 0.15 picocuries per liter. The radionuclides included are: neptunium-237, plutonium-238, plutonium-239, plutonium-240, plutonium-242, americium-241, and americium-243. These changes should be made as part of the EPA's review of radionuclide standards in drinking water that is scheduled for 2006.

2. The DOE should fund a one-time baseline sampling and analysis for public water systems that are hydrologically or hydrogeologically connected to DOE sites with major plutonium wastes or dumps.

DOE sites with wastes buried underground or in tanks containing more than 100 curies of alpha-emitting, long-lived transuranic radionuclides should be considered to have potential risks to drinking water. These sites include the Savannah River Site, Hanford, Idaho National Laboratory, Los Alamos National Laboratory, Oak Ridge, and the Nevada Test Site. Testing of downstream water for the purpose of providing a baseline level of contamination is desirable and should be funded by the DOE since the tiny amounts of alpha-emitting, long-lived transuranic radionuclides in current water supplies are due to military-related atomic energy activities (fallout from testing).

3. The DOE should evaluate its on-site water monitoring from the point of view of the proposed standard and intensify it, if necessary. Resources for independent verification should be provided by the federal government.

The DOE currently carries out extensive surface and ground water monitoring. This may be sufficient for the purposes of providing assurance that downstream water resources continue to be protected from contamination with alpha-emitting, long-lived transuranic radionuclides. If not, the existing programs should be intensified.

The federal government should also provide states and public water system authorities that are hydrologically or hydrogeologically contiguous to DOE sites with the funds to conduct independent checks on DOE's on-site and off-site water monitoring. Such funds would better be provided through the EPA, rather than through the DOE, in order to assure the independence of the monitoring and the continuity of the funding.

4. A separate limit of detection of each alpha-emitting, long-lived transuranic radionuclide of 0.01 picocuries per liter should be set.

5. The DOE should make public the source code for the model that is used to assess the impact of residual radioactivity on food, water, and the environment.

Argonne National Laboratory developed a "family" of programs to assess the radiological impact of environmental contamination by radionuclides. The main one, called simply RESRAD, is used to assess the impact of residual radioactivity in the soil on human beings, by estimating radiation doses by a variety of pathways, such as food and water and re-suspended soil. Its source code is not public. It does not incorporate dose conversion factors for children, infants, or fetuses at various times in their development. Its internal structure and its effects on the resulting estimates of doses and risks are not available for independent scrutiny. We strongly recommend that the RESRAD source code be made public, so that it can be examined and improved in the manner of the operating system Linux. The government, of course, need not adopt any changes that are made by the public unless it finds them useful for implementing environmental regulations. But there is no reason for holding a source code paid for by taxpayer dollars secret, particularly as billions of dollars are being spent on cleanup decisions based on the results generated by the RESRAD program.

I. Introduction

The National Primary Drinking Water Regulations specify rules that will protect drinking water and will maintain it in a state that is safe to drink. In these regulations, 40 CFR 141.66 sets safe drinking water standards for radionuclides in public water supplies under the Safe Drinking Water Act.[1] These standards are set in two ways: by specifying maximum contaminant levels of drinking water or by specifying maximum allowable dose to the whole body or any organ as a result of ingestion of drinking water. However, as demonstrated below, the concentration limits currently in effect for alpha-emitting transuranic radionuclides in drinking water are grossly inadequate to protect public health. Achievement of reductions in concentration is necessary to protect public health.

The current maximum contaminant level (MCL) as set forth in 40 CFR 141.66(c) for gross alpha particle activity, including radium-226, but excluding uranium and radon, is 15 picocuries per liter. There is a sub-limit for radium-226 and radium-228, combined, of 5 picocuries per liter (including any naturally present radium-226 and radium-228). For instance, if water is contaminated with plutonium-239 alone, the level of contamination could reach as high as 15 picocuries per liter if no other qualifying alpha-emitting radionuclides were present. If radium-226 is present to the maximum allowable limit of 5 picocuries per liter,[2] then the rule allows a maximum contaminant level for gross alpha of 10 picocuries per liter. For instance, if plutonium-239 were the only alpha-emitting, long-lived transuranic radionuclide present, the MCL for plutonium-239 in this case would be 10 to 15 picocuries per liter, depending on the concentration of radium-226.

This standard was set in 1976, based on scientific assessments done in the late 1950s by the International Commission on Radiological Protection (ICRP) and the National Committee on Radiation Protection and Measurements (NCRP), a United States agency, and published as ICRP Publication 2 and in abbreviated form in the U.S. by the National Bureau of Standards as NBS Handbook 69.[3]

But the science has changed since then. As a result of these changes, as well as changes in the dose conversion factors adopted by the EPA since that time, dose estimates to the most exposed organ, while complex to assess, are far greater than those implied by the limit of 10 to 15 picocuries per liter when evaluated according to the methods specified in NBS 69.

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[1] The text now published under 40 CFR 141.66 were formerly published under 40 CFR 141.15 and 141.16. (CFR = Code of Federal Regulations). See also SDWA.

[2] This assumes that no radium-228 is present. The radium MCL in the rule is set for the combined concentration of Ra-226 and Ra-228. The former is an alpha-emitter and the latter is a beta-emitter. Hence the latter is omitted from the gross alpha part of the rule.

[3] ICRP-2, 1959 & NBS 69. NBS 69, which also bears the series title NCRP Report No. 22, is a recommendation of the National Committee on Radiation Protection and Measurements, which is now known as the National Council on Radiation Protection and Measurements (NCRP). Tables and scientific discussion are drawn from ICRP-2, 1959. NBS Handbook 69 was published in 1959 and then again, with an added table and errata, in 1963. We cite NBS 69 throughout this report. The dose conversion factors, the scientific content, and other details in NBS 69 are the same as those in ICRP 2. ICRP 2 was published by the International Commission on Radiological Protection in 1959. The NCRP was (and is) a participating organization in ICRP.

It is therefore necessary that the MCLs of transuranics in drinking water be changed in order that the MCL remain within the spirit and framework of the standards as promulgated in 1976. This can be done based on the dose conversion factors that the EPA has since adopted and published in Federal Guidance Report 11,[4] which are the basis for present EPA regulation and risk estimation. They were published in 1988. The EPA has since published Federal Guidance Report 13. This is the most recent EPA scientific publication relevant to safe drinking water standards. The scientific basis of this guidance (ICRP 72)[5] has been adopted for some federal dose calculation purposes, but not yet sanctioned for use in regard to assessing doses from drinking water. In this report, we will consider the changes in the drinking water standards for alpha-emitting, long-lived transuranic radionuclides.

The basis for the needed MCL change is the potential danger that residual radioactive pollutants remaining after cleanup of the Cold War nuclear weapons production sites will pose to individuals in this generation and future generations. Of particular concern are the long-lived transuranic radionuclides neptunium-237, plutonium-238, plutonium-239, plutonium-240, plutonium-242, americium-241, and americium-243. All of these are man-made radionuclides.

II. National Primary Drinking Water Regulations - Radionuclides

In 1959, the National Bureau of Standards published its Handbook 69 (NBS 69), which established the maximum permissible average concentrations of radionuclides in air and water calculated on the basis of a 5 rem dose to the whole body, and a 15 rem dose to the most exposed organ, also called critical organ, for each pathway and solubility class.[6] As discussed below, a somewhat different method was used for bone-seeking radionuclides like radium-226 and plutonium-239. All these limits were established for radiation workers.[7]

ICRP 2 and NBS 69 also set forth the scientific approach for calculating these maximum permissible concentrations, with ICRP 2 providing significantly greater detail. A table adding data and correcting some errors in the 1959 version of NBS 69 was published in 1963, along with the original 1959 NBS 69 publication. In the text that follows, the term NBS 69 refers to this 1963 publication, since the EPA based its drinking water standards on it.

In March 1975, the EPA proposed, for the first time, National Primary Drinking Water Regulations for public water systems.[8] The proposed rules for radionuclides were published in August of that year.[9] The regulations for contaminants other than radionuclides were promulgated in December 1975;[10] the rules for radionuclides were promulgated in July 1976.[11] The MCLs and dose limits were

[4] FGR 11, 1988.
[5] ICRP-72, 1996.
[6] NBS 69.
[7] Until 1958 there were no separate radiation exposure limits for the public. They were the same as for workers. In 1958, the dose limits for the public were set at one-tenth the maximum allowable doses for workers (NBS 59 Addendum, page 5).
[8] Fed. Reg. 1975/03/14.
[9] Fed. Reg. 1975/08/14.
[10] Fed. Reg. 1975/12/24.
[11] Fed. Reg. 1976.

originally codified in 40 CFR 141.15 and 40 CFR 141.16, both of which have since been renumbered and consolidated, without change, into 40 CFR 141.66.[12]

In the final rule of July 1976, the EPA promulgated Maximum Contaminant Levels (MCLs) for radionuclides in public water systems either by directly specifying the MCL values (in picocuries per liter) or by specifying dose limits, which implied MCLs for drinking water, based on an adult water intake of two liters per day. The science underlying the standards was published in NBS 69. The drinking water limit for alpha-emitting radionuclides excluding uranium and radon, but including radium-226, was set at 15 picocuries per liter. There was a separate sub-limit for radium-226 and radium-228 of 5 picocuries per liter. For beta and photon-emitters the dose limit was 4 millirem per year (mrem/year) to the most exposed organ. (For radionuclides that are approximately uniformly distributed in the body, such as cesium-137 and tritium, the most exposed organ is considered to be the whole body.) The MCLs for beta- and photon-emitters were set according to the 4 mrem/year criterion, with a slight variation from this being adopted for tritium and for strontium-90. The limits for these categories have remained the same since that time.[13] Detection limits and analytical methods for radionuclides were set forth in 40 CFR 141.25.

The rule as originally promulgated discusses natural and man-made radionuclides separately. However, it does not explicitly discuss the alpha-emitting transuranic radionuclides that are the subject of this report, but specifies only a gross alpha MCL. The gross alpha limit excludes only uranium and radon and it automatically includes the alpha-emitting, long-lived transuranic radionuclides of concern here, as these radionuclides are explicitly listed in the tables in NBS 69.

The following statement indicates the intent of the regulation that first established maximum contaminant limits for man-made radionuclides in drinking water:

> Man-made radioactivity may enter the public water systems from a variety of sources. Such contamination is usually confined to systems utilizing surface waters. Past deposition of fallout materials from nuclear weapons tests, particularly strontium-90 and tritium, is probably the most important source of contamination. The dose equivalent to individual users of public water systems in some areas of the United States from this pathway is in the range of 1 to 2 millirem (mrem) per year. At present, the dose equivalent from public water systems contaminated by effluents produced in the nuclear fuel cycle is probably only a fraction of that due to fallout materials, though perhaps ranging up to 0.5 mrem per year. The dose equivalent from effluents released by medical, scientific, and industrial users of radioactive materials that enter the public water systems has not been fully quantified. Taken as a whole these users handle much smaller amounts of radioactivity than nuclear power facilities but (with the exception of tritium) their liquid releases and the resultant doses to man may be somewhat comparable.
>
> EPA recognizes that the national use of radionuclides in medicine and industry and the utilization of nuclear power to supply energy needs will unavoidably lead to some radioactivity entering the aquatic environment so that the quality of some surface waters is likely to decrease *slightly* in the future. *Even though the increase of radioactivity in drinking-*

[12] The changed numbering can be found in the 2004 edition of 40 CFR 141.
[13] The limits were first specified in 40 CFR 141.15 and 40 CFR 141.16. An MCL for uranium of 30 micrograms per liter was established on December 7, 2000, in 40 CFR 141.66 (e), based mainly on the heavy metal toxicity of uranium to the kidney. The revision to 40 CFR 141 was announced in Fed. Reg. 2000.

water will normally be small, the Agency believes that the risk of future contamination warrants vigilance. It is the intent of the proposed monitoring and compliance requirements to provide a mechanism whereby the supplier of water can be cognizant of changes in the level of radioactivity in its water sources, so that the appropriate remedial measures may be taken.[14]

While this passage does not explicitly mention nuclear-weapons-related activities and facilities, their inclusion is clearly indicated, notably from the fact that fallout from nuclear weapons testing is discussed as the most important source of surface water contamination. It is also clear from the discussion of fallout that the intent was to consider the most important sources of contamination. The mention of industrial users also does not exclude weapons facilities (which handle radioactivity in considerably smaller amounts when compared to reactor core and spent fuel inventories in the commercial nuclear power sector). It is implicit, therefore, that there was no intent to exclude alpha-emitting man-made radionuclides from the vigilance and concern of the regulations.

The understanding of what is the most exposed organ for alpha-emitting, long-lived transuranic radionuclides has evolved.

The level of doses at which concern and vigilance were warranted in regard to man-made radionuclides was a few millirem per year. The maximum contaminant level for photon- and beta-emitters was set to 4 millirem per year because they were considered to be the most important sources of man-made radioactivity:

> Considering the sum of the deposited fallout radioactivity *and additional amounts due to effluents from other sources currently in existence*, the total dose equivalent from made-made radioactivity is not likely to result in a total body or organ dose to any individual that exceeds 4 millirem per year...[15]

This quote shows that the sum of the doses from military and civilian activities was considered in evaluating the limit of 4 millirem per year that was set for beta- and photon-emitters in 1976. In fact, fallout was the single most important component of the dose from man-made radionuclides evaluated by the EPA.

The cancer fatalities from whole body exposure to 4 millirem per year from man-made beta and photon sources of radioactivity were estimated at between 0.4 and 2.0 deaths per year per million people exposed. This was comparable to the exposure to natural radium-226 and radium-228 estimated at 0.7 to 3 fatal cancers per year per million persons at the level of 5 picocuries per liter selected as the maximum contaminant level. The slightly higher fatality rate for radium (a factor of 1.2 to 1.8) at the allowable limit of 5 picocuries per liter must be seen in the context that it is a ubiquitous, naturally occurring radionuclide, with considerable variation in drinking water concentrations (which the EPA estimated at the time to be between 0.1 and 60 picocuries per liter).[16] The EPA imposed considerable costs on public water systems by requiring remediation of those systems that had levels of radium greater than 5 picocuries per liter in order to bring them to the

[14] Fed. Reg. 1975/08/14, page 34324, emphasis added.
[15] Fed. Reg. 1975/08/14, page 34325, emphasis added.
[16] Fed. Reg. 1975/08/14, page 34325.

regulatory level. Further, the EPA mandated testing of water supplies and established detection limits (at the 95 percent confidence limit) that were considerably below the MCLs set forth in the regulation.[17] The detection limits were set in order to ensure that the mandated MCLs would not be exceeded. In considering the mandated MCLs and detection limits, the EPA took technical, health, and economic considerations into account.

In looking to the future, the EPA did not anticipate that man-made radionuclides would result in a dose of more than 4 millirem per year from drinking water, because it believed that fallout would remain the main source and that this source would decrease with time due to the ban on atmospheric tests[18]:

> The 4 millirem per year standard for man-made radioactivity was chosen on the basis of avoiding *undesirable future contamination of public water supplies as a result of controllable human activities.* Given current levels of fallout radioactivity in public water supply systems and their expected future decline, and the degree of control on effluents from the nuclear industry that will be exercised by regulatory authorities, it is not anticipated that the maximum contaminant levels for man-made radioactivity will be exceeded except in extraordinary circumstances.[19]

There is no explicit exclusion of alpha-emitting transuranic radionuclides from this statement. Also, the National Primary Drinking Water regulations explicitly mention strontium-90 in fallout. Hence, the regulations explicitly took into account a man-made radionuclide from a military activity – nuclear weapons testing – in protecting public water supplies from radioactive contaminants.. Further, the critical organ listed in NBS 69 for strontium-90 and for the transuranic radionuclides that are the subject of this report was the same – the bone.

The language of the regulation indicates that the MCL in the range of 10 to 15 picocuries per liter for the alpha-emitting, long-lived transuranic radionuclides set at the time would have corresponded approximately to a bone dose of a few millirem per year according to then-prevailing estimation methods. We show in the next section, *A. Bone dose estimation in ICRP 2*, that was indeed the case. However, present-day methods result in far higher dose estimates, as discussed below in the section after next, *B. Bone dose estimation, present-day dose conversion factors*.

A. Bone dose estimation in ICRP 2

Bone dose was estimated in ICRP 2 (and NBS 69) as dose to the skeletal bone without the marrow. The reference bone-seeking radionuclide used by ICRP 2/NBS 69 was radium-226 and the reference amount was 0.1 microcurie of radium-226 in the skeletal bone. The amount of energy deposited in the bone each year corresponded to an absorbed radiation dose rate of about 3 rad per year, not accounting for relative biological effectiveness (RBE) of alpha particles. ICRP 2 used an RBE = 10, thus yielding an annual dose for a 0.1 microcurie body burden of radium-226 of 30 rem per year,

[17] Fed. Reg. 1976, page 28404.

[18] Of the nuclear weapons states, only China was testing in the atmosphere at the time. China conducted its last atmospheric nuclear test in 1980.

[19] Fed. Reg. 1975/08/14, pages 34325-34326, emphasis added.

according to the then-prevailing method of estimation.[20] Doses were calculated by estimating a whole-body or organ burden of the radionuclide assuming lifetime ingestion or inhalation at the MCL, for which values were given either in the workplace (40-hour workweek) or continuously (168 hours per week).

Some radionuclides, such the beta-particle-emitting strontium isotopes, were recognized even then to behave somewhat differently than radium-226 in the body in that they tended to concentrate in certain parts of the bone, while radium-226 is distributed less unevenly. Research since that time has validated that observation. For instance, the alpha-emitting, long-lived transuranic radionuclides tend to concentrate adjacent to the endosteal cells on the bone surface. Hence, these radionuclides deliver a considerably higher dose to the endosteal cells than would be indicated by an assumption of uniform distribution over a marrow-free skeleton.

In order to account for non-uniform distribution of several bone-seeking radionuclides, ICRP 2 suggested (and used) a factor of safety of 5 for such radionuclides when estimating maximum permissible levels of radionuclides in air and water for workers.[21] The effect of this safety factor was to reduce the maximum allowable dose for workers from alpha-emitting, long-lived transuranic radionuclides to 6 rem per year, compared to 30 rem per year for radium-226. Correspondingly, the maximum permissible concentrations were also reduced by a factor of five.

This intent to reduce the maximum permissible dose to the bone by a factor of about 5 can be confirmed by estimating the dose corresponding to the maximum permissible burden of plutonium-239 in the bone of 0.04 microcuries specified in NBS 69. Using a value of 5.15 MeV per alpha particle and an RBE = 10, the annual dose corresponding to a bone burden of 0.04 microcuries of plutonium-239 is about 5.5 rem per year. Since the whole body and organ burdens in NBS 69 are rounded, this is in close agreement with the figure of 6 rem inferred by applying the safety factor of 5 to the radium-226 dose of 30 rem.

The MCL for soluble plutonium-239 set in NBS 69 corresponding to the 6 rem per year bone dose would be 5×10^{-5} μCi/cc, or 5×10^{-2} μCi/liter, or 50,000 pCi/liter. The current drinking water limit of 15 picocuries per liter in the absence of radium-226 corresponds to a bone dose of about 1.8 millirem per year (or 1.2 millirem per year corresponding to 10 picocuries per liter, which is the MCL for plutonium-239 in the presence of radium-226 at its MCL of 5 picocuries per liter).[22]

The bone doses corresponding to 15 picocuries per liter for various alpha-emitting, long-lived transuranic radionuclides are shown in Table 1, estimated according to the method in NBS 69 which was the prevailing scientific understanding in 1976, when the EPA first promulgated the MCLs for radionuclides. All of these calculations follow NBS 69 in assuming soluble radionuclides when estimating doses to the bone from drinking water. An assumption of soluble forms of the radionuclides is reasonable (and in keeping with the regulation as originally promulgated) since it is likely that the radionuclides will be in that form if they are present in drinking water. The presence of insoluble colloidal forms is not excluded, but the likely presence of soluble forms makes it necessary to use the uptake coefficient for that form, which has been done throughout this report.

[20] ICRP-2, 1959, page 13 and FGR 11, 1988, page 18. The current value of the RBE, often called the quality factor in the regulatory context, for alpha particles is 20.

[21] FGR 11, 1988, pages 16-19.

[22] This assumes that no Ra-228 is present.

Table 1: Bone dose from alpha-emitting, long-lived transuranic radionuclides according to NBS 69 (ICRP 2)

Radionuclide	Bone dose at 15 pCi/L in mrem/y
plutonium-238	1.8
plutonium-239	1.8
plutonium-240	1.8
americium-241	1.8
neptunium-237	3.0

Note: These doses are estimated by proportionally reducing the doses for these radionuclides corresponding to the MCLs listed in NBS 69, which correspond to a bone dose of 6 rem per year. The figure of 6 rem for bone dose for alpha-emitting, long-lived transuranic radionuclides is derived by applying the safety factor of 5 to the bone dose of 30 rem for radium-226 (see text). NBS 69 lists the kidney as well as bone as the target organs for americium-241. We consider only bone-dose-related MCLs in this report. Plutonium-242 dose is the same as plutonium-239.

The NBS 69 (ICRP 2) calculations for bone dose are not directly comparable to present-day methods of dose estimation. NBS 69 specifies annual doses to the "bone," defined as the marrow-free skeleton. But Federal Guidance Report 11, which lays out methods of dose estimation that are the basis of EPA regulations at the present time, defines committed doses to two different parts of the bone – the "red marrow" and the "bone surface."[23] The latter is defined as the most exposed organ in Federal Guidance Report 11 for alpha-emitting, long-lived transuranic radionuclides because they concentrate adjacent to the endosteal cells, which are located on the bone surface. In other words, the understanding of what is the most exposed organ for alpha-emitting, long-lived transuranic radionuclides has evolved along with the methods of dose estimation since the MCLs were promulgated in 1976.

As shown in Table 1, the range of doses to the bone using a limit of 15 picocuries per liter for alpha-emitting, long-lived transuranic radionuclides estimated according to NBS 69 is approximately from 1.8 to 3 millirem per year. This is about the same as the doses estimated from man-made radionuclides, notably in fallout, in the safe drinking water regulation as promulgated in 1976. Hence we can infer that the intent of the rule was to limit the dose from drinking water to the maximum exposed organ, defined then as the bone, to approximately 2 millirem per year.

While the bone surface was not specified as a target organ for dose calculations in 1976, when the safe drinking water regulations were promulgated, it is possible to estimate the dose to the endosteal cells at a level of drinking water contamination of 15 picocuries per liter based on the NBS 69 dose conversion factors. For plutonium-239, the annual dose to the endosteal cells would be about 26 millirem per year.[24] The bone surface dose for the other radionuclides shown in Table 1 are about the

[23] There is more recent federal guidance on the subject in *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, Federal Guidance Report No. 13. Washington, D.C., Environmental Protection Agency, 1999 (hereafter cited as FGR 13). This report also uses the same two parts of the bone as the target organs for which doses are calculated.
[24] This estimate is derived by using a mass of 120 grams for the endosteal cells corresponding to an overall skeletal mass of 7,000 grams. Further, it is assumed that one-fourth of the energy is deposited in the 120-gram mass of the endosteal cells, with the rest being deposited in other parts of the bone. This mass of the endosteal cells is specified in Federal Guidance Report 11. This gives a ratio of dose to endosteal cells of (7000/120)*0.25 = 14.6. All calculations assume that the dose to the bone permitted under NBS 69 at the specified MCL was 6 rem per year. There is some imprecision

same, except for Np-237, for which the figure is about 44 mrem per year. These estimated doses, which take into account the evolution of scientific understanding in the years after 1976, are far higher than what the safe drinking water regulations allow. The implied dose to the endosteal cells is about a factor of 14.6 higher for plutonium-239. All of these calculations were done within the framework of NBS 69, which was (and continues to be) the scientific guidance for the safe drinking water regulation.

B. Bone dose estimation, present-day dose conversion factors

Scientific understanding of radiation doses and harm from intake of radionuclides has advanced considerably over the years. Regulations have also evolved to some extent, though at a slower pace. Specifically, in the 1970s, the International Commission on Radiological Protection (ICRP) published ICRP 26 and ICRP 30 followed by ICRP 48 in 1986. The scientific work in these publications was incorporated by the EPA into Federal Guidance Report 11 in 1988. The doses from alpha-emitting, long-lived transuranic radionuclides in the new guidance issued by the EPA are much higher than those estimated by NBS 69 methods. Federal Guidance Report 11 is the report that is the basis of current EPA regulatory dose estimation methods. We will estimate bone doses according to Federal Guidance Report 11 (FGR 11) in this section. Then we discuss the same problem using Federal Guidance Report 13 (FGR 13), which is the most recent EPA Guidance, but not yet in force for regulatory calculations for doses from air and water.

1. Bone doses according to FGR 11

As touched upon above, several major changes have transpired from NBS 69 to FGR 11 so far as this analysis is concerned:

- The quality factor, or RBE, was increased from 10 to 20.
- The bone was divided into two different target organs, the "bone marrow" and the "bone surface," as compared to a single organ, the marrow-free skeleton, in NBS 69.
- The division of the bone into two organs in FGR 11 allowed the omission of the safety factor of 5 that was used in NBS 69 to account for selective, non-uniform deposition in the bone of certain radionuclides.
- NBS 69 used annual doses, while FGR 11 provides the conversion factors for committed doses.[25]

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associated with the fact that the MCLs were rounded to one significant figure in NBS 69, but this is not significant in the present context.

[25] "Annual dose" corresponds to the amount of energy from ionizing radiation deposited in the target organ per unit mass of the organ in a single year. The dose in rem is then calculated by applying the RBE to the deposited energy. "Annual committed dose" corresponds to the amount of energy that would be deposited in the organ over the entire time that the radionuclide is present in the organ due to the intake of the radionuclide in a single year. If a radionuclide is eliminated rapidly from the body (say in a few days or weeks), as for instance is the case with tritium, then annual dose and committed dose are usually the same. But if the radionuclide is slowly eliminated from the target organ, over years or even decades (the latter is the case for alpha-emitting, long-lived transuranic radionuclides, their target organ being the bone), the dose to the bone from an intake in any given year is delivered over a period of decades after that. With the annual committed dose, the intake is over a year but the dose is delivered over a different period of time – and, in the case of alpha-emitting, long-lived transuranic radionuclides to the bone, a much longer period of time. Hence, the actual dose delivered to the person in the case of an intake of an alpha-emitting, long-lived transuranic radionuclide late in life (say a

While these technical changes are complex, it is possible to estimate the effect of the changes from NBS 69 to Federal Guidance Report 11 on doses in several different ways, each of which raises some technical issues. The approaches and issues are set forth in Table 2 using plutonium-239 as the reference alpha-TRU radionuclide.

Table 2: Approaches for deriving an updated drinking water limit for plutonium-239 that account for changes from NBS 69 to FGR 11

Approach	Issues	Derived, updated Pu-239 MCL, pCi/liter
1. Compare the NBS 69 annual bone dose to the FGR 11 bone surface annual committed dose	**Advantage**: Uses the prevailing dose framework at the time. **Disadvantages**: (i) For alpha-emitting, long-lived transuranic radionuclides, which have a long biological half-life, committed dose is not equivalent to annual dose. The actual cumulative dose over a lifetime is considerably less than the product of the years and the annual committed dose. (ii) Target organ is different – bone for NBS 69 and bone surface for FGR 11.	0.04
2. Compare NBS 69 cumulative bone dose over a lifetime at 15 pCi/L to actual cumulative bone surface dose estimated from FGR 11	**Advantage**: Closest to the intent of the regulation to limit doses to the most exposed organ. **Disadvantage**: Changes the target organ from marrow-free skeleton to bone surface.	0.08
3. Compare cumulative bone surface dose imputed from NBS 69 to bone surface dose as per FGR 11	**Advantage**: Compares the same target organ. **Disadvantage**: Changes the framework from maximally exposed organ, as defined at the time by prevailing science, to comparing bone surface dose, which was not explicitly defined in NBS 69.	12

Notes: For Pu-239, it is assumed that 63 percent of the committed dose is delivered in 50 years. The values in the last two rows correspond to a 70-year intake. The estimate in Federal Guidance Report 11 for bone "surface seeking alpha-emitters" is a factor of 12, but a value for Pu-239 is not specified. We estimate the ratio of cumulative bone surface dose from FGR 11 to NBS 69 for Pu-239 is a factor of 12.3, which is about the same as the value in FGR 11. This validates the approach used for the calculations in the last row of the above table.

Of these approaches, the first one is the least persuasive scientifically because it compares cumulative annual doses to cumulative committed doses. Since plutonium is eliminated from the bone very

few years before death) is less than the full committed dose and less than the dose that would be delivered from the same intake early in life.

slowly (with a biological lifetime of several decades), most of the dose from intakes in the last years of a 70-year reference lifetime would be delivered after the full lifetime of even a long-lived person (even if one considers a ~100 year life, for instance). Hence, only the latter two approaches are scientifically reasonable. Both yield values for MCLs for alpha-emitting, long-lived transuranic radionuclides that are far below 15 picocuries per liter. However, they yield values also an order of magnitude different from each other – 0.08 picocuries per liter and 1.2 picocuries per liter. The approach shown in the second row is the most close to the intent of the drinking water regulation because it compares cumulative dose over a lifetime to the most exposed organ as defined in 1976 (marrow-free skeleton) and the most exposed organ as currently defined (bone surface). The last approach compares dose to the same organ (bone surface), which has scientific merit. However, it is not in accord with the intent of the regulation to limit dose in that the prevailing views of the most exposed organ (marrow-free skeleton in 1976 and bone surface in 1988) are no longer being compared. Hence, the most appropriate value to use for a new standard based on Federal Guidance Report 11 would be 0.08 picocuries per liter. However, since this is no longer the most recent scientific guidance published by the EPA, this factor would also need to be considered in the review of MCLs for alpha-emitting, long-lived transuranic radionuclides when they are reviewed in 2006.

2. Bone doses according to FGR 13

The most recent regulatory guidance for estimating doses is based on dose conversion factors published in ICRP 72. These have been incorporated into Federal Guidance Report 13, including the compact disk supplement, which has dose conversion factors for various ages published in a database.[26] The dose conversion factors are age-dependent and can be used to estimate committed doses for the remainder of life from the age of intake to age 70 years. This allows the estimation of total dose over a lifetime corresponding to a water contamination at 15 picocuries per liter.

The dose conversion factors in Federal Guidance Report 13 are generally somewhat lower than those in Federal Guidance Report 11. Therefore the total dose to the bone surface using the newer dose conversion factors in Federal Guidance Report 13 is roughly a factor of two lower than that estimated using FGR 11. In addition to the change in the dose conversion factors, water intake variation with age also needs to be considered. The current drinking water MCLs are based on an adult intake of 2 liters of water per day, excluding the water content of food. However, the water intake of children is smaller and there is also some gender variation. Further, children have a greater intake of fluids, notably in the form of milk. Therefore, we have done the Federal Guidance Report 13-based dose calculation using two sets of intake rates for various ages that are published in the literature. The first set corresponds to fluid intakes, including milk. The second set includes only water intake. These assumptions about intake rates are show in Table 3 below:

[26] FGR 13, 1999 and 2002 (the latter for the CD supplement, rev.1).

Table 3: Drinking water assumptions for FGR 13 dose calculations

Age range, years	Fluid intake, including milk, liters/day (Case 1)	Water only intake, liters/day (Case 2)
0 to 4	1.3	0.7
5 to 14	1.3	0.95
15 to 70	1.95	1.65

Note: For Case 1, the main reference is ICRP 23, 1975. The fluid intake rate of 1.4 liters per day for 10 year-olds has been changed here to 1.3 liters per day for ages 0 to 14 years. For Case 2 the main reference is Smith and Jones 2003, which provides the most recent recommendations of the British National Radiological Protection Board.

When total fluid intake is considered (i.e., Case 1 above) the cumulative lifetime dose to the bone surface from plutonium-239 over a 70-year period is about 15,500 mrem. For Case 2, water intake only, the lifetime bone surface dose is about 12,000 mrem. The corresponding dose to the maximally exposed organ under NBS 69 (the marrow-free skeleton) is 126 mrem. These doses are calculated by applying dose conversion factors specified in the relevant publications to the intake of plutonium in drinking water over a 70-year period. This last figure of 126 mrem can be viewed as the intent of the original regulation in terms of the dose to the maximally exposed organ from drinking water contaminated with plutonium to the maximum allowable limit of 15 picocuries per liter. If we compare the value of 126 mrem to the dose to the maximally exposed organ as estimated by the methods specified in Federal Guidance Report 13, we find that for drinking water intakes corresponding to Case 1, the MCL of 15 picocuries per liter is about 123 times too high and for Case 2, it is about 95 times too high. Therefore the most recent science would indicate a tightening of the current MCL for plutonium-239 (15 pCi/L) by about 123 times to about 0.122 picocuries per liter in the case of fluid intake case (Case 1) and by over 95 times to about 0.157 picocuries per liter for water intake only (Case 2). The results for the other alpha-emitting, long-lived transuranic radionuclides are similar, since the dose conversion factors are quite close to those of plutonium-239, with the exception of neptunium-237, for which the dose conversion factors are about a factor of two lower.

III. Conclusions

> **The MCL for alpha-emitting, long-lived transuranic radionuclides should be reduced from 15 picocuries per liter to 0.15 picocuries per liter.**

The analysis in this report shows that the MCL for alpha-emitting, long-lived transuranic radionuclides should be tightened by about a factor of 100 – that is, it should be reduced from 15 picocuries per liter to 0.15 picocuries per liter. A combined standard for all alpha-emitting, long-lived transuranic radionuclides will simplify the rule and reduce the cost of its enforcement. Moreover, since the plutonium isotopes among these dominate the total curie content of DOE waste and since the dose conversion factors for Pu-238, Pu-239, Pu-240, Pu-242, and Am-241 are nearly the same, using Pu-239 as a reference for deriving the combined standard MCL is reasonable from a health standpoint as well as cost-effective.[27]

In considering what should be the optimal value for a drinking water standard for alpha-emitting, long-lived transuranic radionuclides radionuclides, we have also examined the values for a plutonium-239 limit that exists in other standards. Specifically, the surface water standard of the State of Colorado is the most relevant, since that state has been host to one of the most important plutonium handling and processing facilities in the United States, namely, the Rocky Flats Plant, near Denver. The statewide standard for plutonium-239 for surface water is 0.15 picocuries per liter.[28] It is calculated on the basis of a 30-day rolling average – that is, 30 consecutive measurements are averaged; they may or may not be taken on consecutive days. Colorado's standard is based on the risk of one person in one million developing a cancer from consuming 2 liters of water per day for 30 years.[29]

The Colorado Department of Health, Water Quality Control Commission describes the background and the rationale for changing from 15 picocuries per liter to 0.15 picocuries per liter as follows:

> **Background** The Commission previously adopted a basic standard for plutonium of 15 pCi/L and had no basic standard for americium. A basic standard was considered in this hearing for americium because it is closely associated with plutonium and these two radionuclides generally occur together. The current basic standard of 15 pCi/L plutonium was calculated using methodologies in the 1976 National Interim Primary Drinking Water Regulations and was consistent with a goal of keeping exposures below 4 millirem per year. The Basis and Purpose indicated that it was necessary and important to restrict levels because of the difficulty of removing this radionuclide by conventional treatment procedures and because the potential adverse effect on human health suggests that extreme caution be exercised in its

[27] The dose conversion factor for Np-237 is lower than those of the other alpha-emitting, long-lived transuranic radionuclides by about a factor of two.

[28] Colorado Reg. 31, 2005. The State also sets standards for other radionuclides and considers different limits for different watersheds. We have not considered these issues, some of which result in more stringent and others of which result in more lax rules. We have simply used the State of Colorado's statewide surface water limit for Pu-239 as a guide for reference.

[29] CDPHE 2002.

release to State waters. Since plutonium is predominantly an alpha emitter, the basic standard was made consistent with the 15 pCi/L alpha standard....

Basis for Commission Decision Since the previous basic standard was set, several changes have occurred: 1) a new methodology for assessing carcinogens has become the standard practice, 2) new data have resulted in periodic updates to the slope factors used in this methodology, and 3) a more refined Commission policy on appropriate levels of protection for carcinogens has been developed. This latter risk-based policy also parallels a national trend towards risk-based approach to environmental cleanup standards.

The 15 pCi/L dose-based approach was calculated using a "reference-man" and considered exposure during his working life. It was an approach designed to address questions related to occupational exposure. It did not consider sex, age and organ-specific factors over a lifetime. In contrast, the new slope factor methodology, used in EPA's 1989 Risk Assessment Guidance for Superfund Sites, is more complete, more applicable to a general population and has become the standard practice for calculating risk.

The Commission adopted a basic standard of 0.15 pCi/L for plutonium and americium, calculated using a 1×10^{-6} risk level, based on residential use. This risk level is consistent with the Commission's policy for human health protection.[30]

This reasoning is based on CERCLA, the Superfund law, but is qualitatively in accord with the reasoning in this analysis. Specifically, the central scientific point of the Colorado rule is that the science has changed, indicating greater risk than previously assumed from exposure to plutonium and americium; therefore the maximum contaminant limits should be adjusted accordingly. Further, the specific value for plutonium and americium recommended in the Colorado rule is just a factor of two lower than the geometric mean of the two values in the last two rows of Table 2 above.

In view of the complexities created by the change from NBS 69 to Federal Guidance Report 13, an MCL for alpha-emitting, long-lived transuranic radionuclides of 0.15 picocuries per liter is reasonable and justifiable. The action we are recommending is consistent with the intent of the National Primary Drinking Water Regulations as originally promulgated and is directly within the framework of the regulation as promulgated then and as it stands at present.

The primacy of the health goal (rather than numerical limits) is clear from the EPA's own description of the Safe Drinking Water Act, pursuant to which the radionuclide maximum contaminant limits are set. Its fact sheet on the Act states:

US EPA sets national standards for tap water which help ensure consistent quality in our nation's water supply. US EPA prioritizes contaminants for potential regulation based on risk and how often they occur in water supplies. (To aid in this effort, certain water systems monitor for the presence of contaminants for which no national standards currently exist and collect information on their occurrence). US EPA sets a health goal based on risk (including risks to the most sensitive people, e.g., infants, children, pregnant women, the elderly, and the immuno-compromised). US EPA then sets a legal limit for the contaminant in drinking water or a required treatment technique.[31]

[30] Colorado Reg. 31, 2005, pages 138-139.
[31] EPA 2004.

By this standard, the 15 picocuries per liter limit for transuranic radionuclides is obsolete, not protective of public health, against the spirit of the Safe Drinking Water Act, and, as shown above, not in accord with the intent of the initial regulation. Because of this, the EPA should take up consideration of a tightened standard in its upcoming 2006 drinking water radionuclide review.

The 15 pCi/L limit for transuranic radionuclides is obsolete, not protective of public health, against the spirit of the Safe Drinking Water Act, and, as shown above, not in accord with the intent of the initial regulation.

Corresponding to the change in the MCL for alpha-emitting, long-lived transuranic radionuclides, there is also a need for a change in the detection limit. Table B in 40 CFR 141.25 should be modified to include a separate detection limit of 0.01 picocuries per liter for each alpha-emitting, long-lived transuranic radionuclide. This detection limit is well within the capabilities of present-day techniques. The current detection limit for these radionuclides is 0.001 picocuries per liter, according to Argonne National Laboratory. The errors at such low levels can be large however. The error at 0.01 picocuries per liter, the recommended detection limit, is estimated by Argonne National Laboratory to be 10 percent.[32]

We recognize that alpha-emitting, long-lived transuranic radionuclides are not ubiquitous in significant concentrations, unlike naturally occurring radionuclides like radium-226, thorium-232, and thorium-230. The vast majority of public water systems can therefore be exempted from routine monitoring requirements relating to alpha-emitting, long-lived transuranic radionuclides. The monitoring requirements for these radionuclides should be applied to public water systems that draw water from aquifers or surface water that have potential hydrologic or hydrogeologic connections to areas or facilities with waste tanks, waste burial pits, and other potential sources of alpha-emitting, long-lived transuranic radionuclides in combined totals in excess of 100 curies (see below).[33] Wastes disposed of at shallow and intermediate depths are included in this definition. Alpha-emitting, long-lived transuranic radionuclides that are contained in secure buildings with institutional controls would be exempt from this limit and the associated monitoring requirements.

We recognize that the main recommendation of this report, to set a separate standard for alpha-emitting, long-lived transuranic radionuclides, requires that the present gross alpha limit be split up into two parts – one for alpha-emitting, long-lived transuranic radionuclides and the other for naturally occurring alpha-emitting radionuclides. However, this is not a departure from the content or intent of the present rule, for several reasons.

First, the present rule itself does not have a single standard for alpha-emitting radionuclides. There is a sub-limit for radium-226 and radium-228 of 5 picocuries per liter. Since radium-226 is an alpha emitter, there is in effect a separate sub-limit for an alpha emitter up to maximum of 5 picocuries per liter (depending on how much radium-228, a beta-emitter, is also present). Second, the gross alpha

[32] ANL 1995, Chapter 7, Table 7.1.

[33] For instance, the 100 curie limit is equivalent to 1,000 metric tons of transuranic waste containing alpha-emitting, long-lived transuranic radionuclides at the lower limit of 100 nanocuries per gram. It would be equivalent to a larger mass of low-level waste, since the concentration in such waste (by definition) is less than 100 nanocuries per gram.

limit excludes uranium and radon. The limit of 30 micrograms per liter of uranium is set on the basis of heavy metal toxicity. However, this amount of uranium causes some amount of harm as a result of its radioactivity. Recent science indicates that the harm from the heavy metal aspects of uranium may be reinforced by its radioactivity. (See *Section VI. Other risks and radionuclides*, below). Hence, reconsideration of a variety of issues is warranted. In such reconsideration, it would be practical and less costly to separate out alpha-emitting, long-lived transuranic radionuclides. This is because the vast majority of water systems will not require any testing for alpha-emitting, long-lived transuranic radionuclides since they are not at risk.

IV. Costs

Public water systems are not at present contaminated at or near the requested MCL for alpha-emitting, long-lived transuranic radionuclides. A strengthened alpha-TRU drinking water standard is preventive rather than remedial. Only a small, one-time cost for an initial set of baseline samples is anticipated for those water systems that draw water from sources that include DOE sites with significant plutonium waste or soil contamination in drainage areas. We recommend that this one-time cost be borne by the DOE.

Public water systems are not at present contaminated at or near the requested MCL for alpha-emitting, long-lived transuranic radionuclides.

Since no known contamination of public water systems above 0.15 picocuries per liter of alpha-emitting, long-lived transuranic radionuclides exists, no further action would be required of public water systems and no further costs would be incurred provided there is sufficiently thorough monitoring by the DOE, coupled with remediation programs that are suited to free release of the sites in the long term. This will be sufficient to protect downstream surface waters and underground water systems. The DOE is supposed to carry out such monitoring in any case and therefore no additional, ongoing monitoring costs are anticipated.

The Department of Energy, which is responsible for management of almost all the wastes and materials that pose risks of water contamination with alpha-emitting, long-lived transuranic radionuclides, is supposed to take adequate remedial action at sites like the Idaho National Laboratory, Hanford, the Savannah River Site, and Los Alamos National Laboratory. If it does so, no remediation costs for public water systems would be required under our recommended changes to the National Primary Drinking Water Regulations.

The costs of not tightening the standards would be to signal that remediation of nuclear weapons sites with large inventories of plutonium in the waste could proceed without adequate attention to safe drinking water health protection goals. DOE could then remediate these sites and declare them cleaned up without reference to a science-based drinking water standard that corresponds to current understanding of plutonium movement and irradiation of the human body. Finally, some remediation actions could, in the long run, pollute the water above drinking water standards, and worse, be irremediable. No known technology could remediate vast bodies of water such as the Savannah

River or the Snake River Plan Aquifer if, once polluted, the aim is to reduce pollution from a few picocuries per liter to sub-picocurie per liter levels.

V. Estimating the impact of residual radioactivity

Vast areas of land and huge amounts of water remain contaminated with dangerous long-lived radionuclides from operations of nuclear weapons facilities.[34] The DOE has been given the task to clean up these sites. It is therefore of great importance that the levels of residual radioactivity meet strict standards that will protect the health of individuals of this and future generations that will be exposed to the residual contamination.

In the early 1990s, the DOE embarked on a cooperative process with the EPA to develop national cleanup standards, but the DOE pulled out of the process abruptly in 1996 without any plans for its resumption.[35] Since then, the DOE has proceeded on a site-by-site basis that has led to a welter of proposals for cleanup using various scenarios.

At the Savannah River Site in South Carolina, the DOE is grouting high-level waste in tanks as if it were low-level waste. This waste contains significant amounts of transuranic radionuclides. For instance, the residual waste in Tank 19, which has been grouted, had a concentration of plutonium 14 times above the EPA 100 nanocurie-per-gram limit for transuranic waste. DOE is grouting large amounts of plutonium in the tanks even though it has not yet obtained convincing evidence of the durability of grout. The tanks are buried underground in the watershed of the Savannah River, one of the most important rivers in the South Carolina-Georgia region. Experimental and field data leave room for considerable skepticism as to its performance. IEER's evaluation of the state of the research on grout indicates that the performance of grout remains highly uncertain. There is at present no sound basis, whether in experiment or in field data, to assume that leaving large amounts of grouted alpha-emitting, long-lived transuranic radionuclides in the tanks would be protective of the Savannah River.[36]

A large part of the urgency that our recommendations be incorporated into EPA's forthcoming review of MCLs for radionuclides in drinking water derives from the fact that, in 2004, Congress passed a law allowing DOE to reclassify residual high-level waste as incidental waste at its South Carolina and Idaho sites. The law did not set any limits as to the residual radioactivity in waste so reclassified.[37] Several long-lived radionuclides, including plutonium isotopes, strontium-90, and cesium-137, may be grouted in the tanks or disposed of in shallow saltstone vaults. A realistic framework to guide DOE's decision-making, so that it does not endanger crucial water resources, is therefore of urgent and immense importance.

The consequences of the DOE cleanup policy on the concentrations of residual transuranic contamination in the soil and their potential effect on the health of individuals are discussed in a study by IEER entitled *Setting Cleanup Standards to Protect Future Generations: The Scientific*

[34] OTA 1991.
[35] Nichols 1996.
[36] Smith 2004 and Makhijani and Boyd, 2004.
[37] PL 108-375, 2004, Sec. 3116.

Basis of the Subsistence Farmer Scenario and Its Application to the Estimation of Radionuclide Soil Action Levels (RSALs) for Rocky Flats, December 2001.[38] In this study, IEER showed that the specific assumptions about future use have a major impact on what are considered acceptable residual radioactivity levels. A large part of this result is because different future site use scenarios have different assumptions about the use of water and food from the contaminated area in question. Since some radionuclides, including the alpha-emitting, long-lived transuranic radionuclides discussed in this report, are very long-lived, a basic assumption that there will be loss of institutional control over the long-term is essential to sound planning and cleanup.

However, even the adoption of a subsistence farmer scenario as the basis for cleanup cannot assure that levels for residual radioactivity on contaminated sites will be set in a manner that is protective of health and the environment. This is because the translation of residual levels into radiation dose and risk estimates requires the use of complex models and assumptions about the behavior of radionuclides in the environment. For instance, the amount of rainfall, the mobility of radionuclides in specific soil conditions, the porosity of the soil, the solubility of the radionuclides under various circumstances, and the rate of soil erosion are among the critical parameters that need to be known and characterized.

At present, remediation levels are typically assessed by the use of a model developed by Argonne National Laboratory called RESRAD (for residual radioactivity).[39] This computer code is complex and has, over the years, been developed to consider pathways for movement of radioactivity in a sophisticated way. Yet, it does not contain libraries of dose conversion factors for, and thus does not account for, infants or for young people at sensitive times in their hormonal development or for the fetus at various stages of fetal development. The estimation of doses to various segments of the population at sensitive periods in their lives may also require consideration of how the environmental pathways and the systems in the human body are represented in the model's source code.

The RESRAD source code is closely held by the U.S. government; it is not public. Ostensibly, the official rationale is that since RESRAD is used for regulatory decisions, such as those that are made in the context of cleanup at nuclear weapons sites, it should not be made public. However, we do not accept this rationale. The code can be made public and can be an open source code, available for modification in the same manner as the Linux operating system source code. That has resulted in its improvement and efficiency, without problems actually creeping into mass use of the code as an operating system. The U.S. government can surely retain its version of the code for regulatory purposes while making the source code publicly available for examination and improvement. If at a certain stage, the code is improved in a manner that regulatory bodies such as the EPA consider it useful for regulatory purposes, they will freely be able to adopt the changes but will be under no obligation to so.

[38] Makhijani and Gopal 2001.
[39] RESRAD.

VI. Other risks and radionuclides

New scientific work on radiation protection is currently emerging, for instance in relation to (i) protection of the embryo/fetus and infant, (ii) non-cancer effects of exposure to certain radionuclides, (iii) potential synergistic effects of exposure to certain chemicals, such as hormonally active chemicals, and exposure to radiation, (iv) the need for protection of key non-human species and ecosystems, and (v) the synergisms indicated for certain effects between the heavy metal toxicity component of uranium and its radiotoxicity. However, these are still emerging areas of concern, where the risks are not quantitatively well established. How such risks are to be considered in the context of a review of drinking water MCLs will be considered in a future IEER report.

Recent developments in radiobiology and health effects research have increased understanding of radiation doses during fetal development. They indicate that non-cancer health effects resulting from fetal exposure to radiation could be very important. For instance, ICRP 90 emphasizes that the central nervous system is especially vulnerable during a certain period of fetal development:

> ...[B]iological systems with a high fraction of proliferating cells show high radiation responsiveness. High rates of cell proliferation are found throughout prenatal development....Development of the central nervous system starts during the first weeks of embryonic development and continues through the early postnatal period. Thus development of the central nervous system occurs over a very long period, during which it is especially vulnerable. It has been found that the development of this system is very frequently disturbed by ionising radiation, so special emphasis has to be given to these biological processes.[40]

A variety of end points (disease outcomes) are at issue, from central nervous system development to cancer to birth defects to increased risk of miscarriages. Further, these end points raise the issue of the combined effects of other pollutants with radiation more insistently that ever before. For instance, one might ask about the potential for non-linear effects caused by exposure to both lead and radiation or mercury and radiation. One might also ask about the combined effects of exposure to endocrine disrupting chemicals and radiation in relation to a number of end points. These are areas still in a relatively early stage in the science compared to the understanding of radiogenic cancer induction. For these areas, which concern non-cancer end points as a result of fetal exposure, for instance, the conversion of the scientific data in publications such as ICRP 88 and ICRP 90 into regulations for health and environmental protection will take considerable time.[41] The EPA has not even published the necessary guidance documents as yet.

Recent research, much of it done at the Armed Forces Radiobiology Research Institute, pursuant to concerns about the health effects of depleted uranium, points to a surprising variety of harmful health effects of uranium. A recent literature survey by IEER summarized the situation as follows:

> The understanding of the risks of cancer due to radiation exposure from depleted uranium and kidney damage due to its heavy metal properties has expanded greatly in recent years. In addition, evidence is amassing that raises serious concerns regarding the impact of

[40] ICRP-90, 2003, page 9.

[41] ICRP-88, 2002; ICRP-90, 2003.

chronic exposure to DU in relation to a number of other health issues. Studies in humans and animals have shown that uranium can concentrate in the skeleton, liver, kidneys, testes, and brain. In addition, rats implanted with DU pellets have also shown uranium concentrating in the heart, lung tissue, ovaries, and lymph nodes among other tissues. Research, primarily but not exclusively conducted since the 1991 Gulf War, indicates that exposure to uranium may be

> Mutagenic
> Cytotoxic
> Tumorigenic
> Teratogenic
> and Neurotoxic, including in a manner analogous to exposure to lead.
>
> Additionally...some research has also provided indications that there may be a synergistic effect between the heavy metal aspect of exposure to uranium and its radioactive effects....Current research conducted at the Armed Forces Radiobiology Research Institute (AFRRI) indicates that "[i]n the case of DU, cells not traversed by an alpha particle may be vulnerable to radiation-induced effects as well as chemically-induced effects." Additional work at the AFRRI has also shown that depleted uranium can cause oxidative DNA damage and thus provides the first indication that uranium's radiological and chemical affects might potentially play both a tumor initiating and a tumor promoting role. [42]

In other words, uranium may be a kind of radioactive lead, with serious health effects arising both from its heavy metal toxicity and its radioactivity. Should these risks be proven to be substantial, there may be a need to include new limits in the National Primary Drinking Water Regulations relating to the combined radioactive and heavy metal toxic effects of uranium.

There are also a variety of other issues associated with the potential interaction of hormonally active chemicals with radiation, and particular certain radionuclides, like iodine-129, which concentrates in the thyroid and crosses the placenta. The development of certain cancers, like breast cancer, is linked to hormonal systems, possibly to hormonally active chemical pollutants, and to radiation. Hence the issues associated with health protection in regard to certain cancers are likely to be much more complex.

Finally, there are issues that were once recognized but that appear to have been forgotten or ignored in the context of protection of public health from radiation. Consider the following passage from ICRP 2 that occurs in the context of a discussion of bone doses and the calculations that are the subject of this report:

> Certainly, if a major portion of the hematopoietic system were irradiated, e.g., concurrently from the spleen-seeking Po^{210} and from the bone-seeking Ra^{226}, the biological damage would be greater than if only a part of it were irradiated. *It has been shown that in some cases a synergistic effect results when several organs of the body are irradiated simultaneously.*[43]

Some of these synergistic effects are already implicit in the estimates of risk made from Hiroshima/Nagasaki survivors (since they received whole body radiation – i.e., all organs were

[42] Makhijani and Smith 2005, pages 9-10. Typos corrected.
[43] ICRP-2, 1959, page 14, emphasis added.

irradiated). However, others involving internal deposition and that selectively target certain organs may have more complex effects. This indicates that it is important to maintain regulations in the form of dose limits to maximally exposed organs in regulations relating to protection of public health, such as the National Primary Drinking Water Regulations (40 CFR 141), *Environmental Radiation Protection Standards for Nuclear Power Operations* (40 CFR 190), and *Environmental Radiation Protection Standards For Management And Disposal Of Spent Nuclear Fuel, High-Level And Transuranic Radioactive Wastes* (40 CFR 191). At the present time, there is still a significant amount of scientific work that remains to be done in a variety of areas before this framework can be changed into a better one from the point of view of health, environment, future generations, and the economy.

Consideration of changes in radiation protection in the medium- and long-term, that would take into account emerging scientific and risk issues such as those discussed in this section, is needed for a variety of reasons, some of which are mentioned above. However, this will be a complex and difficult task which must be done with due deliberation. It will also likely go far beyond safe drinking water standards. At the present time, the safety and protection of water resources from irreversible contamination with alpha-emitting, long-lived transuranic radionuclides as a result of ongoing activities by the Department of Energy cannot be allowed to be deferred to the longer, more comprehensive social, economic, and health discussion related to the protection of health from radioactive and toxic pollution. It must be considered as part of the EPA's 2006 review of standards for radionuclides in drinking water. A maximum contaminant level for plutonium that is 100 times too lax based on the intent and letter of the Safe Drinking Water Act must not be allowed to persist.

References

40 CFR 141 *Code of Federal Regulations. Title 40--Protection of Environment. Chapter I--Environmental Protection Agency. Part 141--National Primary Drinking Water Regulations.* 7-1-04 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; United States Government Printing Office, 2004. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_04/40cfr141_04.html.

40 CFR 190 *Code of Federal Regulations. Title 40--Protection of Environment. Chapter I--Environmental Protection Agency. Part 190--Environmental Radiation Protection Standards for Nuclear Power Operations.* 7-1-04 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; United States Government Printing Office, 2004. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_04/40cfr190_04.html.

40 CFR 191 *Code of Federal Regulations. Title 40--Protection of Environment. Chapter I--Environmental Protection Agency. Part 191—Environmental Radiation Protection Standards For Management And Disposal Of Spent Nuclear Fuel, High-Level And Transuranic Radioactive Wastes* 7-1-04 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; United States Government Printing Office, 2004. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_04/40cfr191_04.html.

ANL 1995 N.W. Golchert and R.G. Kolzow. *Argonne National Laboratory-East site environmental report for calendar year 1995.* Also called *1995 ANL-E site environmental report.* ANL-96/3. Argonne, IL: ANL-E, 1996. Chapter 7 of the report is on the Web at http://www.anl.gov/Community_and_Environment/Environmental_Reports/1995/chapter7/index.html.

Colorado Reg. 31, 2005 Colorado Department of Public Health and Environment. Water Quality Control Commission. *The Basic Standards and Methodologies for Surface Water (5 CCR 1002-31).* Regulation No 31. Originally adopted in 1979 and last amended on November 8, 2004, with the amendments to be effective March 22, 2005. Link on the Web at http://www.cdphe.state.co.us/op/regs/waterqualityregs.asp. Viewed June 2, 2005.

CDPHE 2002 Colorado Department of Public Health and Environment, Hazardous Materials and Waste Management Division. Interoffice Communication, from Steve Gunderson to the Water Quality Control Commission. October 2, 2002. On the Web at http://www.cdphe.state.co.us/op/wqcc/WQClassandStandards/Reg38/reg38ish.pdf.

EPA 2004 U.S. Environmental Protection Agency. *Safe Drinking Water Act 30th Anniversary: Understanding the Safe Drinking Water Act.* EPA Fact Sheet. EPA 816-F-04-030. Washington, DC, Last updated on Monday, February 14th, 2005. On the Web at http://www.epa.gov/safewater/sdwa/30th/factsheets/understand.html.

Fed. Reg. 1975/03/14 "Environmental Protection Agency [40 CFR Part 141] [FRL 343-8] Primary Drinking Water Proposed Interim Standards." *Federal Register*, v. 40, no. 51, March 14, 1975, p. 11990-11998.

Fed. Reg. 1975/08/14 "Environmental Protection Agency [40 CFR Part 141] [FRL 410-3] Interim Primary Drinking Water Regulations, Notice of Proposed Maximum Contaminant Levels for Radioactivity." *Federal Register*, v. 40, no. 158, August. 14, 1975, p. 34324-34328.

Fed. Reg. 1975/12/24 "Title 40—Protection of Environment. Chapter 1--Environmental Protection Agency. Subchapter D—Water Programs [FRL 464-7] Part 141—National Interim Primary Drinking Water Regulations." *Federal Register*, v. 40, no. 248, December 24, 1975, starting at page 59566.

Fed. Reg. 1976 "Title 40—Protection of Environment. Chapter 1--Environmental Protection Agency. [FRL 552-2] Part 141—Interim Primary Drinking Water Regulations. Promulgation of Regulations on Radionuclides." *Federal Register*, v. 40, no. 133, July 9, 1976, starting at page 28402.

Fed. Reg. 2000 "Environmental Protection Agency. 40 CFR Parts 9, 141, and 142 [FRL 6909-3] RIN 2040-AC98. National Primary Drinking Water Regulations; Radionuclides; Final Rule." *Federal Register*, v. 65, no. 236, December 7, 2000, pages 76708-76753. Available on the Web at http://www.gpoaccess.gov/fr/search.html.

FGR 11, 1988 Keith F. Eckerman, Anthony B. Wolbarst, and Allan C.B. Richardson. *Limiting values of radionuclide intake and air concentration and dose conversion factors for inhalation, submersion, and ingestion.* Federal Guidance Report No. 11. EPA-520/1-88-020. Oak Ridge, TN: Oak Ridge National Laboratory; Washington, DC: Office of Radiation Programs, U.S. Environmental Protection Agency, September 1988. On the Web at http://www.epa.gov/radiation/docs/federal/520-1-88-020.pdf.

FGR 13 Keith F. Eckerman, Richard W. Leggett, Christopher B. Nelson, Jerome S. Puskin, and Allan C.B. Richardson. *Cancer risk coefficients for environmental exposure to radionuclides.* EPA 402-R-99-001. Federal Guidance Report No. 13, CD Supplement. Rev. 1. Oak Ridge, TN: Oak Ridge National Laboratory; Washington, DC: Office of Radiation and Indoor Air, U.S. Environmental Protection Agency, April 2002. Includes original 1999 FGR no. 13, which is also on the Web at http://www.epa.gov/radiation/docs/federal/402-r-99-001.pdf.

ICRP-2, 1959 International Commission on Radiological Protection. *Report of Committee II on Permissible Dose for Internal Radiation (1959).* ICRP Publication 2. New York: Pergamon, Adopted July 1959.

ICRP-23, 1975 International Commission on Radiological Protection. *Report of the Task Group on Reference Man.* [ICRP Publication] No. 23. Oxford: Pergamon Press, 1975. Adopted October 1974.

ICRP-26, 1977 International Commission on Radiological Protection. *Recommendations of the International Commission on Radiological Protection.* ICRP Publication 26. Annals of the ICRP, 1(3). Oxford, UK: Pergamon, 1977.

ICRP-30, 1979 International Commission on Radiological Protection. *Limits for intakes of radionuclides s by workers.* ICRP Publication 30, Part 1. Annals of the ICRP, 2(3/4). Oxford, UK: Pergamon, 1979. Adopted July 1978.

ICRP-48, 1986 International Commission on Radiological Protection. *The Metabolism of plutonium and related elements.* ICRP Publication 48. Annals of the ICRP, 16(2/3). Oxford, UK: Pergamon, 1986.

ICRP-68, 1995 International Commission on Radiological Protection. *Dose coefficients for intakes of radionuclides by workers: Replacement of ICRP Publication 61*. ICRP Publication 68. Annals of the ICRP, 24(4). Oxford, UK: Pergamon, 1995 and CD-ROM Version 2.01: *The ICRP database of dose coefficients: workers and members of the public: An extension of ICRP publications 68 and 72*. (2001).

ICRP-72, 1996 International Commission on Radiological Protection. *Age-dependent doses to the members of the public from intake of radionuclides: Part 5, Compilation of ingestion and inhalation dose coefficients*. ICRP Publication 72. Annals of the ICRP, 26(1) 1996. Adopted September 1995. Oxford, UK: Pergamon, 1996.

ICRP-88, 2002 International Commission on Radiological Protection. *Doses to the embryo and fetus from intakes of radionuclides by the mother*. ICRP Publication 88. Annals of the ICRP, 31(1/3) 2001. Corrected version. Oxford, UK: Pergamon, May 2002.

ICRP-90, 2003 International Commission on Radiological Protection. *Biological effects after prenatal irradiation (embryo and fetus)*. ICRP Publication 90. Annals of the ICRP, 33(1/2). Oxford, UK: Pergamon, 2003.

Makhijani and Boyd 2004 Arjun Makhijani and Michele Boyd. *Nuclear dumps by the riverside: threats to the Savannah River from radioactive contamination at the Savannah River Site (SRS)*. Takoma Park, MD: Institute for Energy and Environmental Research, March 11, 2004. On the Web at http://www.ieer.org/reports/srs/index.html.

Makhijani and Gopal 2001 Arjun Makhijani and Sriram Gopal. *Setting cleanup standards to protect future generations: the scientific basis of the subsistence farmer scenario and its application to the estimation of Radionuclide Soil Action Levels (RSALs) for Rocky Flats*. A report prepared for the Rocky Mountain Peace and Justice Center, Boulder, Colorado. Takoma Park, MD: Institute for Energy and Environmental Research, December 2001. On the Web at http://www.ieer.org/reports/rocky/fullrpt.pdf.

Makhijani and Smith 2005 Arjun Makhijani and Brice Smith. *Costs and risks of management and disposal of depleted uranium from the National Enrichment Facility proposed to be built in Lea County New Mexico by LES*. Takoma Park, MD: Institute for Energy and Environmental Research, November 24, 2004. Version for Public Release Redacted February 1, 2005. On the Web at http://www.ieer.org/reports/du/LESrptfeb05.pdf.

NBS 59 Addendum U.S. National Bureau of Standards. *Maximum permissible radiation exposures to man*. Addendum to National Bureau of Standards handbook 59, *Permissible dose from external sources of ionizing radiation*. Washington, DC: NBS, April 15, 1958. This is a slight revision of the preliminary statement issued on January 8, 1957, by the National Committee on Radiation Protection and Measurements. The original Handbook 59 was issued September 24, 1954.

NBS 69 U.S. National Bureau of Standards. *Maximum permissible body burdens and maximum permissible concentrations of radionuclides in air and in water for occupational exposure*. National Bureau of Standards handbook 69, as amended. AFP-160-6-7. Washington, DC: Govt. Print. Office; U.S. Department of Commerce, August 1963. First published in 1959, with an addendum in 1963. Also bears the series title NCRP report no. 22, of the National Committee on Radiation Protection and Measurements.

Nichols 1996 Mary D. Nichols, Assistant Administrator for Air and Radiation, United States Environmental Protection Agency. Letter to Sally Katzen, Administrator, Office of Information and Regulatory Affairs, Office of Management and Budget, December 19, 1996.

OTA 1991 U.S. Congress. Office of Technology Assessment. *Complex cleanup: the environmental legacy of nuclear weapons production.* OTA-O-484. Washington, DC: U.S. Government Printing Office, February 1991. On the Web at http://www.wws.princeton.edu/~ota/disk1/1991/9113_n.html.

PL 108-375, 2004 *Ronald W. Reagan National Defense Authorization Act for FY2005. Pub. L 108-375.* 118 STAT. 1811-2199 (October 28, 2004). On the Web at http://www.dod.mil/comptroller/bmmp/products/Governance/Public%20Law%20108%20375.pdf.

RESRAD Argonne National Laboratory. Environmental Assessment Division. *RESRAD family of codes.* Argonne, IL, 2005. On the Web at http://web.ead.anl.gov/resrad/home2/resrad.cfm. Viewed June 1, 2005.

SDWA United States. Environmental Protection Agency. *Safe Drinking Water Act (SDWA).* On the Web at http://www.epa.gov/safewater/sdwa/index.html. Last updated February 14th, 2005. Viewed June 1, 2005.

Smith 2004 Brice Smith. *What the DOE knows it doesn't know about grout: serious doubts remain about the durability of concrete proposed to immobilize high-level nuclear waste in the tank farms at the Savannah RiverSite and other DOE sites.* Takoma Park, MD: Institute for Energy and Environmental Research, updated October 18, 2004. On the Web at http://www.ieer.org/reports/srs/grout.pdf.

Smith and Jones 2003 K.R. Smith and A.L. Jones. *Generalised habit data for radiological assessments.* NRPB-W41. Chilton, Didcot, Oxon.: National Radiological Protection Board, May 2003. On the Web at http://www.hpa.org.uk/radiation/publications/w_series_reports/2003/nrpb_w41.pdf.

Uranium factsheet *Uranium: its uses and hazards.* Takoma Park, MD: Institute for Energy and Environmental Research, last updated August 24, 2000. On the Web at http://www.ieer.org/fctsheet/uranium.html.

Appendix G

UNIVERSITY OF COLORADO LAW REVIEW

Dumping on Federalism

Robert J. Cynkar

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DUMPING ON FEDERALISM

ROBERT J. CYNKAR*

INTRODUCTION

One piece of news clearly has not been well-reported, at least west of the Mississippi. It appears that the demand for troops in Iraq and elsewhere is just too great. Congress has found it necessary to reinstitute the draft. Interestingly, the only people to be drafted are young men and women from Colorado. One legislator was quoted as saying: "Those people out there are just having too much fun, particularly at the university in Boulder. Serving their country will be good for them."

Of course, informed Coloradoans were outraged, wondering if their representatives were asleep at the switch. In fact, they were just out voted. The members of Congress from the other forty-nine states had simply gotten together and agreed that it was better for the members from one state, rather than from every state, to take the inevitable political heat for this move. Conveniently, Colorado seemed to have just the right population of draft-age men and women, and so ganging up on Colorado was, well, in the national interest. Someone had to go, after all.

This story about the draft is as outrageous as it is fanciful. Ganging up like that on one state for no good reason strikes any fair (and modestly informed) observer as fundamentally at war with the premises of our federal system. Yet, it is said that truth is sometimes stranger than fiction, and that is certainly true of the process that led to siting the nation's first high-level nuclear waste repository in Yucca Mountain, Nevada. This is the tale of forty-nine of Nevada's sister states ganging up to make Nevada bear a national burden for no good reason, except that they had the votes.

There are two strands of this tale. The first is the story of the nation coming to grips with the problem of the permanent, safe disposal of high-level nuclear waste. In most respects, this is the saga of the enact-

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* Mr. Cynkar is a partner in the law firm of Egan, Fitzpatrick, Malsch & Cynkar, PLLC, the lead firm in the legal team representing the State of Nevada in litigation concerning the high-level nuclear waste repository proposed to be sited at Yucca Mountain, Nevada. This article is based on Mr. Cynkar's presentation at the Eleventh Annual Ira C. Rothgerber Conference, "Constitutional Conflicts on Public Lands," held at the University of Colorado School of Law on January 30-31, 2004. Both his presentation and this article set out legal arguments developed, researched, and written on behalf of Nevada by that team. In addition to Mr. Cynkar, the members of that team who participated in the work on the constitutional analyses set out here are Brian Koukoutchos, who did most of the original research, Joseph R. Egan, Vincent J. Colatriano, and Charles J. Cooper.

ment of the Nuclear Waste Policy Act of 1982 ("NWPA"),[1] and the related evolution of the regulations promulgated by three different agencies. That evolution, and the selection of Yucca Mountain as the site for this repository, generated litigation in the United States Court of Appeals for the District of Columbia Circuit challenging the selection of Yucca Mountain on a variety of grounds, including the constitutional issue we will consider here.

The second strand, by contrast, is as old as the Republic and our federal structure, arising from what the Framers of the Constitution saw as the conundrum of *imperium in imperio*—sovereign power within sovereign power.[2] What the Framers did not lose sight of is the fact that we do not have a unified national government. Our country is a federation of sovereign states whose existence preceded the Union. The existence of these sovereign states is inherent in the Union's structure, and so there is very little direct discussion of state sovereignty in the Constitution. As one of the legal team members representing Nevada, Brian Koukoutchos, aptly put it, "Just as islands need not advertise that they are surrounded by water, because that fact inheres in the very definition of island, so the Constitution should not be expected to dwell on state sovereignty for the simple reason that state sovereignty just is."

At the outset of the NWPA process, neutral criteria were used to determine which state was to be burdened with this waste dump. Logically, those criteria centered on the physical attributes of potential sites, such as geology and hydrology, that determine the ability of any site to isolate highly radioactive waste for generations. But once it was discovered that Yucca Mountain's geologic profile was unsuitable for this purpose, the involved federal agencies rewrote the governing rules to create a new standard that only applies to Yucca Mountain and largely relies on manmade containers to isolate this extraordinarily toxic material. Under such a disposal regime, nothing distinguishes Yucca Mountain, and many sites across the country could serve as home to the nation's nuclear waste dump.

Nevada contends that siting the nation's nuclear waste repository at Yucca Mountain is unconstitutional because it has become a naked act of arbitrary political will that singles out Nevada and invades its sovereignty. The constitutional argument mounted on behalf of Nevada, and offered here, is undeniably novel—there is no existing authority precisely on point. But the argument is also ancient, arising from principles at the root of much of our constitutional jurisprudence.

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1. 42 U.S.C. §§ 10101-10270 (2000).

2. *See* FORREST MCDONALD, STATES' RIGHTS AND THE UNION: *Imperium in Imperio*, 1776-1876, at 1-5 (2000).

The first section of this article will review the nature of the nuclear waste problem and Congress's efforts to establish the first national high-level radioactive waste disposal facility. That section will examine the actions of the Executive Branch departments and agencies to implement Congress's disposal scheme, including the dramatic shift in regulatory standards to ensure that Yucca Mountain would be approved as the repository site.

The second section of the article will identify the principles of federalism that animate the Constitution by examining various precedents in which those principles are manifested. The third section of the article will describe the constitutional argument Nevada mounted against the siting of the nation's nuclear waste dump at Yucca Mountain based on these principles of federalism. The article concludes with a discussion of the D.C. Circuit's adjudication of that argument (among other arguments raised by Nevada) in the series of cases consolidated as *Nuclear Energy Institute, Inc. v. Environmental Protection Agency ("NEI")*.[3]

I. THE NUCLEAR WASTE PROBLEM

The operation of nuclear power plants, research reactors, and military reactors all produce spent fuel. Spent fuel is lethally radioactive; indeed spent fuel is comprised of the most dangerous substances known. For example, if plutonium is ingested through drinking water, it "stays in the body for decades, exposing organs and tissues to radiation, and increasing the risk of cancer."[4] Compounding the danger, spent fuel is an extraordinary hazard not only to those exposed to it, but also, because these materials are "mutagenic," they can pass on biological damage to future generations.[5] The danger posed by these wastes lasts for millennia.[6] The radioactive elements in these wastes have "half-lives" of millions of years.[7] Making the situation even worse, some of these isotopes decay into even more dangerous substances. For example, americium-243 decays, over twenty-thousand years, into the much more dangerous and toxic plutonium-239. "Thus, the toxicity of americium-243 de-

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3. 373 F.3d 1251 (D.C. Cir. 2004).

4. U.S. Environmental Protection Agency, *Radiation Information: Plutonium* (2004), *available at* http://www.epa.gov/radiation/radionuclides/plutonium.htm.

5. H.R. Rep. No. 97-785, Pt. 1, at 46 (1982).

6. OFFICE OF CIVILIAN RADIOACTIVE WASTE MGMT., DEP'T OF ENERGY, FINAL ENVIRONMENTAL IMPACT STATEMENT FOR A GEOLOGIC REPOSITORY FOR THE DISPOSAL OF SPENT NUCLEAR FUEL AND HIGH-LEVEL RADIOACTIVE WASTE AT YUCCA MOUNTAIN, NYE COUNTY, NEVADA, 1-13 (2002) [hereinafter 2002 Final EIS].

7. *See NEI*, 373 F.3d at 1258. A half-life is the time it takes a substance to decay to half of its initial radioactivity level. H.R. Rep. No. 97-785, Pt. 1, at 46.

creases for about 20,000 years, after which it becomes more toxic than it was originally."[8]

This spent fuel and radioactive waste has been produced at 131 sites in thirty-nines States (not including Nevada) at a rate of about 2,000 metric tons per year.[9] Storage of such highly toxic material obviously poses a unique challenge. The logistics of storage are complicated by the fact that, in the process of decay, the wastes produce heat so intense it can boil water out of desert rocks.[10] As a result, spent fuel must be cooled for three to five years in pools at reactor sites before it can even be handled or transported.[11] Initially, it was these pools that served as storage for spent fuel. As they became filled to capacity, however, utilities had to turn to above-ground storage facilities, storing fuel in casks that are continuously monitored and secured by armed guards. The Nuclear Regulatory Commission ("NRC"), which licenses such "dry storage" facilities, has determined they can remain safe for at least 100 years,[12] though the industry has testified that spent fuel "can be stored for centuries safely" at such facilities.[13] Twenty-four dry storage facilities are in operation, with the construction of twenty-one more in the planning stage.[14] Also, under development by utilities is a dry storage facility in Utah that will hold nearly 87 percent of the industry's existing spent fuel.[15]

Another, comparatively short-lived, approach was the notion that spent fuel should be "reprocessed" to extract the reusable uranium and plutonium from it. Reprocessing is important in the history of public efforts to address the disposal of high-level nuclear waste because for years a solution to the problem was postponed because it was assumed spent

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8. H.R. Rep. No. 97-785, Pt. 1, at 46.

9. *See* U.S. NUCLEAR REGULATORY COMMISSION, INFORMATION DIGEST, NUREG 1350 (2003), *available at* http://www.nrc.gov/readingrm/doccollections/nuregs/staff/sr1350/#high_level; Nuclear Energy Institute, *High-Level "Nuclear Waste" Is Really Used Nuclear Fuel* (2004), *available at* http://www.nei.org/doc.aspcatnum=2&catid=62&docid=&format=print.

10. *See* 2002 Final EIS, *supra* note 6, at 2-9 to 2-11.

11. H.R. Rep. No. 97-785, Pt. 1, at 40.

12. Ivan Selin, Chairman, U.S. Nuclear Regulatory Comm'n, Remarks Before the International High-Level Waste Management Conference, at 3 (May 1, 1995) (transcript on file with author).

13. Nuclear Waste Disposal Joint Hearings on S. 637 and S. 1662 Before the S. Comm. on Energy and Natural Res. and the Subcomm. on Nuclear Regulation of the S. Comm. on Env't and Pub. Works, 97th Cong. 358 (1981) (statement of Sherwood Smith, Chairman & CEO, Carolina Power & Light Co., on behalf of the American Nuclear Energy Council, the Edison Electric Institute, and the Utility Nuclear Waste Management Group).

14. Kimberly A. Gruss, Senior Materials Engineer, National Resource Council, U.S. Experience With Dry Cask Storage, A Regulator's Perspective, Presentation at the Dry Spent Fuel Technology Technical Meeting, at 23-24 (June 10-14, 2002) (transcript on file with author).

15. 2002 Final EIS, *supra* note 6 at 1-22.

fuel would be reprocessed. This reprocessing would leave liquid radioactive wastes which would then be "vitrified," or immobilized, into solid glass logs that can be stored safely indefinitely.[16] However, in 1976, the government, for a combination of non-proliferation and economic reasons, ended reprocessing in the United States.[17]

A. The Solution: Geologic Disposal

In 1957, the National Academy of Sciences ("NAS") completed the nation's first comprehensive study of the management and disposal of nuclear waste.[18] "Unlike the disposal of any other type of waste," NAS said, "the hazard related to radioactive waste is so great that no element of doubt should be allowed to exist regarding safety."[19] The best option to meet that standard of certainty, according to NAS, was to bury this waste deep underground in a stable geologic setting that would permanently isolate it from human beings and the rest of the environment. Particularly promising for this task are salt deposits, because "no water can pass through salt" and its "[f]ractures are self-sealing."[20] The bottom line, for NAS, was that we should "return[ ] those wastes to nature in some place where they can be held for very, very long periods of time without jeopardy to our environment or property."[21]

With the endorsement of NAS, "deep geologic isolation" became the cornerstone of every repository program in the world, including what became the U.S. repository program. In 1980, President Jimmy Carter ordered the Department of Energy ("DOE") to prepare a full Environmental Impact Statement ("EIS") recommending an alternative to permanently dispose of high-level nuclear waste.[22] Although DOE's analysis was informed by NAS's endorsement of geologic disposal, DOE evaluated every conceivable method of disposal, including subseabed and ice-sheet disposal, deep-well injection, transmutation, and even disposal in outer space.[23] In the end, the solution proposed by DOE was to dispose of spent fuel in "mined repositories deep within the geologic

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16. *See id.* at 1-7.

17. H.R. Rep. No. 97-491, Pt. 1, at 27 (1982).

18. COMM. ON WASTE DISPOSAL, NATIONAL RESEARCH COUNCIL, THE DISPOSAL OF RADIOACTIVE WASTE ON LAND (1957).

19. *Id.* at 3.

20. *Id.* at 4.

21. *Id.* at 18.

22. 2002 Final EIS, *supra* note 6 at 1-9.

23. 1 ASSISTANT SEC'Y FOR NUCLEAR ENERGY, DEP'T OF ENERGY, FINAL ENVIRONMENTAL IMPACT STATEMENT: MANAGEMENT OF COMMERCIALLY GENERATED RADIOACTIVE WASTE § 1.4 (1980).

formations of the earth,"[24] which would be so effective that "it is extremely improbable that wastes in biologically important concentrations would ever reach the human environment."[25]

The effectiveness of geologic isolation did not mean that man-made, "engineered barriers" were to play no role. DOE explained:

> The multiple barriers that could contain nuclear waste in deep mined repositories fall into two categories (1) geologic or natural barriers and (2) engineered barriers. Geologic barriers are expected to provide isolation of the waste for at least 10,000 years after the waste is emplaced in a repository and probably will provide isolation for millennia thereafter. Engineered barriers are those designed to assure total containment of the waste within the disposal package during an initial period during which most of the intermediate-lived fission products decay. This time period might be as long as 1000 years. . . .[26]

DOE emphasized that "[m]ultiple barriers are intended to act independently to prevent waste migration and enhance isolation."[27] "[T]he engineered components of the multibarrier system would be of greatest importance in the short term and the repository medium and the surrounding geology would be the critical elements over long periods of time."[28] Echoing NAS, DOE concluded, "[t]he host rock with its properties provides the justification for geologic disposal and is the main element in containing the waste within the repository and in isolating the waste from man's environment over the long term."[29] The bottom line for DOE at this time was clear: the geologic setting should be capable of containing wastes to ensure *long-term* safety. That meant isolating this waste for *250,000 to 500,000 years*.[30]

Together, the NAS study and the EIS established the scientific framework for evaluating the suitability of a mined geologic repository. It was this scientific foundation that informed Congress as it considered nuclear waste legislation beginning in 1980, culminating with in enactment of the Nuclear Waste Policy Act ("NWPA") two years later.

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24. *Id.* at § 5.1.
25. *Id.* at § 1.3.4.
26. *Id.* at § 5.1.
27. 3 ASSISTANT SEC'Y FOR NUCLEAR ENERGY, DEP'T OF ENERGY, FINAL ENVIRONMENTAL IMPACT STATEMENT: MANAGEMENT OF COMMERCIALLY GENERATED RADIOACTIVE WASTE 272 (Oct. 1980) [hereinafter 1980 Final EIS (vol.3)].
28. *Id.* at 281.
29. 2 ASSISTANT SEC'Y FOR NUCLEAR ENERGY, DEP'T OF ENERGY, FINAL ENVIRONMENTAL IMPACT STATEMENT: MANAGEMENT OF COMMERCIALLY GENERATED RADIOACTIVE WASTE at B.15 (1980).
30. 1980 Final EIS (vol.3), *supra* note 27 at 360-61.

B. Congress Acts: The Nuclear Waste Policy Act

At the outset, Congress considered approaches to nuclear waste disposal that would dispose of *reprocessed* wastes from spent fuel, not the spent fuel itself.[31] The initial proposal relied primarily on engineered barriers to dispose of vitrified reprocessed wastes.[32] Importantly, DOE opposed the bill on grounds that it was inappropriate to rely primarily on engineered barriers *even for repositories without spent fuel.* In DOE's words,

> Engineered barriers are an essential ingredient in a technically conservative approach to an actual repository, but we do not feel that the existence of such barriers should be used as a basis for a less careful selection of an acceptable geologic media.[33]

As work continued on the Hill, the key committees began to recognize that, given the policy shift away from reprocessing, it was much more likely that the waste to be disposed of was going to be the far more radioactive and dangerous spent fuel itself.[34] The far more dangerous and longer-term risks posed by the disposal of unreprocessed spent fuel meant that some elements of this waste would need "to be isolated for at least 245,000 years."[35] Secure storage for such a phenomenal length of time led away from reliance on any engineered barrier back to the only material that has been around for that long—rock. As the House Commerce Committee put it:

> [T]he ability of any man-made containers to endure for a quarter of a million years is obviated by the fact that the ultimate barrier which prohibits the release of any radioactivity into the biosphere is the geologic media itself. The effectiveness of this method is dependent upon finding a geologic media whose integrity is intact, meaning that it does not have openings which would allow radioactivity to escape into the atmosphere or into the ground water.[36]

The logic governing the choice of a site for a repository was then

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31. *See* H.R. Rep. No. 96-1156, Pt. 1, at 25 (1980).

32. *Id.* at 17-18.

33. *Id.* at 37.

34. *See, e.g.*, S. Rep. No. 96-548, at 11 (1980) (noting the deferral of "commercial reprocessing of spent nuclear fuel for the indefinite future"); H.R. Rep. No. 96-1156, Pt. 2, at 2 (1980) (recognizing that "the option to reprocess spent nuclear fuel is presently foreclosed to the nuclear industry," making it "necessary at this time to do preliminary planning on the basis of geologic disposal of spent fuel").

35. H.R. Rep. No. 96-1156, pt. 3, at 13 (1980).

36. *Id.* at 14.

quite clear. A repository could not just be put anywhere; the site must meet specific requirements. As the House Committee cautioned at the time, "[w]hile it is believed that there are locations within the United States which meet these requirements, it is further believed that the number of such locations is limited."[37]

In this way, reliance on the geology of a repository's site became an essential element of the nation's nuclear waste disposal effort. Finally, in 1982, in the NWPA, the repository program Congress fashioned embodied a

> [c]ommitment to a waste disposal technology relying on primary geologic containment provided by a solid rock formation located deep underground, together with containment by engineered barriers including the form and packaging of the nuclear waste, which will provide safe containment of the waste without reliance on human monitoring and maintenance after an initial period of testing and subsequent closure of the repository.[38]

Selecting a repository site, then, means

> finding a geologic medium whose integrity is intact, meaning that it does not have openings which would allow radioactivity to escape into the atmosphere or into the ground water. The structural integrity of the geologic medium would also have to be stable enough to maintain its integrity during the period of time in which these materials remain radioactive.[39]

The focus on the geology into which a nuclear waste repository will be inserted is evident from the threshold of the NWPA's definitions through the complex process of site selection and repository development established by the statute. Thus, the NWPA defines "repository" as a system to be used for "permanent deep geologic disposal."[40] "Candidate sites" are defined as areas "within a geologic and hydrologic system" that undergo DOE site characterization,[41] which, in turn, means DOE activities "undertaken to establish the geologic condition" of a candidate site.[42] The statute goes on to require DOE to establish guidelines for the selection and recommendation of sites, which "shall specify de-

37. *Id.*
38. H.R. Rep. No. 97-491, Pt. 1, at 30 (1982). *See also* H.R. Rep. No. 97-785, Pt. 1, at 48 (1982).
39. H.R. Rep. No. 97-785, Pt. 1, at 48.
40. 42 U.S.C. § 10101(18) (2000).
41. § 10101(4).
42. § 10101(21).

tailed geologic considerations that shall be primary criteria" for site selection.[43] Moreover, "[s]uch guidelines shall specify factors that qualify or disqualify any site from development as a repository, including factors pertaining to . . . hydrology, geophysics [and] seismic activity. . . ."[44]

A central purpose of the NWPA was to "define the relationship between the Federal Government and the State governments with respect to the disposal of such waste and spent fuel."[45] Three federal agencies were assigned responsibility for the assessment and potential development of proposed repositories. DOE was to evaluate and recommend potential repository sites, and then build and operate the repositories.[46] The NRC was to determine whether to license the repositories in accordance with statutory and regulatory standards.[47] The Environmental Protection Agency ("EPA") was to set the radiological release standards applicable to repositories.[48]

As originally enacted, the NWPA process for the development of a repository was clearly designed to find a site that met the critical geologic attributes essential to the safe, secure, and long—term disposal of nuclear waste. The Secretary of Energy was assigned the task of evaluating potential candidate sites in accordance with the standards established by the statute, and then nominating to the President at least five sites to be subjected to further research as possible candidates to become the first repository.[49] The Secretary was then to narrow this list and recommend three sites to the President by January 1, 1985, which would then proceed to the detailed site characterization stage.[50] The President, in turn, was to decide whether each recommended site should proceed to site characterization.[51]

Once the sites were fully characterized, the Secretary was to recommend to the President a single site to be developed as a repository.[52] Upon such a recommendation, the President was authorized to designate the site to Congress. The President's site designation was automatically to "take effect" after sixty days unless the state in which the site was lo-

43. § 10132(a).
44. *Id.*
45. § 10131(b)(3).
46. § 10134.
47. §§ 10134(d), 10141(b).
48. § 10141(a).
49. § 10132(b)(1)(A).
50. §§ 10132(b)(1)(B), 10101(21).
51. § 10132(c). The National Waste Policy Act established a similar process (with different timetables) for the characterization of sites for possible selection as a second repository. 42 U.S.C. § 10132(b)(1)(c) (2000).
52. § 10134(a).

cated submitted to Congress a "notice of disapproval."[53] If the state did disapprove, the selection of the site could not become effective unless, during the first ninety days after receipt of the notice, Congress passed a "resolution of repository siting approval" overriding the notice of disapproval, and such resolution became law.[54] The precise text of the resolution was dictated by the NWPA, was not amendable, and was considered by the House and the Senate under severely expedited and abbreviated procedures that limited debate, truncated opportunities for normal legislative deliberation, and omitted many of the usual procedural protections for minority interests.[55]

It is important to underscore the fact that Congress did not assume that the site characterization process would automatically lead to the selection of that site for the repository. Quite the contrary, Congress fully appreciated that the federal government could spend considerable time and resources investigating a particular site, only to conclude that the site was unsuitable. As one House Committee noted:

> The risk that a site which had been considered probably adequate for development could be abandoned after significant commitment had been made to the site is a technically unavoidable aspect of repository development. It is a result of the limit of our ability to know with certainty all the characteristics of a rock formation deep underground until the rock site has actually been excavated and surveyed from the "horizon" or level of the repository.[56]

The DOE, NRC, and EPA published rules intended to discharge their obligations under the NWPA.[57] In its first set of site suitability rules in 1984, DOE paid careful attention to the geologic requirements and the physical qualifying and disqualifying conditions recommended by NAS and the 1980 EIS, and required by the NWPA.[58] The NRC concurred in the draft regulations, but only upon DOE's promise to specify "that engineered barriers cannot constitute a compensating measure for deficiencies" in physical attributes of the site.[59] The EPA also warned DOE not to over-rely on engineered barriers.[60]

DOE's final rules accordingly provided that "engineered barriers shall not be used to compensate for an inadequate site; mask the innate

53. § 10135(b).
54. § 10135(c).
55. § 10135(a), (d), (e).
56. H.R. REP. NO. 97-491, Pt. 1, at 32 (1982).
57. 10 C.F.R. Pt. 960 and 60 (2004), 40 C.F.R. Pt. 191 (2003), respectively.
58. *See* 49 Fed. Reg. 47,714 & 47,718 (Dec. 6, 1984).
59. 49 Fed. Reg. at 47,727.
60. 49 Fed. Reg. at 47,727.

deficiencies of a site; disguise the strengths and weaknesses of a site and the overall system; and mask differences between sites when they are compared."[61] As the NWPA requires, DOE also specified both qualifying and disqualifying conditions for a site. A key disqualifying condition was that of groundwater travel time, since "[t]he most likely mechanism for the release of radionuclides from a repository to the accessible environment is transport by ground water."[62] Accordingly, DOE specified that surface rainwater trickling through the repository site must take no less than 1,000 years to descend from the repository into the water table and the accessible environment.[63]

C. The Focus on Yucca Mountain

In 1986, complying with the NWPA timeline, the Secretary of Energy recommended and the President approved three sites for detailed site characterization: Yucca Mountain, Nevada; Deaf Smith County, Texas; and Hanford, Washington.[64] However, in 1987, due to rising cost estimates for site characterization at the three sites chosen by DOE, Congress amended the NWPA to provide that Yucca Mountain would be the only site characterized.[65] Significantly, however, in narrowing site characterization to Yucca Mountain, Congress did *not* prejudge the Yucca site's suitability, but instead made clear that "[i]f the Secretary at any time determines the [Yucca Mountain] site to be unsuitable for development as a repository," he was to terminate all activities and notify Congress.[66] Moreover, Congress did nothing to change the physical siting requirements it had enacted in the original NWPA. Although the focus for site characterization was now solely on Yucca Mountain, the statute continued to mandate that the original criteria for evaluating the suitability of a site still governed that process.[67]

As commanded by the 1987 amendments of the NWPA, DOE released a "Site Characterization Plan" that underscored that the 1987 changes did nothing to disturb the standards for evaluating a repository site.[68] Indeed, DOE stressed that repository safety was inextricably

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61. 10 C.F.R. § 960.3-1-5(e) (2004).

62. 49 Fed. Reg. at 47,732.

63. 10 C.F.R. § 960.4-2-1(d) (2004).

64. *See* Nevada v. Watkins, 939 F.2d 710, 713 (9th Cir. 1991).

65. *See generally*, Nuclear Waste Policy Amendments Act of 1987, Pub. L. No. 100-203, tit. V, subtit. A.

66. 42 U.S.C. § 10133(c)(3) (2000).

67. § 10133 (b)(1)(A)(iv).

68. *See* U.S. Dept. of Energy Office of Civilian Radioactive Waste Management, Site Characterization Plan: Yucca Mountain Site, Nevada Research and Development Area, Nevada, Vol. I, Pt. A, at I-8-9 (Dec. 1988).

linked to the physical setting, stating that "[g]eologic conditions are intrinsic to the performance of a repository. . . ."[69]

Congress again tinkered with the NWPA in the Energy Policy Act of 1992 ("EnPA") to resolve a long-standing tug-of-war between the NRC and EPA by giving the EPA responsibility to set the primary radiological standards for waste emissions at Yucca Mountain.[70] Again, Congress did nothing in EnPA to alter the NWPA's standards governing the site suitability analysis and the geologic isolation of waste, as DOE subsequently confirmed both in 1994[71] and in 1995.[72]

D. 1996 and Beyond: The Perfect Storm Hits DOE

For more than a decade after enactment of the NWPA, DOE consistently viewed "geologic" isolation as statutorily required and scientifically necessary for the safe, permanent disposal of nuclear waste. It also understood, logically, that the choice of a repository site was a function of its geologic attributes. Then, in 1996, a confluence of events created what was for DOE's bureaucracy, the perfect storm. First, Congress slashed the Yucca Mountain budget for fiscal year 1996 by forty percent,[73] which is by any measure "draconian budget cuts."[74] Second, in *Indiana-Michigan Power Co. v. U.S. Dept. of Energy*,[75] the D.C. Circuit ruled that DOE had an "unconditional obligation" to dispose of utilities' spent fuel by the NWPA's 1998 statutory deadline. In view of DOE's impending breach, the decision presented DOE with potentially crushing financial liability, perhaps up to $56 billion.[76]

Third, and worst of all, ominous results were pouring in from stud-

69. U.S. Dept. of Energy Office of Civilian Radioactive Waste Management, Site Characterization Plan Overview: Yucca Mountain Site, Nevada Research and Development Area, Nevada, at 16 (Dec. 1988).

70. Energy Policy Act of 1992 § 801(a)(1), note to 42 U.S.C. § 10141 (2000).

71. *See* 59 Fed. Reg. 39,766 (Aug. 4, 1994).

72. *See* 60 Fed. Reg. 47,737-39 (Sept. 14, 1995).

73. U.S. Dept. of Energy, Draft Civilian Radioactive Waste Management Program Plan, DOE/RW-0458 Revision 1, at vi (May 1996).

74. Daniel A. Dreyfus, Director, U.S. Dept. of Energy Office of Civilian Radioactive Waste Management, Program Status and Outlook, Presentation Before the Nuclear Waste Technical Review Board 1996 Winter Meeting, at 1 (Jan. 10, 1996).

75. 88 F.3d 1272, 1275 (D.C. Cir. 1996).

76. Nuclear Energy Inst., DOE To Breach 16-Year Legal Obligation To Manage Used Nuclear Fuel; U.S. Taxpayers Face $56 Billion in Liabilities, at 2 (Jan. 30,1998), *available at* http://www.nei.org/doc.asp?Print=true&DocID=&CatNum=4&CatID=11. *See also* Northern States Power Co. v. U.S. Dept. of Energy, 128 F.3d 754, 759 (D.C. Cir. 1997) (referring to "billions" of dollars of delay-related costs); Alabama Power Co. v. U.S. Dept. of Energy, 307 F.3d 1300, 1302 (11th Cir. 2002) (referring to "tide of litigation arising out of this massive breach").

ies in a five-mile tunnel DOE had bored deep into the Yucca Mountain "unsaturated" zone. It had become apparent that Yucca's geology was incapable of serving as the primary isolation barrier because groundwater flow through the site was far faster than expected. Absent near-perfect performance by man-made barriers, the fast flowing groundwater was likely to carry radioactive particles so quickly that radiological emission standards could never be met. Geologists, for example, discovered chlorine-36 in fractures in the area where the repository was to be constructed.[77] The abundance of this rare isotope meant it had originated from fallout during atmospheric nuclear testing in the 1950s, and suggested that it had migrated from surface rainwater through hundreds of feet of rock in previously unsuspected "fast flow paths."[78] Geologists found pockets of trapped water in what was thought to be the dry, "unsaturated" zone. In some areas, nearly *a million cubic meters* of water were discovered.[79] After further studies, DOE's geologists confirmed that "flow along fast preferential pathways through fractures is a significant and perhaps the dominant flow regime in the unsaturated zone," leading to "travel times of less than 50 years from the land surface to the saturated zone."[80] Far from permanently isolating waste, Yucca Mountain's geology would allow groundwater to carrying radionuclides into the water table far sooner than required to prevent contamination of the human environment.[81]

In 1998, after reviewing DOE's reports to the Nuclear Waste Technical Review Board ("TRB"), which is a board of scientists established by Congress that serves as a technical auditor of DOE's work, Nevada's governor urged DOE to disqualify the Yucca Mountain site.[82] The Secretary's response conceded that DOE's analyses showed that up to 20

77. D.L.Barr, *et al.*, Bureau of Reclamation and U.S. Geological Survey, *Geology of the North Ramp: Stations 4+00 to 28+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada*, at 125 (1996).

78. *See* J.T. Fabryka-Martin, *et al.*, Summary Report of Chlorine-36 Studies: Systematic Sampling for Chlorine-36 in the Exploratory Studies Facility, Abstract, at i (March 29, 1996).

79. G.S. BODVARSSON & T.M. BANDURRAGA, DEVELOPMENT AND CALIBRATION OF THE THREE-DIMENSIONAL SITE-SCALE UNSATURATED ZONE MODEL OF YUCCA MOUNTAIN, NEVADA, at 265 (1996) (hereinafter "UNSATURATED ZONE MODEL").

80. J. Fairley & E. Sonnenthal, *Preliminary Conceptual Model of Flow Pathways Based on Cl-36 and Other Environmental Isotopes*, in UNSATURATED ZONE MODEL, at 399 (G.S. Bodvarsson & T.M. Bandurraga eds., 1996).

81. John Bartlett, former Director of U.S. Dept. of Energy's Yucca Program, confirmed that U.S. Dept. of Energy's studies showed that "rates of water infiltration into the mountain were on the order of 100 times higher than had been expected; [and] that water flowed very rapidly through fracture pathways in some of the geologic layers." Affidavit of Dr. John W. Bartlett 22 (Jan. 2002) (hereinafter "Bartlett Aff.").

82. Letter from Bob Miller, Governor of the State of Nevada, to Bill Richardson, Secretary of Energy 2 (Dec. 4, 1998) (on file with author).

percent of all water moving through the repository would reach the water table in less than 1,000 years, but concluded that "additional study [was] warranted" before the site could be disqualified.[83] Yet those additional studies presented only more bad news. A 1999 repository "performance assessment" by DOE showed that the geologic setting at Yucca Mountain contributed almost nothing to the repository's total waste isolation capabilities.[84] That is, DOE's model of the repository "system" showed almost total reliance on engineered barriers—barriers yet to be fully designed.[85] Another DOE performance analysis in 2000 told a similarly bleak story: if engineered barriers failed, the natural barriers would permit a dose rate more than 666 times the EPA limit within the 10,000-year compliance period.[86] A 2001 analysis also showed that if engineered barriers failed, the dose at the site boundary was projected to be more than six times the EPA limit at only 1,000 years. By the 3,000-year mark, the expected dose would rise to 67 times the EPA limit.[87]

E. If at First You Don't Succeed . . . Change the Rules

As it became clear that the Yucca Mountain site could not meet the requirements of the NWPA or the regulations three agencies had promulgated pursuant to that statute, DOE adopted a new strategy: change the site suitability rules, but only with respect to Yucca Mountain. Accordingly, DOE began intensively lobbying the NRC and the EPA to change their respective Yucca Mountain rules to focus on "system" performance analysis in which there would be no separate standards for the component parts of that "system."[88] In doing so, the DOE sought to allow the

83. Letter from Bill Richardson, Secretary of Energy, to Bob Miller, Governor of the State of Nevada (Dec. 18, 1998) (on file with author).

84. Dennis C. Richardson, U.S. Dept. of Energy Office of Civilian Radioactive Waste Management, Postclosure Defense in Depth in the Design Selection Process, Presentation Before the Nuclear Waste Technical Review Board Panel for the Repository, at 18 (Jan. 25, 1999).

85. *See* Bartlett Aff., *supra* note 82, at ¶ 30. The Department of Energy conceded to the Nuclear Waste Technical Review Board that Yucca's natural barriers would be ineffective to protect against uncertainties in the performance of its engineered barriers, and that "defense-in-depth" could only exist only by stacking one man-made barrier onto another, since geologic factors could make no significant contribution. *See* Dennis C. Richardson, Dept. of Energy Office of Civilian Radioactive Waste Management, Barrier Neutralization Analyses, Presentation to DOE/NRC Technical Exchange: Total System Performance Assessments – Site Recommendation Briefing (Jan. 23, 2001) (hereinafter "*Barrier Neutralization Analyses*").

86. TRW Environmental Safety Systems, Inc., Repository Safety Strategy: Plan to Prepare the Postclosure Safety Case to Support Yucca Mountain Site Recommendation and Licensing Considerations, at E-11 (Jan. 2000).

87. *Barrier Neutralization Analyses*, *supra* note 85, at 17.

88. *See* Daniel A. Dreyfus, Director, U.S. Dept. of Energy Office of Civilian Radioactive Waste Management, Status of the Civilian Radioactive Waste Management Program, Presenta-

very thing it had said should not be done in 1984: the masking of the deficiencies of the site through reliance on engineered barriers. DOE clearly abandoned any effort to find the right site, which it now called "a false target."[89] DOE wanted to be sure that the Yucca Mountain site could meet any standard that was established, whether or not the physical attributes of the site effectively isolated radioactive waste. DOE went so far as to caution both NRC and EPA that, in formulating new rules, "[p]romulgating a standard that cannot be implemented may result in the *de facto* rejection of the Yucca Mountain site . . . ."[90]

DOE's maneuver to change the rules for Yucca Mountain entered its penultimate phase in 1999, when it published proposed amendments to its repository guidelines, Part 960, announcing a new Part 963 *applicable only* to Yucca Mountain. Part 960 was to be revised to limit its application only to *other* potential repository sites.[91] The new Part 963 established new "site suitability criteria" for *Yucca alone*, abandoning each of the geologic and hydrologic criteria of the NWPA and all qualifying and disqualifying site features. Instead, Part 963 would require DOE to meet just a single qualifying criterion—that a total system performance assessment of the entire repository "system" would demonstrate compliance with the EPA dose limit for the EPA's regulatory compliance period, and thus the repository could ostensibly get an NRC construction permit.[92]

Having lobbied NRC and EPA for three years to change their rules

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tion Before the U.S. Nuclear Regulatory Comm'n, at 4-6 (Jan. 30, 1996) ("Dreyfus Presentation"); Testimony of Lake Barrett, U.S. Dept. of Energy Office of Civilian Radioactive Waste Management, Before the U.S. Nuclear Waste Technical Review Board, at 16 (April 30, 1996); Testimony of Stephan J. Brocum, Assist. Manager for Suitability and Licensing, Yucca Mountain Site Characterization Project Office, Before the NRC Advisory Committee on Nuclear Waste, at 332, and supporting power point slides (June 26, 1996); Testimony of Stephan J. Brocum, Assist. Manager for Suitability and Licensing, Yucca Mountain Site Characterization Project Office, Before the Nuclear Waste Technical Review Board, at 42 (Oct. 9, 1996); Stephan J. Brocum, Assist. Manager for Suitability and Licensing, Yucca Mountain Site Characterization Project Office, Program Overview to License Application, Presentation Before the Nuclear Waste Technical Review Board, at 10 (Oct 9-10, 1996); Lake Barrett, U.S. Dept. of Energy Office of Civilian Radioactive Waste Management, Status of the Civilian Radioactive Waste Management Program, Presentation Before the Nuclear Waste Technical Review Board, at 6 (Oct. 22, 1997).

89. Testimony of Russ Dyer, U.S. Dept. of Energy Office of Civilian Radioactive Waste Management, Before the U.S. Nuclear Waste Technical Review Board, at 152 (April 30, 1996).

90. Dreyfus Presentation, *supra* note 89, at 16. *See also* Stephan J. Brocum, Assist. Manager for Suitability and Licensing, Yucca Mountain Site Characterization Project Office, DOE Perspective on Time Frame of Compliance, Presentation Before the Advisory Committee on Nuclear Waste, at 3-9 (March. 27, 1996).

91. 64 Fed. Reg. 67,054-55 (1999).

92. 64 Fed. Reg. at 67,066-70 (1999).

to a system-based regime that would obscure the distinctive roles of natural and engineered barriers, DOE now blamed the abandonment of Part 960 and the promulgation of Part 963 on the rule changes enacted by those agencies.[93] This was especially ironic given that EPA had earlier objected to DOE's abandonment of Part 960, saying that a "major reason" for the move was DOE's discovery of "significantly faster water flow" than its regulations allowed.[94] According to the EPA, "the waste isolation capability of the natural features of the Yucca Mountain site is at present highly uncertain and largely unassessed."[95] Moreover, the "total-system approach proposed by the DOE could be viewed as masking this uncertainty and the potentially insufficient waste isolation capability of site features if the contributions and uncertainties of the natural and engineered barriers are not individually assessed."[96] The NRC and the EPA had finally relented on changes, largely on the premise that it was solely *DOE*'s statutory role to determine site suitability, not NRC's or EPA's.[97]

DOE's final Part 963 guidelines, applicable only to Yucca Mountain, were published in November 2001 and became effective a month later.[98] By removing from the site selection analysis any independent reliance upon the capabilities of the site's natural barriers to isolate waste, DOE's Yucca Mountain guidelines were "site-specific" only in the narrow sense that they technically applied solely to Yucca Mountain. As a substantive matter, the guidelines rendered the physical characteristics of the Yucca Mountain site irrelevant. At the same time that it adopted new guidelines applicable only to Yucca Mountain, DOE also maintained its earlier site suitability/selection guidelines, which continued to adhere to the NWPA's commitment to primary geologic isolation, for all other potential repository sites. Thus, the federal government established two sets of rules: one dramatically watered-down set for the site in Nevada and one set for sites in any other state.

93. 64 Fed. Reg. at 67,068-72 (1999); C. Kouts, DOE Office of Civilian Waste Management, *Proposed Yucca Mountain Site Suitability Guidelines, 10 CFR 963*, Presentation to Affected Units of Government Meeting, at 3 (Jan. 27, 2000); 66 Fed. Reg. 57,298-99 (2001).

94. General Comments on the Proposed Amendments to 10 CFR Part 960, at 2, *enclosure to* Letter from E. Ramona Trovata, Director, EPA Office of Radiation and Indoor Air, to April V. Gil, DOE Office of Civilian Radioactive Waste Management (March 17, 1997).

95. *Id.* at 3.

96. *Id.*

97. *See, e.g.*, Transcript, NRC Advisory Committee on Nuclear Waste, 90th Meeting, at 99 (March 20, 1997) (stating that it "is their call to make").

98. 66 Fed. Reg. 57,298 (Nov. 14, 2001).

F. Yucca is Selected

On February 14, 2002, barely two months after Part 963 became effective, the Secretary of Energy issued to President George W. Bush a Site Recommendation for Yucca Mountain, saying the "site is scientifically and technically suitable for development of a repository."[99] One day later, President Bush, in a letter to Congress, approved the recommendation. Sixty days later, Nevada's governor submitted to Congress a formal notice of disapproval of the site designation. Congress then proceeded to pass a Joint Resolution overriding the notice of disapproval, which the President signed on July 23, 2002.[100] With that, DOE was both entitled and required to submit a License Application to NRC within ninety days.[101] DOE failed to do so, although it now insists that it will submit an application in December 2004.

II. THE LITIGATION

Now the second strand of the story: the one that more directly involves constitutional issues. The NWPA provides for review in the courts of appeals of "any final decision or action" of the President, the Secretary of Energy, or the NRC taken under the NWPA.[102] Nevada brought a series of petitions for review in the D.C. Circuit challenging the lawfulness of various acts along the way to the selection of the Yucca Mountain site, including the new regulations of DOE, EPA, and NRC; the Secretary of Energy's decision to recommend the site to the President; DOE's Environmental Impact Statement; and the President's decision to recommend the site to Congress.[103] One of these cases is the subject here: Nevada's constitutional challenge to the Joint Resolution by which Congress overrode Nevada's disapproval of the selection of Yucca Mountain as the repository site.[104] All these cases were consolidated and argued *en masse* before the D.C. Circuit on January 14, 2004.

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99. RECOMMENDATION BY THE SECRETARY OF ENERGY REGARDING THE SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR A REPOSITORY UNDER THE NUCLEAR WASTE POLICY ACT OF 1982, at 45 (Feb. 14, 2002) (hereinafter "SITE SUITABILITY RECOMMENDATION"), *available at* http://www.ocrwm.doe.gov/ymp/sr/sar.pdf.

100. *See* Pub. L. No. 107-200, 116 Stat. 735 (2002) (codified at 42 U.S.C. § 10135 (Supp. IV 2004)).

101. *See* 42 U.S.C. § 10134(b) (2000).

102. 42 U.S.C. § 10139(a) (2000).

103. *See NEI*, 373 F.3d at 1261-62.

104. Pub. L. No. 107-200, 116 Stat. 735 (2002).

A. The Constitutional Case: An Overview

Nevada's constitutional challenge to the Joint Resolution rests on a straightforward proposition: the constitutional status of the states as sovereigns entitled to equal dignity and respect requires that Congress exercise its legislative power over the states on the basis of generally applicable, facially neutral criteria and prevents the national government from imposing arbitrary burdens upon particular states. By arbitrarily singling out Nevada to bear the burden of disposing of the nation's nuclear waste (leaving Nevada politically isolated and powerless), the Joint Resolution operates in derogation of Nevada's sovereignty and exceeds the authority granted to the national government under the federal system of government established by the United States Constitution.

Nevada's argument rests on three factual premises. First, that Congress, in the NWPA, adopted the judgment of the scientific community that geologic isolation was critical to the safe, permanent disposal of nuclear waste. Second, that the national government has in fact concluded that Yucca Mountain does not and cannot meet the statutory standard of primary geologic isolation. And, third, that the national government has nevertheless decided to abandon the only neutral standards for safe disposal it had established, forcing Nevada to bear the burden of disposing of this waste.

The difficulty in fashioning this argument was that no constitutional text directly addresses the question at issue. Accordingly we knew that our argument "must be sought in historical understanding and practice, in the structure of the Constitution, and in the jurisprudence of th[e Supreme] Court."[105] Moreover, a body of Supreme Court decisions over the last ten years or so have spurred significant developments in the law of federalism and reinvigorated the practical implications of state sovereignty. The principles animating these decisions, and not their precise holdings, provided the building blocks for Nevada's argument.

B. The Eleventh Amendment

Much of the recent development of the jurisprudence of federalism has involved the Eleventh Amendment, and so those cases were logically the first body of precedent to which we turned. On a first examination, one would not think the Eleventh Amendment would offer much help. The amendment provides that the "Judicial power of the United States shall not be construed to extend to any suit in law or equity, commenced

105. Printz v. United States, 521 U.S. 898, 905 (1997).

and prosecuted against one of the United States by Citizens of another State, or by Citizens or Subjects of any Foreign State."[106] Neither the NWPA, nor our real target, the Joint Resolution, purported to create a cause of action against Nevada or to bring the "judicial power" of the United States to bear against Nevada.

Yet an examination of Eleventh Amendment cases shows a consistent analytical approach that disregards the actual text of the Eleventh Amendment in favor of reliance on principles of sovereignty and on the structure of federalism imbedded in the Constitution. This approach is not a contemporary innovation. For example, in the early part of the last century, the Supreme Court rejected Monaco's effort to sue Mississippi on bonds that the state had issued, holding it to be "manifest[ ]" that

> we cannot rest with a mere literal application of the words of § 2 of Article III, or assume that the letter of the Eleventh Amendment exhausts the restrictions upon suits against non-consenting States. Behind the words of the constitutional provisions are postulates which limit and control. There is the . . . postulate that States of the Union, still possessing attributes of sovereignty, shall be immune from suits, without their consent, save where there has been "a surrender of this immunity in the plan of the convention."[107]

The appearance of this method—going "behind the words of the constitutional provisions" to find "postulates which limit and control"—in modern federalism precedents was provoked, oddly enough, by a dispute over Indian gambling in Florida. When the Seminole Indian Tribe sued Florida to compel the state's compliance with the federal Indian Gaming Regulatory Act,[108] the Court used the Eleventh Amendment as the ground for its decision holding that Congress lacks power under Article I to abrogate the states' sovereign immunity from suits commenced or prosecuted in the federal courts. The Court frankly recognized that "the text of the Amendment would appear to restrict only the Article III diversity jurisdiction of the federal courts."[109] Nevertheless, the Court continued,

> we have understood the Eleventh Amendment to stand not so much for what it says, but for the presupposition . . . which it confirms." That presupposition, first observed over a century ago in *Hans* v. *Louisiana*, has two parts: first, that each State is a sovereign entity in

106. U.S. CONST. amend. XI.

107. Principality of Monaco v. Mississippi, 292 U.S. 313, 322-323 (1934) (quoting THE FEDERALIST No. 81 (Alexander Hamilton)).

108. Seminole Tribe of Fla. v. Florida, 517 U.S. 44 (1996).

109. *Id.* at 54.

> our federal system; and second, that "it is inherent in the nature of sovereignty not to be amenable to the suit of an individual without its consent.[110]

Three years later, in *Alden v. Maine*,[111] the Court took the opportunity of a lawsuit by state probation officers against their employer, the state of Maine, for alleged violations of the Fair Labor Standards Act, to stretch the Eleventh Amendment's limitation on the reach of federal judicial power out of the context of federal jurisdiction altogether. Here again, the Court turned to fundamental attributes of sovereignty to hold that Congress cannot make the States liable to private suit even in their own state courts, despite the fact that the text of the Eleventh Amendment restricts only *federal* court jurisdiction.

To the *Alden* Court, the actual parameters of the constitutional text posed no difficulty. "To rest on the words of the Amendment alone would be to engage in the type of ahistorical literalism we have rejected in interpreting the scope of the States' sovereign immunity since the discredited decision in *Chisholm*."[112] Rather, the analysis must proceed from "'history and experience, and the established order of things,' rather than 'adhering to the mere letter' of the Eleventh Amendment, in determining the scope of the States' constitutional immunity from suit."[113] The Court justified this approach by pointing out that

> sovereign immunity derives not from the Eleventh Amendment but from the structure of the original Constitution itself. *See, e.g., Idaho* v. *Coeur d'Alene Tribe of Idaho*, 521 U.S. 261, 267-268 (1997) (acknowledging "the broader concept of immunity, implicit in the Constitution, which we have regarded the Eleventh Amendment as evidencing and exemplifying"); *Seminole Tribe, supra,* at 55-56; *Pennhurst State School and Hospital* v. *Halderman*, 465 U.S. 89, 98-99 (1984); *Ex parte New York, supra,* at 497. The Eleventh Amendment confirmed rather than established sovereign immunity as a constitutional principle; it follows that the scope of the States' immunity from suit is demarcated not by the text of the Amendment alone but by *fundamental postulates implicit in the constitutional design*.[114]

Under the *Alden* Court's reasoning, the Eleventh Amendment was not even necessary to preserve state sovereign immunity. As the Court explained:

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110. *Id.* (citations omitted).
111. 527 U.S. 706 (1999).
112. *Id.* at 730.
113. *Id.* at 727 (citations omitted).
114. *Id.* at 728-29 (emphasis added).

> While the constitutional principle of sovereign immunity does pose a bar to federal jurisdiction over suits against nonconsenting States, this is not the only structural basis of sovereign immunity implicit in the constitutional design. Rather, "there is also the postulate that States of the Union, still possessing attributes of sovereignty, shall be immune from suits, without their consent, save where there has been 'a surrender of this immunity in the plan of the convention.'" This *separate and distinct structural principle* is not directly related to the scope of the judicial power established by Article III, but *inheres in the system of federalism established by the Constitution.* In exercising its Article I powers Congress may subject the States to private suits in their own courts only if there is "compelling evidence" that the States were required to surrender this power to Congress pursuant to the constitutional design.[115]

As the reasoning of these sovereign immunity cases unfolds one sees that, to the Court's mind, they are not so much about immunity as about the sovereignty from which that immunity arises. The Court affirmed this view just two years ago, in *Federal Maritime Commission v. South Carolina State Ports Authority*,[116] noting that the sovereign immunity doctrine's "central purpose is to 'accord the States the respect owed them as' joint sovereigns."[117] The Court emphasized, moreover, that "[d]ual sovereignty is a defining feature of our Nation's constitutional blueprint."[118] What Madison wrote in 1787 has lost none of its vitality in our constitutional order: the "States thus retain 'a residuary and inviolable sovereignty.' They are not relegated to the role of mere provinces or political corporations, but retain the dignity, though not the full authority, of sovereignty."[119]

The implications of this precedent for our constitutional argument in the Yucca Mountain case are profound. Our system of federalism not only limits *what* Congress may do, but also limits *how* Congress may do it.

> When Congress legislates in matters affecting the States, it may not treat these sovereign entities as mere prefectures or corporations.

115. *Id.* at 730-31 (emphases added; citations omitted).

116. 535 U.S. 743, 760 (2002) (holding that state sovereign immunity bars the Federal Maritime Commission from "adjudicating a private party's complaint that a state-run port has violated the Shipping Act of 1984").

117. *Id.* at 765.

118. *Id.* at 751.

119. Alden v. Maine, 527 U.S. 706, 715 (quoting THE FEDERALIST No. 39 (James Madison)); *see also* Federal Mar. Comm'n v. South Carolina State Ports Auth., 535 U.S. at 743, 751 (2002) ("States, upon ratification of the Constitution, did not consent to become mere appendages of the Federal Government.").

> Congress must accord States the esteem due to them as joint participants in a federal system, one beginning with the premise of sovereignty in both the central Government and the separate States. Congress has ample means to ensure compliance with valid federal laws, but it must respect the sovereignty of the States.[120]

It follows that although Congress may establish a national nuclear waste repository, it may not run roughshod over Nevada's sovereign dignity in the process.

C. *The "Commandeering" Cases*

In *New York* v. *United States*[121] and *Printz* v. *United States*,[122] the Supreme Court held that Congress cannot "commandeer" the states by requiring them to enact federal policies into law or to administer federal laws. *New York v. United States* has interesting parallels with the Yucca Mountain controversy as it arose from the effort of Congress, in the Low-Level Radioactive Waste Policy Amendments Act of 1985, to encourage the states to provide for the disposal of low-level radioactive waste generated within their borders. Congress adopted three devices to provide this "encouragement." Monetary incentives and "access incentives" (that is, barring states that had not taken any action to develop their own disposal facilities from access to out-of-state disposal sites) passed constitutional muster.[123] However, the third device required states that had not provided for disposal of in-state low-level waste to "take title" to that waste or to regulate such waste according to congressional directives. This went too far: "[w]hether one views the take title provision as lying outside Congress's enumerated powers, or as infringing upon the core of state sovereignty reserved by the Tenth Amendment, the provision is inconsistent with the federal structure of our Government established by the Constitution."[124]

In *Printz*, two local law enforcement officers, one from Montana and one from Arizona, objected to "being pressed into federal service" by provisions of the Brady Handgun Violence Protection Act that imposed an obligation on state law enforcement officers to conduct background checks on prospective purchasers of handguns.[125] The Court found these objections to be well-taken and held those provisions to be

120. *Alden*, 527 U.S. at 758.
121. 505 U.S. 144 (1992).
122. 521 U.S. 898 (1997).
123. 505 U.S. at 171-74.
124. *Id.* at 177.
125. 521 U.S. at 905.

unconstitutional. Following its reasoning from *New York v. United States*, the Court concluded that both commands to the states to address particular problems and commands to the states' officers to enforce a federal program "are fundamentally incompatible with our constitutional system of dual sovereignty."[126]

Here again, the precise holdings of these cases are not implicated in the Yucca Mountain matter. The Joint Resolution does not attempt to legislate for Nevada as a state, or to commandeer state instrumentalities or officers to implement federal policies.[127] Yet the rationale for these holdings is relevant, for it is predicated on a vision of the dignity and role of states in a federal system. In *Printz*, for example, the Court explained that its holding was compelled by the fact that "[p]reservation of the States as independent political entities" was "the price of union."[128] Although the Court noted in *New York v. United States* that this "inviolable sovereignty" was "reserved explicitly to the States by the Tenth Amendment,"[129] the Tenth Amendment hardly sets out the contours of that sovereignty in a handy way for adjudicating particular cases, much less explicitly drawing a clear perimeter around the permissible actions of the national government.[130]

On the other hand, the majority in *Printz* admitted, "[b]ecause there is no constitutional text speaking to this precise question, the answer to the [States'] challenge must be sought in historical understanding and practice, in the structure of the Constitution, and in the jurisprudence of this Court."[131] As a result of that search, the *Printz* Court found the Constitution's system of "dual sovereignty" and the states' "residuary and inviolable sovereignty" to be

> reflected throughout the Constitution's text, *Lane County* v. *Oregon*, 74 U.S. 71 (1869); *Texas* v. *White*, 74 U.S. 700, 725 (1869), including (to mention only a few examples) the prohibition on any involuntary reduction or combination of a State's territory, Art. IV, § 3; the Judicial Power Clause, Art. III, § 2, and the Privileges and Immunities Clause, Art. IV, § 2, which speak of the "Citizens" of the States; the amendment provision, Article V, which requires the votes of

126. *Id.* at 935.

127. *See, e.g.*, Nevada v. DOE, 133 F.3d 1201, 1207 (9th Cir. 1998) ("Nevada has not been directly compelled to enact or enforce a federal regulatory program. . . . The NWPA itself . . . is implemented entirely by federal government agencies.").

128. 521 U.S. at 919.

129. 505 U.S. at 188.

130. *See* U.S. CONST. amend. X ("The powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively, or to the people.").

131. 521 U.S. at 905.

> three-fourths of the States to amend the Constitution; and the Guarantee Clause, Art. IV, § 4, which "presupposes the continued existence of the states and . . . those means and instrumentalities which are the creation of their sovereign and reserved rights," *Helvering v. Gerhardt*, 304 U.S. 405, 414-415 (1938). Residual state sovereignty was also implicit, of course, in the Constitution's conferral upon Congress of not all governmental powers, but only discrete, enumerated ones, Art. I, § 8, which implication was rendered express by the Tenth Amendment's assertion that "the powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively, or to the people."[132]

In the commandeering cases, then, the Supreme Court turned to the first principles of the federal system, which it derived from reviewing the entire structure set forth in the Constitution, in order to make the "residuary and inviolable sovereignty" of the states something more than an evanescent platitude. As the Court observed, "[s]ome truths are so basic that, like the air around us, they are easily overlooked."[133] Those basic truths form the bedrock of Nevada's constitutional complaint against the siting of the nation's nuclear waste repository at Yucca Mountain.

D. Equal Protection as a Component of State Sovereignty

Respecting Nevada's residual sovereignty is obviously a good thing, but further refinement of that general proposition is needed to establish a specific constitutional objection to the siting of a nuclear waste repository in the state. If there is to be a viable constitutional claim grounded on some affront to Nevada's sovereignty, it logically must involve some notion that Nevada has not been treated with a dignity equal to that of her sister states; that is, that the dump truly has been dumped on Nevada.

Not only does such equality of respect among the states seem logically entailed by their equal stature as sovereigns, several provisions of the Constitution offer cases in point for this equal treatment. The Port Preference Clause, for example, provides that "[n]o Preference shall be given . . . to the Ports of one State over those of another."[134] Similarly, the Uniformity Clause mandates that "Duties, Imposts and Excises shall be Uniform throughout the United States."[135] Obviously, neither the Joint Resolution nor the NWPA has anything to do with ports, duties, imposts or excise taxes. But these provisions arose out of the Framers'

132. *Id.* at 919.
133. New York v. United States, 505 U.S. 144, 187 (1992).
134. U.S. CONST. art. I, § 9, cl. 6.
135. U.S. CONST. art. I, § 8, cl. 1.

recognition that the broad commerce power delegated to the national government created a risk that the "National Government would use its power over commerce to the disadvantage of particular States."[136]

When the Constitutional Convention's Committee of Detail released its formulation of the Commerce Clause in the August 6, 1787 draft, Delaware delegate John Dickinson noted in the margin, next to the Commerce Clause, "no Preference or Advantage to be given to any persons or place—Laws to be equal."[137] So great was the concern over discriminatory congressional employment of the commerce power that it appears likely that the Constitution would not have made it out of the Philadelphia convention, let alone have been ratified, if these guarantees of equal treatment had not been included. In the words of one delegate, "I do not hazard much in saying, that the present Constitution had never been adopted without those preliminary guards in it."[138] As Justice Story concluded,

> [i]f this provision, as to uniformity of duties, had been omitted, although the power might never have been abused to the injury of the feebler States of the Union, (a presumption which history does not justify us in deeming quite safe or certain) yet it would, of itself, have been sufficient to demolish, in a practical sense, the value of most of the other restrictive clauses in the Constitution.[139]

These widespread concerns led to the adoption of the Port Preference and Uniformity Clauses, both barring the national government from discriminating against any particular state. These limitations "were intended to allay . . . the fear that Congress might discriminate against certain of the States."[140] "The clear and obvious intention of the articles mentioned was that Congress might have no power of imposing unequal burdens; that it might not be in their power to gratify one part of the Union by oppressing another."[141]

Thus the Uniformity and Port Preference Clauses make explicit an equality principle that, out of respect for state sovereignty, must be un-

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136. United States v. Ptasynski, 462 U.S. 74, 81 (1983).

137. 1 THE RECORDS OF THE FEDERAL CONVENTION OF 1787 209 (Max Farrand, ed., rev. ed. 1937) [hereinafter FARRAND RECORDS]. *See also* 2 FARRAND RECORDS 211 (James McHenry); *id.* at 637 n.21, 639-40 (George Mason); 3 FARRAND RECORDS 333 (Alexander Hamilton); CHARLES WARREN, THE MAKING OF THE CONSTITUTION 575-76, 588 (1928).

138. 3 FARRAND RECORDS, *supra* note 137, at 366 (Hugh Williamson).

139. JOSEPH STORY, COMMENTARIES ON THE CONSTITUTION OF THE UNITED STATES § 479 (1833).

140. WARREN, *supra* note 137, at 588.

141. 3 FARRAND RECORDS, *supra* note 137, at 366 (Hugh Williamson). *See also* 2 FARRAND RECORDS at 417-18 (James Madison); *id.* at 420 (James McHenry).

derstood as implicit in the Commerce Clause insofar as Congress applies the commerce power to the States. Since the Commerce Clause is one root of the national government's power to establish a national nuclear waste repository, this limitation has an important and direct role in Nevada's argument against the Yucca Mountain facility.

Not to be overlooked is the Constitution's ban, for both Congress and the state legislatures, on bills of attainder.[142] The term "bill of attainder" originally applied to legislative enactments decreeing death for named individuals (or designated groups) for high crimes, usually treason. The targets were "attainted" and therefore their property could not be inherited, which usually meant that the crown got the property. Bills of attainder were, accordingly, a popular means for raising revenue as well as getting rid of those whom the state feared. Over time the term came to refer to, and to forbid, all forms of legislative trial and punishment, because legislative trials were seen as violating the separation of powers. Legislatures were not to declare a named individual guilty of a crime, but rather were to enact laws that described criminal offenses in general terms and to leave to the courts the task of applying those general laws in individual cases.[143]

The Bill of Attainder Clause protects only persons, not states, and states lack standing to invoke the clause against the federal government on behalf of their citizens.[144] Therefore, the clause cannot be directly invoked by Nevada in making its case against the Yucca Mountain repository. However, the principle animating the clause does shed light on the constitutional wrong being inflicted on Nevada. After all, the ban on bills of attainder confirms the central importance of *generality* as a safeguard for ensuring just laws.[145] A bill of attainder acts by *naming* those who are targets of legislation, by *specifying* those who are to be singled out for special treatment under a specially enacted law. Proper laws describe *general characteristics* of the subject of legislation and set forth *generally applicable rules* that apply to all those who fit the legislative description.[146] Chief Justice Marshall identified the constitutional vice of a bill of attainder as being a violation of the principle that the legisla-

142. *See* U.S. CONST. art. I, § 9, cl. 3; art. I, § 10, cl. 1.

143. *See generally* LAWRENCE TRIBE, AMERICAN CONSTITUTIONAL LAW §§ 10-4 to 10-6 (2d ed. 1988). Montesquieu located the origins of the bill of attainder in the Roman practice of enacting *privilegia*, or private laws, against specific parties. He noted that "Cicero was for having them abolished, *because the force of a law consists in its being made for the whole community*." MONTESQUIEU, THE SPIRIT OF THE LAWS, bk. 12, ch. 19 (1748), *reprinted in* 3 THE FOUNDERS' CONSTITUTION 343 (Philip B. Kurkland & Ralph Lerner, eds., 1987) (emphasis added).

144. *See* South Carolina v. Katzenbach, 383 U.S. 301, 324 (1966).

145. *See* TRIBE, *supra* note 143, at 641.

146. *See id.* at 646.

ture should "prescribe general rules."[147]

Modern cases repeatedly emphasize this core principle: Congress may not impose legal burdens except "by rules of general applicability."[148] Indeed, a law that "designates" the parties who will bear its burdens, instead of "set[ting] forth a generally applicable rule,"[149] cannot properly be dignified with the title of "law." The very definition of a "law" is that it applies generally; it prescribes not a result in one case but "a rule" for all cases.[150] Yet, what is the Joint Resolution, if not an enactment that prescribes a result in only one case? Isn't the Joint Resolution a purported "law" that singles out Nevada for the application of a discriminatory nuclear waste disposal site regulation that will govern only Yucca Mountain and not any other site anywhere in the other forty-nine States?

Interestingly, the Supreme Court's Tenth Amendment jurisprudence also reflects this principle. The Court has held that a state may invoke judicial enforcement of the Tenth Amendment's protection of state sovereignty if it can demonstrate "defects in the national process."[151] The Court's example of such a "defect" involved showing that the state "*was singled out in a way that left it politically isolated and powerless.*"[152] This is clearly a variation on the principle driving the ban on bills of attainder, a principle that now can be seen as part of Tenth Amendment doctrine to trigger judicial intervention to protect state sovereignty. The Tenth Amendment will be discussed further in the next section.

Some well-recognized limits on the national government's ability to discriminate among the states are found not in particular clauses of the Constitution, but in the federal (rather than national) structure of the Union. Such limits arise "from the very nature and objects" of the Union itself.[153] One good example of such limits is found in the "equal footing doctrine," which recognizes that the several states entered the Union "equal in power, dignity and authority," and requires that Congress respect each state's "equality in dignity and power with other States."[154]

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147. Fletcher v. Peck, 10 U.S. 87, 136 (1810).

148. United States v. Brown, 381 U.S. 437, 461 (1965). *See also id.* at 446 (holding that the legislature must "'prescribe general rules'") (quoting *Fletcher v. Peck*); *id.* at 454-55 (holding that a law is permissible only if "Congress was legislating with respect to general characteristics rather than with respect to a specific group of men").

149. *Id.* at 450.

150. *See* W. Johnson, Note to *Satterlee v. Mathewson*, 2 Pet. 380, n. 416 (1829) (discussing Blackstone), *reprinted in* 3 THE FOUNDERS' CONSTITUTION 351 (Philip B. Kurkland & Ralph Lerner, eds., 1987).

151. South Carolina v. Baker, 485 U.S. 505, 512 (1988).

152. *Id.* at 513 (emphasis added).

153. Coyle v. Smith, 221 U.S. 559, 575 (1911) (citation omitted).

154. *Id.* at 567-68.

The "constitutional equality of the States is essential to the harmonious operation of the scheme upon which the Republic was organized. When that equality disappears we may remain a free people, but the Union will not be the Union of the Constitution."[155]

Although the equal footing doctrine is usually implicated in cases dealing with the congressional power to admit states to the Union, it has also arisen in the context of the Commerce Power and the Treaty Power.[156] For example, in *United States v. 43 Gallons of Whiskey*, the Court considered an equal footing challenge to a federal law regulating commerce in liquor.[157] The Court rejected the argument that the law discriminated against Minnesota, finding that it legislated in general terms that applied to particular circumstances wherever they existed, rather than to particular states.[158] The Court concluded: "The principle that Federal jurisdiction must be everywhere the same, under the same circumstances, has not been departed from. The prohibition rests on grounds which, so far from making a distinction between the States, apply to them all alike."[159]

The equal footing doctrine thus embodies an anti-discrimination principle that arises from a broader, generally applicable "constitutional mandate that the States be on an equal footing."[160] This does not mean that Congress may not legislate with respect to differing conditions: "Area, location, geology, and latitude have created great diversity in the economic aspects of the several States. The requirement of equal footing was designed not to wipe out those diversities but to create parity as respects political standing and sovereignty."[161] It is this "parity" in "sovereignty" that mandates that States can be treated differently by Congress only insofar as they are *in fact* different. Different treatment of a given state simply because it is the state named by the national government would be arbitrary and an abuse of the national legislative power. Yet that is exactly what Congress did in the Joint Resolution approving the Yucca Mountain site.

E. The Tenth Amendment: The Foundation of the Argument

Although the principles on which Nevada built its constitutional ar-

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155. *Id.* at 580.
156. *See, e.g.*, Mayor of New Orleans v. United States, 35 U.S. 662, 736-37 (1836); United States v. 43 Gallons of Whiskey, 93 U.S. 188, 191, 193-94 (1876).
157. 93 U.S. at 191.
158. *Id.* at 194-95, 197.
159. *Id.* at 197.
160. Baker v. Carr, 369 U.S. 186, 226 n.53 (1962).
161. United States v. Texas, 339 U.S. 707, 716 (1950).

gument against the Yucca Mountain Joint Resolution ultimately are derived from the structure of government created by the Constitution, the jurisprudence of the Tenth Amendment provides the most helpful illumination of that structure. The Tenth Amendment simply states that the "powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively, or to the people."[162]

The Tenth Amendment can strike one as restating the obvious; what is not given to the new national government is not given to the new national government. For that reason, perhaps, for at least a century, America's leading jurists and constitutional thinkers delighted in belittling the Tenth Amendment. It has been dismissed as "redundant," a "constitutional tranquilizer," or an "empty declaration."[163] Chief Justice Stone no doubt thought he was penning the amendment's epitaph when he wrote that it "states but a truism that all is retained which has not been surrendered."[164] Yet "to diminish the Tenth Amendment as merely 'declaratory' is likewise to vitiate the Supremacy Clause and the Necessary and Proper Clause, for each, Hamilton wrote in No. 33 of the *Federalist*, was merely declaratory."[165]

Moreover, unlike either of those two clauses, the Tenth Amendment is something a little different, a bit more special, because it is *a rule of construction*. Indeed, it is one of only two rules of construction in the entire Constitution, the other being the Ninth Amendment. Consistent with the long-standing disregard of the Tenth Amendment, its very status as a rule of construction has sometimes been a basis for derogating it. Justice Story described it as "a mere affirmation of what, upon any reasoning, is a necessary rule of interpreting the Constitution."[166] But to suggest that the Tenth Amendment is *less* worthy of our attention because it is a rule of construction rather than a substantive "rule of law,"[167] is to get things precisely backward. Rules of construction tell us (judges, legislators, and citizens) *how to read the Constitution*. In such rules the Framers step back from the task of erecting a government and turn to face the camera, as it were. They address posterity directly, tell-

162. U.S. CONST. amend. X.

163. *See* FELIX FRANKFURTER, THE COMMERCE CLAUSE 40 (1937); ALPHEUS THOMAS MASON, THE STATES RIGHTS DEBATE: ANTIFEDERALISM AND THE CONSTITUTION 5, 190 (1967).

164. United States v. Darby, 312 U.S. 100, 124 (1941).

165. RAOUL BERGER, FEDERALISM: THE FOUNDER'S DESIGN 81 (1987). *See also* THE FEDERALIST NO. 33, at 204-05 (Alexander Hamilton) (Jacob E. Cooke ed., 1961).

166. JOSEPH STORY, 3 COMMENTARIES ON THE CONSTITUTION OF THE UNITED STATES 752 (1833). *See also* Walter Berns, *The Meaning of the Tenth Amendment*, *in* A NATION OF STATES 126, 131-32 (Robert A.Goldwin ed., 1961).

167. Berns, *supra* note 166, at 131.

ing us that when we sit down to construe the document to decide some controversy we are required to read it in a certain way. The rules of construction are the owner's manual to the Constitution, and few passages in a founding charter could be more important.

As a consequence, despite its scholarly and judicial detractors, the Tenth Amendment has become, over time, much more than a simple reservation to the states of non-delegated powers. As the majority in *South Carolina v. Baker* put it, the Tenth Amendment has come to represent, and to serve as shorthand for, "any implied constitutional limitation on Congress's authority to regulate state activities, whether grounded in the Tenth Amendment itself or in principles of federalism derived generally from the Constitution."[168]

In resolving fundamental questions of federalism, the Tenth Amendment requires the Court to consider "the design of the Government and to appreciate the significance of federalism in the whole structure of the Constitution."[169] "The question, always, is whether the exercise of power is consistent with the entire Constitution; a question that can be answered only by taking into account, so far as they are relevant, all of the values to which the Constitution—as interpreted over time—gives expression."[170]

It should come as no surprise that the values of federalism have shaped the constitutional text, resulting in constitutional protections for the states as sovereign entities entitled to equal respect and treatment. After all, the independent existence of the states preceded not only the Constitution, but also the Union. Some of the states individually declared independence from Great Britain (and substituted governance by their own elected officials for the sovereignty of the king) even *before* Congress promulgated the Declaration of Independence. Rhode Island declared independence on May 4, 1776 and announced its intention to "promot[e] confederation" with the "other colonies;" Virginia declared independence on May 15, 1776.[171]

Richard Henry Lee's resolution on independence, passed by the Continental Congress on July 2, 1776, asserted the new status of the sev-

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168. 485 U.S. 505, 511 n.5 (1988).

169. United States v. Lopez, 514 U.S. 549, 575 (1995) (Kennedy, J., concurring). *See also* U.S. Term Limits v. Thornton, 514 U.S. 779, 853 (1995) (Thomas, J., dissenting) (Tenth Amendment issues "'depend on a fair construction of the whole [Constitution].'") (quoting McCulloch v. Maryland, 17 U.S. 316, 406 (1819) (alteration in original)).

170. Garcia v. San Antonio Metro. Transit Auth., 469 U.S. 528, 586 (1985) (O'Connor, J., dissenting) (quoting Terrance Sandalow, *Constitutional Interpretation*, 79 MICH. L. REV. 1033, 1055 (1981)).

171. MERRILL JENSEN, THE ARTICLES OF CONFEDERATION 102-03 (1940).

eral former colonies as plural "free and independent *States*."[172] Far from declaring independence as a unified national entity, or establishing a sovereign national government for North America, the congressional resolution called for the representatives of the now-independent states to prepare a "plan of confederation" to be "transmitted to the respective Colonies for their consideration."[173] Pursuant to the formal Declaration of Independence signed two days later, the "States of America" by the authority of the "good People of these Colonies" separated themselves from Great Britain by declaring that they were "Free and Independent states," and that "they have full Power" to do all "Acts and Things which Independent States may of right do."[174]

When the Continental Congress made good on Lee's resolution and proposed a form for the national government, the resulting "articles of Confederation and perpetual Union between the States of New Hampshire, Massachusetts-bay," and so on down the roster, declared that "[e]ach state retains its sovereignty, freedom and independence."[175] On September 13, 1783, the status of the states as individual, independent sovereigns was confirmed by the peace treaty that ended the Revolutionary War. The Treaty of Paris—which is the document that formally recognized the independence of the States—was, like Lee's Resolution, Jefferson's Declaration, and the Articles of Confederation, cast in plural form and filled with references to "the said United States:" "His Brittanic Majesty acknowledges the said United States, viz. New Hampshire, Massachusetts Bay," *et al.*, "to be free sovereign and independent States."[176] Article V of the treaty provided that British subjects were to be free to go to "any of the thirteen United States," thereby signifying that Great Britain was treating with thirteen sovereign States rather than with a single unitary nation.[177]

Having recently fought a revolution to free themselves from distant, centralized authority in London, the states were not about to allow themselves to be subsumed in the undifferentiated, common mass of a new and more powerful national government. The states convened in Philadelphia as free, independent, and equal sovereigns. Madison explained that the "equality" of the States is "no less acceptable to the large than to

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172. HENRY STEELE COMMAGER, DOCUMENTS OF AMERICAN HISTORY 100 (7th ed., 1963) (emphasis added).

173. *Id.*

174. *See* THE DECLARATION OF INDEPENDENCE ¶ 32 (U.S. 1776).

175. ARTICLES OF CONFEDERATION art. II (1781).

176. 1 TREATIES, CONVENTIONS, INTERNATIONAL ACTS, PROTOCOLS AND AGREEMENTS BETWEEN THE UNITED STATES AND OTHER POWERS, 1776-1909, at 587 (William M. Malloy ed., 1910).

177. *Id.*; *see also* RAOUL BERGER, FEDERALISM: THE FOUNDER'S DESIGN 29 (1987).

the small states; since they are not less solicitous to guard by every possible expedient against an improper consolidation of the states into one simple republic."[178] Even James Wilson, the second-most influential of the Framers and among the most nationalist in his thinking, insisted that the federal government, "instead of placing the state governments in jeopardy, is founded on their existence. On this principle, its organization depends; it must stand or fall, as the state governments are secured or ruined."[179] Indeed, Madison emphasized that the Constitution's authority would derive from popular consent "given by the people, not as individuals composing one entire nation, but as composing the distinct and independent States to which they respectively belong."[180] Madison reassured the state ratifying conventions that "[e]ach State, in ratifying the Constitution, is considered to be a sovereign body, independent of all others."[181]

Once in the Union, however, the states were bound by democratic majority rule under the Constitution's terms. Even the Constitution itself can be amended without the consent of any given state.[182] Consequently, "the Constitution, in all its provisions, looks to *an indestructible Union, composed of indestructible States*."[183] It is this proposition that sets out the essential dynamic in our federal Union of sovereign states. *Precisely because* the states are not free to secede from the Union and will be bound by democratically enacted supreme federal law—laws which particular states may oppose—there are implicit limits on how much the national government may invade the sovereign prerogatives of

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178. THE FEDERALIST NO. 62, at 417 (James Madison) (Jacob E. Cooke ed., 1961).

179. James Wilson, *Summation and Final Rebuttal, Speech to the Pennsylvania Ratifying Convention, December 11, 1787, reprinted in* 1 THE DEBATE ON THE CONSTITUTION 841 (Bernard Bailyn, ed., 1993).

180. THE FEDERALIST NO. 39, at 254 (James Madison) (Jacob E. Cooke ed., 1961); *see also* 3 THE DEBATES IN THE SEVERAL STATE CONVENTIONS ON THE ADOPTION OF THE FEDERAL CONSTITUTION 94 (J. Elliot 2d ed. 1836) (remarks of James Madison at the Virginia convention).

181. THE FEDERALIST NO. 39, at 254 (James Madison) (Jacob E. Cooke ed., 1961); *see also* THE FEDERALIST NO. 40, at 261 (James Madison) (Jacob E. Cooke ed., 1961) (States are "regarded as distinct and independent sovereigns" by "the Constitution proposed").

> The ultimate source of the Constitution's authority is the consent of the people of each individual State, not the consent of the undifferentiated people of the Nation as a whole. The ratification procedure erected by Article VII makes this point clear. The Constitution took effect once it had been ratified by the people gathered in convention in nine different States. But the Constitution went into effect only "between the States so ratifying the same." It did not bind the people of North Carolina until they had accepted it.

U.S. Term Limits v. Thornton, 514 U.S. 779, 846 (Thomas, J., dissenting).

182. *See* U.S. CONST. amend. V (describing amendment process).

183. Texas v. White, 74 U.S. 700, 725 (1869) (emphasis added); *see also* New York v. United States, 505 U.S. 144, 162 (1992) (quoting Texas v. White).

the states. That is, because the states are "chained" to the Union, there are limits on how much Congress can yank that chain. Thus "the preservation of the States, and the maintenance of their governments, are as much within the design and care of the Constitution as the preservation of the Union and the maintenance of the National government."[184]

Yet recognizing that the sovereignty of the States is to be protected in our constitutional order is to say nothing about *how* that sovereignty is to be protected. In the mid-1980s the Supreme Court, in Tenth Amendment cases such as *Garcia v. San Antonio Metropolitan Transit Authority*[185] and *South Carolina v. Baker*,[186] appeared to drastically curtail the judiciary's power to protect against encroachments on state sovereignty by the federal government.[187] Following the *Garcia* and *Baker* decisions, the conventional wisdom for some time was that the only real limits on congressional exercise of the Commerce Clause power were: (1) the political check provided by the national political process, with its fifty state delegations of representatives and senators in Congress, and (2) what Justice O'Connor memorably described as Congress's "underdeveloped capacity for self-restraint."[188]

But *Garcia* did *not* hold that the *only* restraint on congressional invasion of state sovereignty was the political process; rather, it held that the political process was the "principal and basic limit."[189] The Court expressly disclaimed any broader ruling, explaining that the case did "not require us to identify or define what affirmative limits the constitutional structure might impose on federal action affecting the States under the Commerce Clause."[190] At that point *Garcia* cited *Coyle v. Smith*,[191] which had held that irreducible state sovereignty *does* impose some substantive limits on congressional power.

Four of the five Justices who constituted the *Garcia* majority are no longer on the Court. Since that decision seventeen years ago, a narrow but determined majority of the Court has issued a series of decisions

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184. Texas v. White, 74 U.S. at 725; New York v. United States, 505 U.S. at 162 (quoting Texas v. White).

185. 469 U.S. 528 (1985).

186. 485 U.S. 505 (1988).

187. In *Garcia*, the Court, in a 5-4 decision, overruled its earlier decision in *National League of Cities v. Usery*, 426 U.S. 833 (1976), and rejected a Tenth Amendment challenge to a federal statute imposing minimum wage and overtime pay standards on State governments. In *Baker*, the Court rejected a Tenth Amendment challenge to a provision of the Internal Revenue Code removing a federal income tax exemption for interest earned on certain types of bonds issued by state and local governments.

188. *Garcia*, 469 U.S. at 588 (O'Connor, J., dissenting).

189. *Id.* at 556.

190. *Id.*

191. 221 U.S. 559 (1911).

championing state sovereignty over the legislative prerogatives of Congress.[192] To whatever extent *Garcia* and *Baker* might be read to rigidly foreclose judicial protection of states' prerogatives within the Constitution's federal structure, they no longer appear to be good law.

Certainly, the notion of a flat ban on judicial enforcement of principles of federalism was always deeply problematic. The horizontal axis of the Constitution—the separation of powers into legislative, judicial, and executive bailiwicks—is amenable to, and entitled to, judicial policing. Why shouldn't the vertical axis—federalism—be as well? Nobody at either end of the political spectrum would insist that the Constitution's structural and textual separation of powers must be enforced exclusively by democratic processes – must, in effect, be treated as a political question off-limits to the judiciary. It is therefore hard to understand why such a rule should govern the equally important structural rules of federalism.

Again, the Tenth Amendment is a rule for construing the Constitution. To whom is that rule addressed, if not to the courts, which are charged with expounding the Constitution?[193] "The States' role in our system of government is a matter of constitutional law, not of legislative grace,"[194] and therefore the boundaries between federal and state sovereignty must be judicially policed, just like the boundaries between the legislative and executive branches. "If federalism so conceived and so carefully cultivated by the Framers of our Constitution is to remain meaningful, this Court cannot abdicate its constitutional responsibility to oversee the Federal Government's compliance with its duty to respect the legitimate interests of the States."[195]

States can no more be relegated to exclusively political safeguards for fundamental states' rights than individuals can be relegated to the political process for the protection of their rights. The fundamental flaw in the *Garcia* majority's reasoning is that its "political process" argument applies equally to individuals as to states, and that reveals its fundamental fallacy. As Justice Powell explained in *Garcia*, "One can hardly imagine this Court saying that because Congress is composed of individuals, individual rights guaranteed by the Bill of Rights are amply pro-

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192. *See* Federal Maritime Comm'n v. S.C. State Ports Auth., 535 U.S. 743 (2002); United States v. Morrison, 529 U.S. 598 (2000); Alden v. Maine, 527 U.S. 706 (1999); Printz v. United States, 521 U.S. 898 (1997); Seminole Tribe of Fla. v. Florida, 517 U.S. 44 (1996); United States v. Lopez, 514 U.S. 549 (1995); New York v. United States, 505 U.S. 144 (1992).

193. *Cf.* Marbury v. Madison, 5 U.S. 137, 177 (1803); Garcia v. San Antonio Metro. Transit Auth., 469 U.S. 528, 567 (1985) (Powell, J., dissenting).

194. *Garcia*, 469 U.S. at 567 (Powell, J., dissenting).

195. *Id.* at 581 (O'Connor, J., dissenting).

tected by the political process. Yet, the position adopted today is indistinguishable in principle. The Tenth Amendment also is an essential part of the Bill of Rights."[196]

The notion that the Bill of Rights was about *individual* rights—a notion clearly animating the *Garcia* majority—while perhaps a function of the Court's focus on individual rights in the last half of the twentieth century, is profoundly ahistorical. The Tenth Amendment was, if anything, the *most important* part of the Bill of Rights with respect to the vital, practical issue of securing ratification of the Constitution. Eight of the original eleven States that ratified the Constitution[197] did so only after proposing amendments, and every one of those States included some version of what ultimately became the Tenth Amendment.[198] Indeed, the Tenth Amendment was the *only* amendment proposed by every single state ratifying convention that offered amendments.[199] The leading proponents of a bill of rights consistently "linked the project to an express reservation of states' rights."[200] Surely the states (and their people) are just as entitled to judicial enforcement of the Tenth Amendment as individuals are to the protections of the Fourth Amendment.

Notwithstanding the flaws in *Garcia's* reasoning, outright reversal of that decision is not necessary to forge a constitutional argument for Nevada on Tenth Amendment grounds. Again, *Garcia* did not purport to define every limit imposed by the structure of the Constitution on federal action affecting the states. As the Court acknowledged three years later in *South Carolina v. Baker*, "*Garcia* left open the possibility that some extraordinary defects in the national political process might render congressional regulation of state activities invalid under the Tenth Amendment."[201] Note well the scope and seriousness of the opening left by the Court: defects in the political process do not merely render congressional legislation *subject to judicial challenge* under the Tenth Amendment, they "render congressional regulation of state activities *invalid* under the Tenth Amendment."[202]

The *Baker* Court declined to "attempt any definitive articulation" of such political "defects," but it did establish two categories. A state might

196. *Id.* at 565 n.8 (Powell, J., dissenting).

197. North Carolina did not ratify the Constitution until November 21, 1789 – after the Bill of Rights had been approved by Congress and forwarded to the States on September 25, 1789. Rhode Island did not ratify the Constitution until May 29, 1790.

198. *Garcia*, 469 U.S. at 569 (Powell, J., dissenting).

199. AKHIL REED AMAR, THE BILL OF RIGHTS 123 (1998); EDWARD DUMBAULD, THE BILL OF RIGHTS AND WHAT IT MEANS TODAY 163 (1957).

200. AMAR, *supra* note 199, at 126-27 (1998) (discussing statements of, *inter alia*, George Mason, Luther Martin, Thomas Tredwell, and James Madison).

201. 485 U.S. 505, 512 (1988).

202. *Id.* (emphasis added).

allege (1) that "it was deprived of any right to participate in the national political process" or (2) that "it was singled out in a way that left it politically isolated and powerless."[203] To be sure, every effort to invoke this defective-process exception to *Garcia*—and there have been at least a dozen of them—has failed. Yet, on closer inspection, it is fair to say those efforts failed because they misconceived the specific Tenth Amendment argument left open by the Court in *Baker*. Most of these cases focused on the first category of process defect mentioned by the Court—the deprivation of a state's right to participate in the national political process—and did not even allege the second category—being singled out and politically isolated.[204] Several states have tried to invoke the first exception identified in *Baker* by arguing that they were deprived of political participation because their representatives or senators were not present during the congressional debates or committee meetings on the challenged legislation. These arguments failed because in each case all the usual legislative rules had been followed. A state has no entitlement to have its delegates appointed to a given committee of Congress, and principles of federalism are not implicated simply because a state gets out-voted, much less because a state's senators or representatives fail to show up and participate in a given committee meeting or floor debate.[205]

Baker's second category, however, may comfortably apply to the predicament in which Nevada finds herself after passage of the Joint Resolution. Although the *Baker* Court did not explicitly elaborate on what it had in mind when it spoke of the political isolation of a state (in large measure because South Carolina did not invoke it), in both *Baker* and *Garcia* the Court gave us a great deal of information to help determine the contours of this category.

In touting the adequacy of the political process to protect states' rights, *Garcia* relied first and foremost on the theories of James Madison, who "explained that the Federal Government 'will partake sufficiently of

203. *Id.* at 512-13.

204. Printz v. United States, 521 U.S. 898 (1997); Adams v. Dep't of Juvenile Justice, 143 F.3d 61, 65 (2d Cir. 1998); Reich v. New York, 3 F.3d 581, 589 (2d Cir. 1993); Nevada v. Skinner, 884 F.2d 445, 452-54 (9th Cir. 1989); Int'l Ass'n of Firefighters v. West Adams County Fire Prot. Dist., 877 F.2d 814, 821 & n.9 (10th Cir. 1989). *See* New Jersey v. United States, 91 F.3d 463, 469 (3d Cir. 1996); Mack v. United States, 66 F.3d 1025, 1033 n.10 (9th Cir. 1995), *rev'd on other grounds sub nom.*; Schmitt v. Kansas, 844 F. Supp. 1449, 1455 (D. Kan. 1994); Delaware v. Cavazos, 723 F. Supp. 234, 245 (D. Del. 1989), *aff'd*, 919 F.2d 137 (3d Cir. 1990).

205. *See* EEOC v. Vermont, 904 F.2d 794, 802 (2d Cir. 1990); Nevada v. Watkins, 914 F.2d 1545, 1556-57 (9th Cir. 1990), *cert. denied*, 499 U.S. 906 (1991); Nevada v. Burford, 708 F. Supp. 289, 300-01 (D. Nev. 1989), *aff'd*, 918 F.2d 854 (9th Cir. 1990), *cert. denied*, 500 U.S. 932 (1991).

the spirit [of the States], to be disinclined to invade the rights of the individual States, or the prerogatives of their governments.'"[206] But the rest of that *Federalist* paper reveals that Madison's analysis was expressly predicated on the premise that the national legislature had to act by generally applicable laws, rather than by laws applicable to, and burdening, only one named, isolated state:

> But ambitious encroachments of the Federal Government, on the authority of the State governments, would not excite the opposition of a single State or of a few States only. They would be signals of general alarm. Every Government would espouse the common cause. A correspondence would be opened. Plans of resistance would be concerted. One spirit would animate and conduct the whole.[207]

Only if "an unwarrantable measure of the Federal Government" applied and was unpopular in multiple "states" would "the means of opposition to it" be "powerful and at hand."[208] Madison explained that federal measures encroaching on state governments would be defeated politically because they "would be contending against thirteen sets of representatives, with the whole body of their common constituents on the side of the latter."[209]

With this foundation in *Garcia, Baker* elegantly conveys a great deal by citing Justice Stone's famous footnote four from *United States v. Carolene Products Co.*[210] The Carolene Products Company had challenged the constitutionality of a federal statute that prohibited the shipment of compounds of milk and other fats in interstate commerce. This was an obscure subject matter, to be sure, but the equal protection claim advanced by Carolene Products generated, in footnote four, a statement from the Court of perhaps the single most important element of equal protection doctrine. Specifically, a statute directed at "discrete and insular minorities" tends to limit "the operation of those political processes ordinarily to be relied upon" to ensure the equal protection of the laws.[211] When a law is written so as to apply to and burden only members of some political minority, whether defined by religious, ethnic, or other classification, the majoritarian political process is, by its very nature, unreliable at fending off such legislative oppression, for the simple

206. Garcia v. San Antonio Metro. Transit Auth., 469 U.S. at 551 (1985) (quoting THE FEDERALIST No. 46, at 319 (James Madison) (Jacob E. Cooke ed., 1961)).

207. THE FEDERALIST No. 46, at 320 (James Madison) (Jacob E. Cooke ed., 1961).

208. *Id.* at 319.

209. *Id.* at 320.

210. 304 U.S. 144, 152 n.4 (1938); *see South Carolina v. Baker*, 485 U.S. 505, 513 (1988).

211. *Carolene Products Co.*, 304 U.S. at 152 n.4.

reason that the majority is often quite happy to enact a law vexing a minority so long as that law does not apply to the majority. Hence the virtue of laws of general application and the Constitution's condemnation of bills of attainder. As Hamilton explained, a legislator is induced to enact just laws by "the necessity of being bound himself and his posterity by the laws to which he gives his assent."[212]

We thus see emerging from *Garcia* and *Baker* a rule that makes the national political process the primary bulwark of states' rights *only if* the national legislature enacts laws of general application that treat the states equally. This understanding of the "politically isolated" exception is further confirmed by examination of the antecedents on which *Carolene Products* relied. The *Carolene Products* footnote was, of course, discussing racial or religious minorities and dealing with individual rights to equal treatment under the law, but the authority it cited was *McCulloch* v. *Maryland*[213] and *South Carolina* v. *Barnwell Brothers*.[214] Since neither *McCulloch* nor *Barnwell Brothers* involved discrimination against religious or racial minorities, the *Carolene Products* Court clearly understood that the legal principle it was bringing to bear in footnote four was more fundamental and far larger than only the interests of those minorities.

McCulloch involved a tax imposed by Maryland on a federal instrumentality. Chief Justice Marshall reasoned that the "only security against the abuse of this power, is found in the structure of the government itself. In imposing a tax the legislature acts upon its constituents. This is in general a sufficient security against erroneous and oppressive taxation."[215] But this political safeguard broke down because the burden of Maryland's tax fell ultimately on all the states of the Union and thereby on their citizens, while only Maryland's citizens were represented in the Maryland legislature.[216]

Barnwell involved a state regulation banning trucks over a certain size from the state's highways. The political process did not self-correct because the burden of the regulation fell mostly on trucking companies from outside of the state. The Court reasoned that the political process is an unreliable safeguard for rights when the challenged law's "burden falls principally upon those" who are not represented in the legislature that enacted the law, or when the law does not "affect[] adversely some interests" who have political power within the state and who supported

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212. THE FEDERALIST No. 35, at 221 (Alexander Hamilton) (Jacob E. Cooke ed., 1961).
213. 17 U.S. 316, 428 (1819).
214. 303 U.S. 177, 184 n.2 (1938).
215. *McCulloch*, 17 U.S. at 428.
216. *Id.*

the law.[217]

South Carolina v. Baker itself helps to illuminate the problem of political breakdown by showing the contrasting situation. *Baker*, like *McCulloch*, was a case involving intergovernmental tax immunity, only this time it was a federal tax on a state. The Court noted that state immunity from federal taxation "arises from the constitutional structure and a concern for protecting state sovereignty."[218] As in *McCulloch*, the Court explained that the principal safeguard against abuse of this taxing power is the political process: the states, which all send delegations to Congress, will not oppressively tax themselves.[219] But as we have seen, that mechanism works only if the tax law in question does not weaken the political restraints by discriminating against a particular state. Thus, in *Baker*, the Supreme Court hinted that the federal tax *would be unconstitutional* if "Congress . . . imposed a tax that applied exclusively to South Carolina."[220] The tax at issue in *Baker* did not discriminate against South Carolina, nor even against States as distinguished from other taxpayers. Therefore, there was no need for federal judicial intervention.

But the vice that was absent in *Baker* is present in the context of the siting of the nation's nuclear waste dump in Nevada through the enactment of the Joint Resolution. The Joint Resolution applies by name to Nevada, and it subjects Nevada, and Nevada alone, to a unique set of criteria for licensing a high-level nuclear waste repository. A state can negotiate with other states in the Union when the issue is what general standards, rules, and criteria to apply in deciding where to dump nuclear waste, because all states have an interest in fair and workable rules, given that they are all at risk of being stuck with the waste. But when rules and standards of general application have been summarily dispensed with and one site has been arbitrarily chosen, then the state where that site is located loses its natural allies in the national political process and has, indeed, been "singled out in a way that le[aves] it politically isolated and powerless."[221]

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217. *Barnwell Bros.*, 303 U.S. at 184 n.2.

218. *South Carolina v. Baker*, 485 U.S. 505, 518 n.11 (1988).

219. *Id.* at 512-13; Helvering v. Gerhardt, 304 U.S. 405, 416 (1938).

220. *Baker*, 485 U.S. at 516; *see id.* at 525-26 n.15 ("The nondiscrimination principle at the heart of modern intergovernmental tax immunity case law does not leave States unprotected from excessive federal taxation—it merely recognizes that the best safeguard against excessive taxation (and the most judicially manageable) is the requirement that the government tax in a nondiscriminatory fashion.").

221. *Id.* at 513.

F. The Property Clause: Carte Blanche to the National Government?

As we unveil the edifice of protections for state sovereignty fashioned by our Constitution's federalist structure, it is important not to lose sight of the counterbalancing protections for the national government's sovereign choices in that same structure. Foremost among those protections that are relevant here is the Property Clause.

Yucca Mountain is federal property. Indeed, it has allegedly been owned by the federal government since Nevada was a mere territory. The Property Clause provides that "Congress shall have Power to dispose of and make all needful Rules and Regulations respecting the Territory or other Property belonging to the United States."[222] Yet, congressional power to "make all needful Rules and Regulations respecting" federal property within a state does not strip the state of concurrent jurisdiction. It merely gives Congress a measure of jurisdiction over the same lands—jurisdiction that, pursuant to the Supremacy Clause, trumps any conflicting state regulation:

> [W]hile Congress can acquire exclusive or partial jurisdiction over lands within a State by the State's consent or cession, the presence or absence of such jurisdiction has nothing to do with Congress' powers under the Property Clause. Absent consent or cession a State undoubtedly retains jurisdiction over federal lands within its territory, but Congress equally surely retains the power to enact legislation respecting those lands pursuant to the Property Clause. And when Congress so acts, the federal legislation necessarily overrides conflicting state laws under the Supremacy Clause.[223]

Nevada remains free to regulate Yucca Mountain (for example, by the state's criminal statutes or laws of trespass), but only insofar as the

222. U.S. CONST. art. IV, § 3, cl. 2.

223. Kleppe v. New Mexico, 426 U.S. 529, 542-43 (1976)(citations omitted). *See also* James v. Dravo Contracting Co., 302 U.S. 134, 141-42 (1937) ("[I]t is not unusual for the United States to own within a State lands which are set apart and used for public purposes. Such ownership and use without more do not withdraw the lands from the jurisdiction of the State. The lands 'remain part of her territory and within the operation of her laws, save that the latter cannot affect the title of the United States or embarrass it in using the lands or interfere with its right of disposal.'") (quoting Surplus Trading Co. v. Cook, 281 U.S. 647, 652 (1930); Utah Power & Light Co. v. United States, 243 U.S. 389, 404 (1917) ("True, for many purposes a State has civil and criminal jurisdiction over lands within its limits belonging to the United States, but this jurisdiction does not extend to any matter that is not consistent with full power in the United States to protect its lands, to control their use and to prescribe in what manner others may acquire rights in them."); Nevada v. Watkins, 914 F.2d 1545, 1554 (9th Cir. 1990).

regulations do not conflict with the federal government's chosen use for the property—namely, as a nuclear waste dump. The Property Clause confers on Congress something like a police power over federal property.[224] Indeed, the Property Clause comes complete with its own textual analog of the Necessary and Proper Clause,[225] insofar as Congress is empowered to "make all needful Rules and Regulations respecting the Territory or other Property belonging to the United States."[226] Thus, the clause, "in broad terms, gives Congress the power to determine what are 'needful' rules 'respecting' the public lands,"[227] and "while courts must eventually pass upon them, determinations under the Property Clause are entrusted primarily to the judgment of Congress."[228]

That being said, nothing about this deference to congressional policy judgments places the Property Clause power beyond other constitutional curbs on government power. While *Kleppe v. New Mexico* recognized that "Congress exercises the powers both of a proprietor and of a legislature over the public domain,"[229] in our constitutional regime neither proprietors nor legislatures have absolute power (even regarding subjects appropriately within their purview). Moreover, *Kleppe* does not suggest that the Property Clause conveyed such absolute power to Congress.[230] Exercises of the power delegated by the Property Clause, just like exercises of the commerce power, must still be compatible with the principles of federalism embodied in the Constitution. As *Ashwander v. Tennessee Valley Authority*,[231] explains: "The [Property Clause] is silent

224. *See* Camfield v. United States, 167 U.S. 518, 525 (1897) ("The general Government doubtless has a power over its own property analogous to the police power of the several States, and the extent to which it may go in the exercise of such power is measured by the exigencies of the particular case."); *Utah Power & Light*, 243 U.S. 389, 405 ("And so we are of opinion that the inclusion within a State of lands of the United States does not take from Congress the power to control their occupancy and use, to protect them from trespass and injury and to prescribe the conditions upon which others may obtain rights in them, even though this may involve the exercise in some measure of what commonly is known as the police power."); *Kleppe*, 426 U.S. at 540 ("Congress exercises the powers both of a proprietor and of a legislature over the public domain."); United States v. San Francisco, 310 U.S. 16, 29 (1940) ("[T]he power over the public land thus entrusted to Congress is without limitations"); California Coastal Comm'n v. Granite Rock Co., 480 U.S. 572, 580 (1987) (same); *Watkins*, 914 F.2d at 1553 ("Yucca Mountain is federally owned land, subject to Congress' plenary power to regulate its use.").

225. *See* U.S. CONST. art. I, § 8, cl. 18.

226. U.S. CONST. art. IV, § 3, cl. 2.

227. *Kleppe*, 426 U.S. at 539.

228. *Id.* at 536.

229. *Id.* at 540.

230. *Id.* at 537-38.

231. 297 U.S. 288, 338 (1936). *See also Watkins*, 914 F.2d at 1553-54 ("The powers granted to Congress to legislate in specific areas 'are always subject to the limitation that they may not be exercised in a way that violates other specific provisions of the Constitution.'") (quoting Williams v. Rhodes, 393 U.S. 23, 29 (1968)).

as to the method of disposing of property belonging to the United States. That method, of course, . . . must be consistent with the foundation principles of our dual system of government and must not be contrived to govern the concerns reserved to the States."[232]

Indeed, *Kleppe's* link of Property Clause power to the Supremacy Clause confirms the existence of such constitutional limits. "The Supremacy Clause . . . makes 'Law of the Land' only 'Laws of the United States which shall be made in Pursuance [of the Constitution];' so the Supremacy Clause merely brings us back to the question" whether the challenged laws "violate state sovereignty and are thus not in accord with the Constitution."[233] Thus, the Property Clause, though it undeniably gives the national government broad discretion over federal land, does not give the national government a pass on other constitutional constraints on its power.

III. FORMULATING AN ARGUMENT

In light of this dynamic of federalism permeating the constitutional structure of our government, certain basic principles are evident from which Nevada built its constitutional arguments:

- Federalism analysis draws on the entire Constitution.
- Protection of state sovereignty lies at the core of our federal structure.
- The Constitution mandates equal treatment for the sovereign states.
- Congress may not single out a state for adverse treatment, but must legislate by generally applicable, neutral criteria.

The original NWPA repository standard put all fifty states in the same situation: they were *all* potential candidates to host the nation's radioactive waste. A *single* set of *neutral*, scientifically based standards was developed to govern evaluation and certification of nuclear waste

232. 297 U.S. 288, 338 (1936). *See also Watkins*, 914 F.2d at 1553-54 ("The powers granted to Congress to legislate in specific areas 'are always subject to the limitation that they may not be exercised in a way that violates other specific provisions of the Constitution.'") (quoting Williams v. Rhodes, 393 U.S. 23, 29 (1968)).

233. *Printz*, 521 U.S. at 924-25 (quoting U.S. CONST. art. VI, cl. 2). *See also* Alden v. Maine, 527 U.S. 706, 731 (1999); Fed. Mar. Comm'n v. South Carolina State Ports Auth., 535 U.S. 743, 766-68 (2002).

repositories *everywhere* in the United States. The core of those standards was deep geologic isolation. Under this regime, some states were more at risk of getting the repository due to variations in local geology, hydrology, and other variables relevant to the NWPA's standards. But any resulting differential impact among the states of these "facially neutral" criteria was attributable to the "accident of geo[logy], not any deliberate discrimination against" any state.

All this vanished when DOE discovered that Yucca Mountain was not suitable under NWPA standards. Yucca geology could contribute virtually nothing to the repository system's waste isolation capabilities. DOE reacted to this discovery by simply rewriting the rules. These new standards for engineered containment of waste apply *exclusively* to Nevada's Yucca Mountain. The Joint Resolution's approval of a repository applies, by name, only to "Yucca Mountain, Nevada." This maneuver grossly discriminates against Nevada. The rules requiring deep, permanent geologic isolation remain in effect to govern the development of any repository that might be proposed in any other state. But in Nevada, a repository can now be built, despite the failure to meet that standard, by virtually exclusive reliance on man-made containers. Thus, forty-nine states get "permanent deep geologic disposal" while Nevada gets metal drums and wishful thinking.

It would be hard to invent a clearer example of a *Baker* defect in the political process. A state can negotiate and politick with other states when the issue before Congress is what general standards to apply in deciding where to bury nuclear waste because all states have an interest in fair, reasonable, and workable rules given that they are all at risk of being stuck with an unpopular burden. But when rules of general application have been abandoned, and the question is simply a yea or nay on whether to put waste in one designated site arbitrarily chosen and announced in advance, then the state where that site is located loses its natural allies in the national political process and has, indeed, been "singled out in a way that le[aves] it politically isolated and powerless."[234]

Perhaps the sovereign state of Nevada would have to accept the nuclear waste repository if, after application of reasonable, agreed-upon, generally applicable criteria, it turned out that Nevada was the best place for the nation to put it—just as Virginia and Maryland in the eighteenth and nineteenth centuries had to tolerate, in the national interest, the erection of coastal forts necessary to protect the approaches to the Chesa-

234. The truncated legislative procedures specially enacted for the joint resolution even foreclose the use of those mechanisms that a minority can normally employ to have its concerns addressed in congressional deliberations: extended consideration in committee, filibuster, and amendments.

peake Bay and the nation's capital. But Nevada should not have to tolerate an imposition that resembles not so much national legislation as a group mugging. Thus, here the failure of the usual political check on violations of state sovereignty is linked to the nature of the violation of state sovereignty itself.

Nevada's argument does not generate a constitutional claim whenever legislation affects only one state: that happens routinely, *e.g.*, when Congress passes legislation respecting a particular national park within the borders of one state, or respecting oil leases off a particular state's coast, or respecting some other unique problem affecting only one state. But such legislation operates in accord with general standards and criteria apart from the fact that the legislation's impact will happen to focus within a particular state: *i.e.*, a given national park has special needs, or Alaskan oil drilling in the tundra presents special problems, *etc.* The case is different when legislation singles out one state, by name, to bear a unique burden on behalf of all of the states, not because that state is best situated to bear that burden, in accord with some set of generally applicable criteria, but only because the rest of the states, acting through the national government, have cynically concluded "better him than me" and have arbitrarily imposed the invasive burden on that lone state as a unapologetic act of naked political will.

The geology of Yucca Mountain will contribute virtually *nothing* to containing radioactivity; virtually *everything* now depends on man-made barriers. A waste containment system built entirely on engineered barriers can be put literally anywhere. Therefore, there is no longer any basis for preferring Nevada to New York, California, or Virginia. Indeed, Yucca Mountain is only ninety miles from Las Vegas, the fastest- growing city in the United States.

This argument does not make light of the problem posed by the long-term, safe disposal of radioactive waste. However, it is precisely in such circumstances, when the urgency of addressing such a public problem seems most acute, that the wisdom of our Constitution must inject a certain humility and restraint into public policy. As the Supreme Court put it, "The shortage of disposal sites for radioactive waste is a pressing national problem, but a judiciary that licensed extraconstitutional government with each issue of comparable gravity would, in the long run, be far worse."[235]

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235. *New York v. United States*, 505 U.S. at 187-88.

A. The Argument Is Tested: The D.C. Circuit Proceedings

On January 14, 2004, a panel of the D.C. Circuit heard oral argument on the thirteen consolidated cases involving the Yucca Mountain facility.[236] Nevada's constitutional case against the Joint Resolution was among them. The court's questions concerning the constitutional argument evidenced considerable skepticism on the part of the panel, essentially focusing on the scope of the national government's prerogatives over federal land under the Property Clause. The sticking point for the panel was what one judge called Nevada's creating "this equality argument out of the standard rational basis test."[237] The thrust of the panel's objection was not that the national government had unlimited discretion under the Property Clause, but simply that

> [i]t's their property, and so if they're required to show that it's a rational regulation, it seems to me the more reasonable argument is they have to show that it's rational as to this piece of property, not as to all other pieces of property, not as to all other pieces of property that they could have regulated similarly, and they chose only to regulate this one.[238]

Elaborating on this point, two questions posed by Judge Tatel illuminated the key issue:

> Where do you draw the line between, as you said, nuclear waste depository sites and major prisons and all other uses of federal property?
>
> . . .
>
> So your principle, then, really is that Congress cannot rationally use its own property in a particular state without making sure that that particular use is neutrally, based on neutral principles, justifiable in terms of all other property?[239]

Unfortunately, these exchanges with the panel suggested that the panel misconceived the thrust of the argument. The respect that must be accorded to the sovereignty of a state does not create some rigid requirement that the national government must undertake a comparative

236. The panel consisted of Judges Edwards, Tatel, and Henderson.

237. Transcript of Oral Argument, Nuclear Energy Inst. v. United States Environmental Protection Agency, No. 01-1258, *et al.*, at 120 (Jan. 14, 2004) (Judge Tatel).

238. *Id.* at 122 (Judge Edwards).

239. *Id.* at 164 (Judge Tatel).

analysis among all federal property in every other state whenever it wants to do something on its property in one state. What the sovereignty of a state entails depends on the particular circumstances.

This can be understood by examining Judge Tatel's hypothetical, the siting of a prison versus the siting of a nuclear waste repository. At first blush, there seems to be a nice symmetry here: a penitentiary imprisons dangerous criminals while the repository imprisons toxic waste. But that is not true. With wholesale abandonment of geologic isolation (and the inevitable failure of the man-made containers holding the waste), the long-term disposal of waste at the repository at Yucca Mountain now relies, not on imprisoning the waste, but on its slow dilution through the surrounding Nevada countryside as it *by design* seeps out of the repository itself.[240]

In other words, the Yucca Mountain nuclear waste repository is now designed to rely on the territory outside the repository to do its job. That is the burden that Nevada is being forced to bear with the Yucca Mountain facility, a highly dangerous burden that surely implicates the state's sovereign responsibility for the health, safety, and welfare of its residents. How the national government uses its property, when that use is a high-level nuclear waste septic field crossing into state territory and sited above state water, inherently implicates the sovereign concerns of a state. Why a particular state should bear this risk on behalf of the whole nation, as opposed to other sites in other states, *is* inherently part of any rational basis for *this particular use* of federal property. That is, Judge Tatel was quite right in sensing that there is not a stark line to be drawn between Nevada's argument, sounding in equal protection notions, and rational basis concerns.

In short, there are really two steps in the proper analysis here. First, is the site, in the words of Judge Tatel, "geographically suitable"?[241] Second, if the site does belong in the group of sites that are geographically suitable, why choose this site as opposed to other suitable sites?[242]

240. As EPA acknowledged, "during the post-closure period, the ground water will transport radionuclides released from the repository to the surrounding area." EPA, *Radiological Pathways Through the Biosphere*, in Background Information Document for 40 C.F.R. 197, at 8-1 (June 2001).

241. Judge Tatel suggested that the rational basis for a lawful use of federal land need only be a determination that "Yucca Mountain was geographically suitable." Transcript of Oral Argument at 162, *Nuclear Energy Inst* (No. 01-1258). Even if that were sufficient, the determination rests on a question of fact, not of policy. The question, then, would be whether it is true as a factual, scientific matter that the Yucca geography is "suitable." Surely Congress's say-so in the joint resolution cannot definitively resolve the question.

242. To be sure, the rational basis for selecting an otherwise suitable site from among others could rest on a variety of concerns, including the comparative cost of constructing a facility there, the relative accessibility of the site to reliable avenues of transportation, and so on.

Correspondingly, we normally do not think of the security of a prison as being achieved by letting the inmates run through the countryside. The risk of an escape from a federal prison is relatively remote, and in any event a hypothetical escapee would be trying to get as far away from that site as possible. Thus, it is fair to say that the siting of a prison on federal property does not, without more, implicate the state's sovereign responsibility for the health, safety, and welfare of its residents to a degree anywhere near the level of a nuclear waste dump. As a result, the sovereign concerns of the state could be fully respected if the siting of the prison were otherwise rational, that is, if the obvious concerns for the security of nearby residents were fully addressed by the location, design, and operation of the prison.[243]

B. The Case Decided?

The D.C. Circuit handed down its decision in the Yucca Mountain cases on July 9, 2004. As was expected from the tenor of the Court's questions during oral argument, it ruled against Nevada's constitutional argument. The decision was disappointing not simply because Nevada lost, but because the Court's reasoning was surprisingly superficial, utterly failing to come to grips with the substance of the arguments Nevada had offered.

To the D.C. Circuit panel, "the plenary nature of Congress's Property Clause authority [and] the considerable deference that we accord to Congress's judgment in exercising that authority" determined the outcome.[244] Given the broad scope of the Property Clause power as the Court understood it, the Court's only role was limited to "determining whether there is a rational relationship between Congress's stated end and its chosen means."[245] Here, the Court summarily concluded that the "Administration had adequately demonstrated that the Yucca site was likely to be suitable for development" as the much-needed national radioactive waste dump.[246] The Court could not go farther "to examine the strength of the evidence upon which Congress based its judg-

243. Yet in a particular case the facts could be different enough to require more even in the siting of a prison. If, for example, the federal government decided to put all its most dangerous, clever inmates, all convicted of horrible crimes, in one new super-secure facility, it may be that a location in one State makes much more sense than a location in another in terms of minimizing the risks to the surrounding population, and that such a comparative analysis of different sites would be required to respect the sovereign concerns of the involved States for the safety of their residents.

244. *NEI*, 373 F.3d at 1308.

245. *Id.* at 1304.

246. *Id.*

ment."[247] Consequently, the Joint Resolution was an appropriate exercise of Congress's authority under the Property Clause.

The D.C. Circuit did acknowledge that it was required to go somewhat farther to examine "whether the Resolution violates some other provision of the Constitution."[248] In launching that examination, the Court recapitulated what it called Nevada's "equal treatment" claim, and even noted that Nevada's argument "is not based upon any specific provision of the Constitution, but rather on principles of federalism ostensibly inherent in the Constitution as a whole."[249] Notwithstanding this apparent recognition of the premises of Nevada's constitutional case, the Court then proceeded to analyze the state's argument in terms confined to the specific facts and circumstances of each case that Nevada had offered as a manifestation of the "dual sovereignty" that shapes and informs the Constitution.[250] With that method, it was easy for the panel to conclude that Nevada's argument "has no textual basis in the Constitution."[251]

This opinion is flawed on many levels. Most alarmingly, it is at war with the proposition that principles of federalism *are* inherent in the Constitution, and the opinion treats the Property Clause as an unbounded reservoir of federal power.

The Court's Property Clause analysis most obviously ignores the Supreme Court's admonition that exercises of Property Clause power "must be consistent with the foundation principles of our dual system of government and must not be contrived to govern the concerns reserved to the States."[252] Nowhere in the opinion is there the slightest recognition that Nevada may have some appropriate concern about the impact of a highly radioactive waste dump on its citizens and its environment, especially since, as the Court itself acknowledged, radiation even at lower doses "can have devastating health effects, including increased cancer risks and serious birth defects such as mental retardation, eye malformations, and small brain or head size."[253] To be sure, the Court acknowledged that the whole point of a genuine "geologic" nuclear waste repository was "to isolate this waste for . . . epochal years."[254] That is, "the disposal system's 'natural barriers,' *i.e.*, the characteristics of the rock formations under Yucca Mountain, are intended to protect the waste

247. *Id.*
248. *Id.* at 1305.
249. *Id.*
250. *See id.* at 1304-09.
251. *Id.* at 1308.
252. Ashwander v. Tenn. Valley Auth., 297 U.S. at 338.
253. *NEI*, 373 F.3d at 1258.
254. *Id.* at 1261.

from water infiltration and to dilute radiation releases expected to occur from leakage of the engineered barriers or from their failure thousands of years from now."[255] The suitability of the Yucca Mountain site for a radioactive waste dump accordingly rests on this foundation: the "Energy Department expects that this surrounding rock will both limit water from seeping into the waste packages and delay radioactive particles from migrating into the human environment."[256]

Put in the most practical terms, Nevada's fundamental complaint against the Yucca Mountain facility is that its "rock formations" will not do what DOE "expects" they will do; they will not provide sufficient isolation of the radioactive waste to be dumped there to protect the health and environment of Nevadans. Nevada's status as a sovereign state surely gives it a legitimate responsibility to protect the health and environment of its citizens from such danger, a responsibility that the structure of dual sovereignty established by the Constitution respects and accommodates far more than the D.C. Circuit's decision would allow.

The utter lack of respect for state sovereignty in the D.C. Circuit's opinion is evident from the fact that these judges did not find their notion of a near-absolute federal power in the Property Clause in any way jarring to their constitutional sensibilities. To this panel, such a power is "merely the natural and constitutionally unobjectionable result of the Supremacy Clause."[257] Yet this breezy observation is merely an exercise in circular reasoning. As discussed above, a federal law not made "in pursuance" of the Constitution – that is, a law that violates state sovereignty – does not become the "law of the land" under the Supremacy Clause.[258] The D.C. Circuit did not even consider the implications of Nevada's status as a sovereign state—and the legitimate public interests it has a duty to vindicate—in its application of the Property Clause to Nevada's case. Thus, while a simple reference to the Supremacy Clause may mark the beginning of the constitutional analysis needed to adjudicate Nevada's claim, it certainly does not—indeed, cannot—mark its conclusion.

The failure of the panel to address the bounds state sovereignty may place on the Supremacy Clause lies at the heart of their flawed reliance on *Kleppe* to reach their result. As the last major pronouncement of the Supreme Court on the Property Clause, *Kleppe* was bound to loom large in this case. But in fairness to the *Kleppe* Court—and to fairly appreciate what *Kleppe* may or may not mean—it must be remembered that the *Kleppe* plaintiffs claimed that Congress had no power whatsoever to pro-

255. *Id.*
256. *Id.*
257. *Id.* at 1306.
258. *See supra* note 233.

tect wild horses on federal lands unless those horses were moving in interstate commerce or were damaging federal land.[259] It was in rejecting these severe qualifications on the scope of the Property Clause power that *Kleppe* held that this federal power is "without limitations,"[260] and "necessarily overrides conflicting state laws."[261] *Kleppe* involved no claim that some other constitutional principle constrained how the government protected these horses; its focus was solely on whether the government had the power to enact such protections at all.[262]

While deferring to Congress in making "needful" rules for federal property, *Kleppe* does not suggest that such rules are beyond judicial scrutiny, but that the "courts must eventually pass on them."[263] The D.C. Circuit correctly noted that the courts are not to "reweigh the evidence" animating Congress's action.[264] Yet that proposition cannot justify the panel's rejection of Nevada's far more fundamental constitutional claim, which sought no such "reweighing" of closely competing evidence. Rather, Nevada claimed that Congress had *no* basis by which to choose Yucca Mountain, from among all other possible locations, for the nation's radioactive waste repository. Most strikingly, there is not even a rational basis to conclude that the Yucca Mountain site is suitable for such a repository, irrespective of whether it is a rational location from among all the other possible sites.

Of course, although the D.C. Circuit was willing to broadly defer to the judgment of Congress in siting a nuclear waste dump at Yucca Mountain, the panel did conclude that there "is a rational relationship between Congress's stated purpose . . . and its decision to approve the Yucca site."[265] Yet it is impossible to see how the panel's fairly cursory conclusion that the Joint Resolution had a rational basis could be correct, given the panel's decisions with respect to other issues in the Yucca Mountain cases.

The D.C. Circuit rested its "rational basis" conclusion on the fact that a "primary purpose" of the NWPA was that a nuclear waste repository "'provide a reasonable assurance that the public and the environment will be protected from the hazards posed by' such wastes."[266] The

259. 426 U.S. at 532-33.

260. *Id.* at 539.

261. *Id.* at 543.

262. As the *Kleppe* Court noted, the exercise of the Property Clause power "merely overrides the New Mexico Estray Law insofar as it attempts to regulate federally protected animals." *Id.* at 545.

263. *Id.* at 536.

264. *NEI*, 373 F.3d at 1304 (quoting *Kleppe*, 426 U.S. at 541 n.10).

265. *Id.*

266. *Id.* (quoting 42 U.S.C. § 10131(b)(1)).

Court observed that the relevant Senate committee report had concluded "that the Administration had adequately demonstrated that the Yucca site was likely to be suitable for development" of such a repository.[267] Although in its Property Clause analysis the panel stopped there, earlier in this opinion it had concluded that the "Administration" had used the *incorrect* standard in concluding that the "public and the environment" would be protected from the hazards of radioactive wastes at the Yucca Mountain site.

The key issue, obviously, in determining whether a repository site will work to safely dispose of radioactive wastes is whether it will in fact "isolate" those wastes for the time needed.[268] The question then becomes what amount of time is needed for such isolation. Put another way, the question is how far into the future must we measure the amount of radioactivity inevitably leaking from a repository in order to say with reasonable confidence that that site can safely isolate radioactive wastes. For Yucca Mountain, the EPA adopted a rule that would measure the radiation leaking from the repository 10,000 years after nuclear waste was dumped there.[269]

However, in authorizing EPA to promulgate health and safety standards for the Yucca Mountain repository, Congress, in the Energy Policy Act of 1992, required that EPA's standards be "based upon and consistent with the findings and recommendations of the National Academy of Sciences."[270] As the D.C. Circuit itself emphasized, NAS "expressly rejected 10,000 years as a proper benchmark."[271] NAS rejected the 10,000-year standard quite logically on the ground that the measurement of escaping radiation should "be conducted for the time when the greatest risk occurs."[272] According to NAS, "at least some potentially important exposures might not occur until after several hundred thousand years,"[273] with "the highest critical group risk . . . calculated to occur . . . on the order of [one million] years."[274] In short, the EPA did not even come close to promulgating a safety standard "consistent with" NAS's recommendation—the standard commanded by Congress based on its judgment of what would make a safe repository site. As the D.C. Circuit

267. *Id.*

268. *See id.* at 1261.

269. *Id.* at 1262; Protection of Environment, 40 C.F.R. § 197.20 (2004).

270. *Id.* at 1267 (quoting Energy Policy Act of 1992, Pub. L. No. 102-486, 106 Stat. 2776, 2921 (1992) (codified at 42 U.S.C. § 10141(2000)).

271. *Id.* at 1271.

272. *Id.* at 1270 (quoting Committee on Technical Bases for Yucca Mountain Standards, Nat'l Research Council, *Technical Bases for Yucca Mountain Standards* 6-7 (1995) ("NAS Report")).

273. *Id.*

274. *Id.* at 1271 (quoting NAS Report at 67).

put it, the agency "unabashedly rejected NAS's findings."[275] But the law did not give EPA that option:

> It was Congress that required EPA to rely on NAS's expert scientific judgment, and given the serious risks nuclear waste disposal poses for the health and welfare of the American people, it is up to Congress—not EPA and not this court—to authorize departures from the prevailing statutory scheme.[276]

Thus, the Court vacated EPA's rule (and the parts of an NRC rule that incorporated the EPA 10,000-year standard).[277]

By finding that the safety standard set by EPA did not conform to the safety standard Congress wanted the agency to establish, the D.C. Circuit dealt a profound blow to the choice of the Yucca Mountain site. EPA's 10,000-year standard ultimately infected the entire process of selecting Yucca Mountain. In recommending to the President that Yucca Mountain become the repository site, the Secretary of DOE set out three "decision criteria" that led him to recommend the Yucca Mountain site.[278] The very first was the EPA standard the D.C. Circuit concluded was unlawful: "is Yucca Mountain a scientifically and technically suitable site for a repository, *i.e.*, a site that promises a reasonable expectation of public health and safety for disposal of spent nuclear fuel and high-level radioactive waste for the next 10,000 years?"[279] As the D.C Circuit noted, the Secretary of Energy's recommendation was the core of the "Administration's case for selecting the Yucca site" that it made to Congress,[280] specifically including the Administration's reliance on the 10,000-year standard.[281] In short, Congress's decision to approve the Yucca Mountain site, which the Court said was rationally related to Congress's purpose of providing for "the safe disposal of radioactive waste,"[282] essentially rested on a measure of that safety that the Court simultaneously declared to be unlawful. The panel's conclusion that the choice of the Yucca Mountain site had a rational basis simply cannot stand in the face of its rejection of the EPA health and safety standard on which that choice was based.

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275. *Id.* at 1270.

276. *Id.* at 1273.

277. *Id.* at 1315.

278. *See* SITE SUITABILITY RECOMMENDATION, at 8.

279. *Id.* at 8-9. *See also id.* at 10 ("The EPA and NRC adopted . . . standards so as to assure . . . that after the repository is sealed, radiation doses to those in the vicinity would be at safe levels for 10,000 years.").

280. *NEI*, 373 F.3d at 1310.

281. S. REP. NO. 107-159, at 8 (2002).

282. *NEI*, 373 F.3d at 1304.

Having concluded, wrongly, that the exercise of the Property Clause power in the Joint Resolution met minimal levels of rationality, the Court then turned to the potential constraints on that power posed by other provisions of the Constitution embodied in what it called Nevada's "equal treatment" claim.[283] The Court rejected that claim, pronouncing in sweeping terms that "[w]e find it beyond serious dispute that Nevada's proposed 'equal treatment' requirement cannot reasonably be inferred from the provisions and doctrines upon which Nevada purports to rely."[284]

Quite disappointingly, the panel did not analyze Nevada's constitutional argument in the manner in which that conclusion implies. The precedents Nevada cited were simply cases in point of the application of the federalism principles embedded in the structure of the Constitution. Rather than address Nevada's argument in terms of the constitutional first principles on which it rested, the panel focused on the specific holdings or circumstances of the cases Nevada cited to reach the grand conclusion that (surprise!) Nevada's case did fit within the four corners of those cases.[285] The panel's treatment of *South Carolina v. Baker* and the Tenth Amendment illustrates their method.

The Court equated "state interests of the kind protected by the Tenth Amendment" with the "congressional regulation of state activities" simply because such congressional activity was what was at issue in *South Carolina v. Baker*.[286] Yet the Tenth Amendment does not impose a specific rule that applies only to certain kinds of federal action. Rather, it "expressly declares the constitutional policy that Congress may not exercise power in a fashion that impairs the States' integrity or their ability to function effectively in a federal system."[287] This "constitutional policy" of respecting "our system of dual sovereignty" [288] is the whole point of the Constitution; its solicitude for balancing the interests of those dual sovereigns is not so limited as to be triggered only by certain federal activities.

So thoroughgoing is this constitutional policy that even in reviewing regulations of purely private behavior courts must ensure that the "federal balance" is not "contradict[ed]."[289] The vigilance of the courts to maintain the "federal balance" has not been limited to circumstances where there is regulation of the states as states, but has been manifested

283. *Id.* at 1305.
284. *Id.* at 1308.
285. *Id.* at 1305-09.
286. *Id.* at 1305.
287. Fry v. United States, 421 U.S. 542, 547 n.7 (1975).
288. *Printz*, 521 U.S. at 923 n.13.
289. *Lopez*, 514 U.S. at 583 (Kennedy, J., concurring).

"through judicial exposition of doctrines such as abstention, the rules for determining the primacy of state law, the doctrine of adequate and independent state grounds, the whole jurisprudence of preemption, and many of the rules governing . . . habeas jurisprudence."[290] The governing principles of federalism always inform judicial review, and so are expressed in such varied ways because "the federal balance is too essential a part of our constitutional structure and plays too vital a role in securing freedom for [the Court] to admit inability to intervene when one or other level of Government has tipped the scales too far."[291] Clearly, *South Carolina v. Baker* cannot be understood as rigidly setting out the metes and bounds of either the Tenth Amendment or the federal balance of dual sovereigns that is the hallmark of the Constitution.[292]

The failure of the D.C. Circuit to address seriously Nevada's constitutional argument is also apparent from the absence of any discussion in the opinion of critically important primary sources from the framing of the Constitution, such as *The Federalist* or the records of the ratification of the Constitution. One cannot come away from this opinion without the distinct impression that this panel was fundamentally antagonistic to the classic notions of federalism that animated the Framers. Consider the Court's admission that it could not see "how the constraints demanded by Nevada's claim would be consistent with the plenary nature of Congress's Property Clause authority,"[293] or its statement that the "substantive constraint on legislation and the judicial role implicit in Nevada's 'equal treatment' requirement are, in our view, totally at odds with the broad interpretation given to Congress's Property Clause powers."[294] To both these statements the obvious rejoinder is, "Maybe so, but perhaps you have inflated the Property Clause far beyond its proper scope. The genius of the Constitution, after all, is that each constitutional power or right is hemmed in by competing powers and rights."[295]

290. *Id.* at 578.

291. *Id.*

292. The D.C. Circuit also tried to distinguish the defects in the "political process" discussed in *South Carolina v. Baker* from what it considered to be Nevada's "substantive" objections to the Joint Resolution. *See NEI*, 373 F.3d at 1306. Since Nevada's constitutional complaint arises from the lack of neutral criteria in selecting Nevada, from among all other possible sites, to be the home of the nation's radioactive waste dump, the panel's distinction between process and substance seems arbitrary at best.

293. *Id.* at 1308.

294. *Id.*

295. To further buttress the conclusion that Nevada's constitutional argument is beyond serious consideration, the D.C. Circuit suggests that respect for the sovereignty of a state could encumber many uses of federal property – the siting of a military installation, a prison, a dam, a conservation area, and so on. *Id.* But using neutral criteria by which to choose the location of any of these facilities is hardly as burdensome as the Court suggests. Natural features often clearly dictate the locations of a dam, a conservation area, or even a fort. Indeed, irrespective

CONCLUSION

Nevada's constitutional challenge to the Yucca Mountain repository certainly made no headway in the D.C. Circuit, but it remains to be seen whether the constitutional principles championed by Nevada truly lost any ground either. At bottom, the D.C. Circuit's dismissive treatment of Nevada's argument recognizes no sovereign interest of the states that could in any way circumscribe the scope of the federal government's Property Clause power. The Court thus advanced an understanding of the Property Clause that has no principled limit grounded in the federal structure of the Constitution, suggesting that the federal government has an unfettered choice to do what it will with federal property irrespective of any competing sovereign interest of the states. Nowhere did the Court even acknowledge the authority of the states as "sovereign entities"[296] that is the "presupposition of our constitutional structure."[297]

Although Nevada's case is in many respects unique, it exemplifies a profound tension between a broad view of federal power over federal land (with an impact far beyond the federal domain) that is drawn from the Supreme Court's Property Clause precedents, and elementary principles of federalism that are at the foundation of the Constitution's structure and have been given prominence in the Court's cases over recent years. As of this writing, whether the Court will have the opportunity to address this tension in the context of Nevada's case remains to be seen. Ironically, though the D.C. Circuit rejected Nevada's complaint when articulated in constitutional terms, the panel's opinion in many respects gave Nevada the relief it needed by its rejection of the EPA's 10,000-year standard. In rejecting that standard, the D.C. Circuit rejected a health and safety standard crafted only for the Yucca Mountain site, and commanded EPA to return to what Congress had mandated: a neutral health and safety standard, applicable to any possible repository site, recommended by the scientific community. If the EPA faithfully complies, the Yucca Mountain site may in the end be judged by the neutral, rational criteria that Nevada has claimed was its right.

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of concerns for state sovereignty, the use of such criteria is simply an attribute of responsible decision-making. If one were constructing a maximum security prison for the most hardened federal convicts, for example, Alcatraz is a more logical location than Central Park.

296. *Alden*, 527 U.S. at 758.

297. Blatchford v. Native Vill. of Noatak, 501 U.S. 775, 779 (1991). *See also* THE FEDERALIST No. 40 at 261 (James Madison) (Jacob E. Cooke ed. 1961) (States are "regarded as distinct and independent sovereigns" by "the Constitution proposed").

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SITE SPECIFIC DIGITAL TEXTS

Attorney General's Manual *on the* Administrative Procedure Act

Prepared by the United States Department of Justice Tom C. Clark, Attorney General, 1947.

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overlapping between the defini-[14]tion of "rule" in section 2 (c) and of "license" in section 2 (e). Thus, "rule" includes the "approval * * * for the future * * *", and "license" is defined to include "any agency permit, certificate, approval * * * or other form of permission."

An obvious principle of construction is that agency proceedings which fall within one of the specific categories of section 2 (c), e.g., determining rates for the future, must be regarded as rule making, rather than as coming under the general and residual definition of adjudication. Furthermore, the listing of specific subjects in section 2 (c) as rule making is not intended to be exclusive. It is illustrative only. H.R. Rep. 20 (Sen. Doc. p. 254). Thus, in determining whether agency action on a particular type of application is "rule making", the purposes of the statute involved and the considerations which the agency is required to weigh in granting or withholding its approval will be relevant; if the factors governing such approval are the same, for example, as the agency would be required to apply in approving a recapitalization or reorganization (clearly rule making), this circumstance would tend to support the conclusion that agency action on such an application is rule making.

More broadly, the entire Act is based upon a dichotomy between rule making and adjudication. Examination of the legislative history of the definitions and of the differences in the required procedures for rule making and for adjudication discloses highly practical concepts of rule making and adjudication. Rule making is agency action which regulates the future conduct of either groups of persons or a single person; it is essentially legislative in nature, not only because it operates in the future but also because it is primarily concerned with policy considerations. The object of the rule making proceeding is the implementation or prescription of law or policy for the future, rather than the evaluation of a respondent's past conduct. Typically, the issues relate not to the evidentiary facts, as to which the veracity and demeanor of witnesses would often be important, but rather to the policy-making conclusions to be drawn from the facts. Senate Hearings (1941) pp. 657, 1298, 1451. Conversely, adjudication is concerned with the determination of past and present rights and liabilities. Normally, there is involved a decision as to whether past conduct was unlawful, so that the proceeding is characterized by an accusatory flavor and may result in disciplinary action. Or, it may involve the determination of a person's right to bene-[15] fits under existing law so that the issues relate to whether he is within the established category of persons entitled to such benefits. In such proceedings, the issues of fact are often sharply controverted. Sen. Rep. p. 39 (Sen. Doc. p. 225); 92 Cong. Rec. 5648 (Sen. Doc. p. 353).

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RADIATION PROTECTION

ICRP PUBLICATION 46

Radiation Protection Principles for the Disposal of Solid Radioactive Waste

A report of Committee 4 of the
International Commission on Radiological Protection

ADOPTED BY THE COMMISSION IN JULY 1985

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provided explicit guidance as to how to resolve the problems involved in assessing long-term radiation impacts or to interpret the results of these assessments for decision-making purposes. A recent report by an international expert group[5] has recognized the same problems and discusses methods of resolving them.

4. It is necessary, therefore, to build on the present system of dose limitation to provide a more explicit method for judging whether waste disposal options are radiologically acceptable, while preserving the system's fundamental features.

5. It is not necessary to deal with the control of radioactive effluents in detail in this report. Nonetheless, it must be borne in mind that the system of dose limitation, particularly the optimization requirement, should be applied to the entire waste management system and could entail comparisons between discharges as effluents or disposals as solidified wastes for the same radionuclides. In a comparison of waste management systems, the results of optimization of protection and the estimates of radiation impact may themselves need to be considered as inputs to a decision-making process that also takes into account other, non-radiation, considerations, such as technical, social and political aspects. Except insofar as these form part of the process of optimization of protection, they are beyond the scope of the Commission's recommendations.

6. The development of criteria for re-use of materials is not covered in this report, because these materials are not wastes. Treatments which merely transform radionuclides from one physico-chemical form to another are also incidental to the main purpose of this report and are not considered, although they will have practical implications for waste management and can lead to the production of solid wastes. Non-radiation detriments associated with wastes, e.g. chemical toxicity, are also excluded.

2. RADIOACTIVE WASTES AND MANAGEMENT OPTIONS

7. Radioactive wastes arise from a wide range of activities; the use of radionuclides in hospitals and research laboratories: the use of radioactive materials in industrial processes; the production of electricity by nuclear power and as a by-product from processes not directly using the radioactive properties. It is electricity production, and the associated fuel cycle of uranium mining, fuel fabrication and fuel reprocessing, that generates the largest quantities of radioactive wastes that generally require long-term disposal arrangements.

2.1. Radioactive Waste Characteristics

8. The two principal characteristics of wastes that influence their management are their volume and their radionuclide content. This particularly applies to radionuclides with half-lives longer than several decades. These characteristics vary over a very wide range, depending on the process from which the wastes originate. A variety of different management and disposal procedures is, therefore, appropriate.

9. Radioactive wastes from medical procedures contain generally only short-lived radionuclides, as do many radioactive sources used in conventional industrial processes, but their volumes can be large. There are a few exceptions where long-term considerations arise, such as in disposal of radium sources, but the volumes of such wastes are usually small.

10. The nuclear fuel cycle generates some radioactive wastes at each step. The mining of uranium results in accumulations of very large volumes of uranium mill tailings, containing naturally-occurring radium and thorium as well as the unextracted uranium. These radioactive elements and some of their radioactive decay products are long-lived and the wastes, therefore,

require management procedures that take this into account. Uranium enrichment and nuclear fuel fabrication produce significant volumes of radioactive waste, most of which is of a low activity concentration. The naturally-occurring isotopes of uranium are the only significant radioactive contaminants.

11. The operation of nuclear power plants gives rise to a variety of wastes contaminated with radionuclides from neutron activation of structural materials and leakages of small amounts of fission products from fuel. These wastes consist mainly of resins and filters used to trap radionuclides in cooling circuits, storage ponds and ventilation systems. Low levels of contamination with longer-lived actinides may be associated with failures of fuel cladding. The volumes of wastes are predictable and are substantial.

12. Reprocessing of spent fuel to recover uranium and plutonium allows over 99% of the radioactive elements to be concentrated into a small volume of high-level radioactive waste, but also gives rise to other waste streams containing lower levels of contamination with both fission products and actinides. If spent fuel is not reprocessed, it must eventually be considered itself as a waste and will contain all the plutonium generated in the nuclear reactor, as well as all other radionuclides that would have been in the high-level wastes and other streams from reprocessing.

13. Decommissioning of nuclear installations will give rise to very large volumes of material with a wide range of radionuclide contents, varying from barely detectable contamination on much of the dismantled structures to higher levels of contamination and activation of some metal components in the reactor structure and containment.

2.2. Management Options for Radioactive Wastes

14. A range of choices exists in many nuclear installations between release of radionuclides in effluents and their partial removal from liquid and gaseous effluent streams. If some fraction of the radionuclides is removed, this will give rise to radioactive waste in solid or slurry form. In some cases, containment of this waste will allow a natural decrease through radioactive decay, but, where very long-lived radionuclides are involved, containment in storage facilities will only provide a period of delay before dispersion takes place. Even disposal in regions of high natural isolation will not provide a guarantee of indefinite isolation for very long-lived radionuclides.

15. For wastes that arise in a liquid form, some treatment is generally required to convert the waste to a stable and solid form suitable for storage and disposal. The type of treatment will depend on the volume of waste, its chemical and physical characteristics, the content of radionuclides and the role the waste matrix is expected to play during storage and following disposal.

16. Some wastes containing very small quantities of radionuclides and arising in large volumes may be disposed of as they arise, but interim storage often has a useful role in providing a supervised period during which radioactive decay reduces the hazard posed by wastes, facilitating their eventual disposal. This is particularly valuable for short-lived radionuclides with half-lives in the range from a few days to a few years.

17. Interim storage of wastes implies surveillance and maintenance of the storage facility. Storage, therefore, involves operational exposures to personnel involved in maintenance and surveillance; continuing risks of accidental releases; as well as financial provision to cover operating expenditure.

18. While storage involves a commitment to containment of radioactive waste for a definite time, disposal options differ in both the degree of containment and the likely duration of containment for radionuclides. The type of disposal that is seen to be appropriate for particular

6. APPLICATION OF INDIVIDUAL REQUIREMENTS TO A SOURCE

6.1. Source and Risk Upper Bounds

53. The total dose to the critical group will be composed of doses from the source being assessed, doses from other local sources, and doses from other regional and global sources. Also, overlapping doses from different sources to the same critical group are not restricted to any given instant in time. Releases of material during 1 year may cause doses in future years. The dose rate resulting from the combined effect of all such annual releases may, therefore, increase to some steady state or, if the releases stop at some time in the future, a maximum. The maximum value of the annual dose could, therefore, occur far in the future and be maintained over considerable periods of time.

54. To allow for dose contributions from present practices and to provide a margin for unforeseen future activities, the Commission recommends that national authorities select a fraction of the dose limits as a source upper bound for each source of exposure, to ensure that the exposure of individuals will remain below the relevant dose limit.

55. For radioactive waste disposal, the normal release mechanism and its resulting exposure pattern are assumed to occur. The source upper bound that serves as the design constraint for the repository would, therefore, be the difference between the dose limits and the summation of other local exposures, regional and global exposure contributions, and the allowance for future activities. The assessment of the global contribution to the critical group can use the forecasts of doses resulting from all practices using ionizing radiation, as assessed by relevant international bodies, particularly UNSCEAR.[15] The summation should include consideration of the potential build-up of doses due to prolonged releases, as well as the degree of interaction between different sources. In general, a prudent fraction of the dose limits should be reserved for potential future sources which cannot be predicted accurately.

56. In accordance with the general policy of the Commission to consider the fundamental principles of protection measures, and to leave the elaboration of detailed guidance to the various national or international bodies,[1] it is not considered appropriate to provide detailed guidance on the choice of numerical values for the source upper bound. Suggested procedures may be found in the literature.[13,16,17]

57. In a manner similar to the establishment of the source upper bound, the Commission recommends that national authorities select some fraction of the risk limit as a risk upper bound for the source being evaluated. A requirement of the assessment would then be that the sum of all risks from probabilistic events associated with a single source, which could expose the same critical group at any time, be less than the risk upper bound selected.

6.2. Assessment of Individual Risks

58. To use a system of limitation on annual individual risk requires that the probability of exposure at or above various levels of annual dose should be assessed. It is important in doing this that a distinction be made between the probability of exposure and the probability of disruptive events at waste disposal facilities which may give rise to exposures. The link between these parameters involves the distribution over time of the radiation impact associated with the disruptive event.

59. The basic information often used to characterize the likelihood of a disruptive event consists of the probability of occurrence in a defined interval, usually a year, as a function of time as shown in Fig. 1. For some events, the probability of occurrence in a given time interval will be

United States
Environmental Protection
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EPA

Protecting The Nation's Ground Water: EPA's Strategy For The 1990s

The Final Report Of The EPA Ground-Water Task Force

AUG 11 1999
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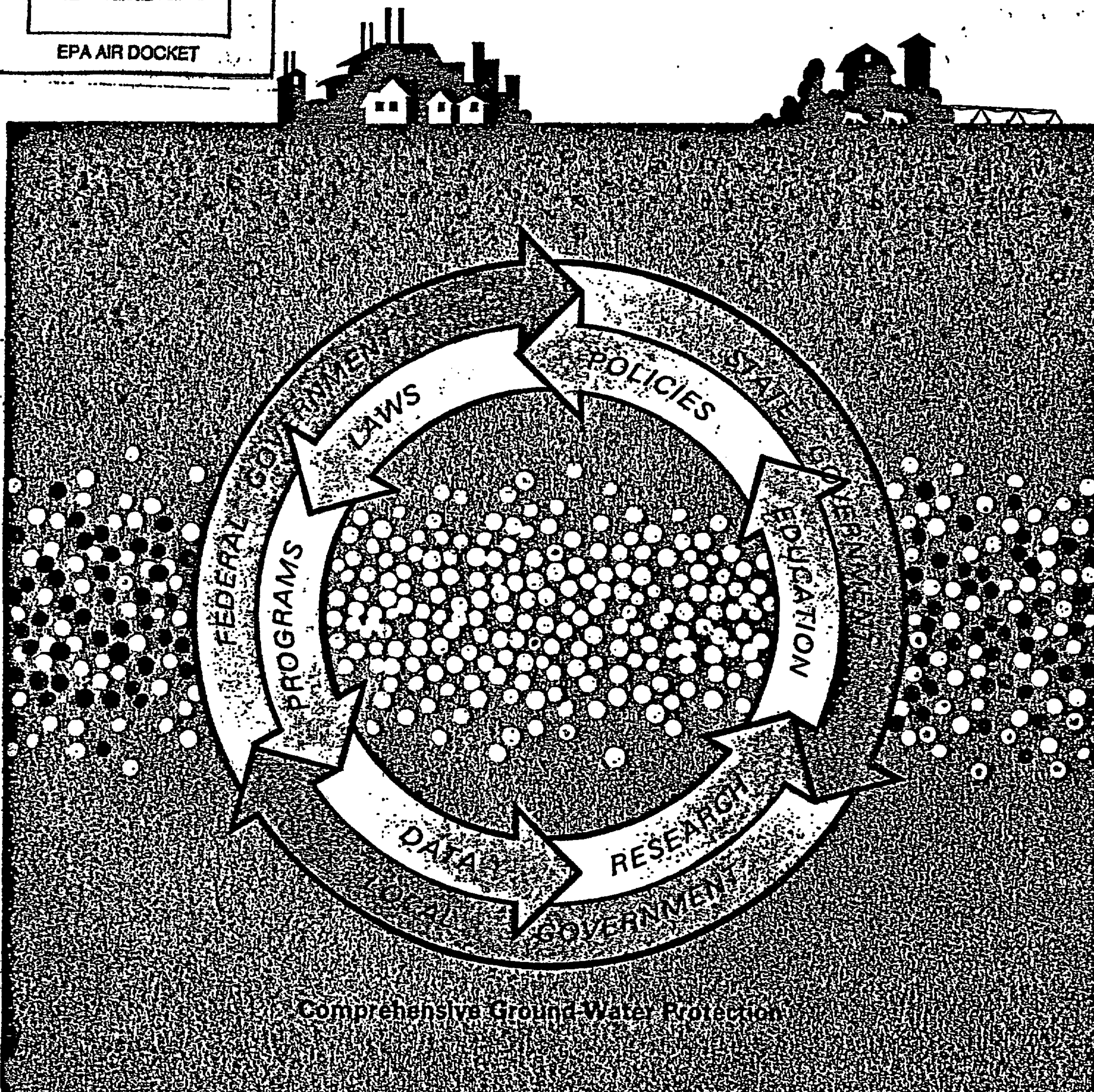

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 28 1991

OFFICE OF
THE ADMINISTRATOR

Dear Friends:

Ground-water resources are of vital importance to this country -- to the health of our citizens, the integrity of many of our ecosystems, and the vigor of our economy. We must make every effort to protect the quality of these resources, which are increasingly threatened by a variety of human activities from industrial by-products, to excessive use of agricultural chemicals, to faulty business operations, and to improper disposal of household wastes.

In 1984, the Environmental Protection Agency (EPA) issued a Ground-Water Protection Strategy which articulated what was known about protecting ground-water resources and set out an appropriate role for the Agency. Over the last several years, EPA and the States have made significant strides under the Agency's 1984 Strategy. Last year, the time was right to take a hard look at the Agency's ground-water protection efforts, and to develop a more integrated approach for moving forward with this issue in the 1990s. We formed an EPA Ground-Water Task Force of senior Agency managers from all offices with ground-water related responsibilities to develop recommendations for providing a more integrated and effective approach to *comprehensive* protection of ground-water resources. Significant input was provided to the Task Force by State and local governments, other Federal agencies, environmentalists, industry, and public interest groups.

The outcome of this review is the report "Protecting the Nation's Ground Water: EPA's Strategy for the 1990s." This report states Agency policy, accompanied by implementation principles that reflect an aggressive approach to protecting the Nation's ground-water resources; they will guide the course of EPA and State efforts over the coming years. The policy puts clear priority on preventing ground-water contamination, recognizes that ground water is a uniquely local resource for which States and local governments must assume primary responsibility, and strives to improve EPA's coordination of ground-water activities under all our statutes and programs. This policy will be reflected in EPA programs and resource allocations as we continue our partnership with State and local governments, private industry and the public in addressing this issue.

Protecting our ground-water resources is one of the most complex environmental issues we face in the 1990s. With over 50 percent of the population relying on ground water as their primary source of drinking water, and the recent EPA Science Advisory Board report which ranks the contamination of drinking water as one of the higher risks to human health, we cannot delay protecting this resource. This Task Force Report reflects the accomplishments and experience of the States and EPA over the last few years. Under this new and integrated cross-program framework for action, we can all work together to ensure that this vital resource is available for use by the present and future generations.

Sincerely yours,

William K. Reilly

William K. Reilly
Administrator

F. Henry Habicht II
Deputy Administrator

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Part A

EPA's Ground-Water Protection Principles

The overall goal of EPA's Ground-Water Policy is to prevent adverse effects to human health and the environment and to protect the environmental integrity of the nation's ground-water resources; in determining appropriate prevention and protection strategies, EPA will also consider the use, value, and vulnerability of the resource, as well as social and economic values.

- **In all events, EPA will execute this goal and the principles below in accordance with Federal law.**
- **Adverse effects mean those risks that are significant to the affected population and determined to be unreasonable where appropriate under relevant statute.**
- **EPA's fundamental premise is that the attainment of this goal is necessary to achieve the sustainability of the resource and closely hydrologically connected surface water systems, not just for the near term but for the future as well.**
- **In addition, because ground-water cleanup is extremely costly, and usually difficult and in some cases impossible to achieve and demonstrate, EPA's goal is to emphasize prevention of pollution where appropriate.**

In order to achieve this goal, the Agency's principles are:

WITH RESPECT TO PREVENTION:

♦ **Ground water should be protected to ensure that the nation's currently used and reasonably expected drinking water supplies, both public and private, do not present adverse health risks and are preserved for present and future generations.**

♦ **Ground water should also be protected to ensure that ground water that is closely hydrologically connected to surface waters does not interfere with the attainment of surface water quality standards, which is necessary to protect the integrity of associated ecosystems.**

♦ **Ground-water protection can be achieved through a variety of means including: pollution prevention programs; source controls; siting controls; the designation of wellhead protection areas and future public water supply areas; and the protection of aquifer recharge areas. Efforts to protect ground water must also consider the use, value, and vulnerability of the resource, as well as social and economic values.**

- Ground water is a uniquely local resource due to the ease with which small sources can affect it, and the impact that use and hydrologic characteristics (e.g. vulnerability) can have on its quality. As such, ground-water programs will require an appropriate blend of several protection methods.

WITH RESPECT TO REMEDIATION:

♦ **Ground-water remediation activities must be prioritized to limit the risk of adverse effects to human health first and then to restore currently used and reasonably expected sources of drinking water and ground water closely hydrologically connected to surface waters, whenever such restorations are practicable and attainable.**

- Given the costs and technical limitations associated with ground-water cleanup, a framework should be established that ensures the environmental and public health benefit of each dollar spent is maximized. Thus, in making remediation decisions, EPA must take a realistic approach to restoration based upon actual and reasonably expected uses of the resource as well as social and economic values.

- In an ideal world of unlimited funds, prioritization would be unnecessary. However, because resources do not permit all contamination to be addressed at once, the need for prioritization must be recognized.

- Moreover, given the expense and technical difficulties associated with ground-water remediation, EPA is emphasizing early detection and monitoring so that it can address the appropriate steps to control and remediate the risk of adverse effects to human health and the environment.

WITH RESPECT TO FEDERAL, STATE, AND LOCAL RESPONSIBILITIES:

♦ **The primary responsibility for coordinating and implementing ground-water protection programs has always been and should continue to be vested with the States. An effective ground-water protection program should link Federal, State, and local activities into a coherent and coordinated plan of action.**

♦ **EPA should continue to improve coordination of ground-water protection efforts within the Agency and with other Federal agencies with ground-water responsibilities.**

- Since ground water in any given area may be subject to contamination from a wide variety of point and non-point source activities, coherence and coordination in any plan of action are vitally important. EPA must ensure that the ground-water protection programs it implements under the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), the Safe Drinking Water Act (SDWA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and the research programs that it funds under these Acts, are directed toward achieving the principles outlined above. In the design and timing of regulatory initiatives, EPA will address the highest risks. In addition, the authority of each State to allocate water within its jurisdiction should not be abrogated.

- Given the uniquely local nature of ground-water pollution and use, the States and localities must have primary responsibility for assessing and prioritizing risks to the resource and for implementing programs to protect the resource within each state so that it is available for various uses. However, where specific Federal responsibilities are provided for under the law, the requirements of the law must prevail.

- Not only must Federal, State, and local activities be linked to form a coherent plan of action; but air, water, and land practices, to the extent practicable, must also be examined in an integrated fashion to ensure protection of the ground-water resource.

Part D

Agency Policy on EPA's Use of Quality Standards in Ground-Water Prevention and Remediation Activities

The purpose of this policy statement is to describe the approach the Agency will use in making specific decisions with quality standards when carrying out EPA's ground-water related statutory responsibilities.

When EPA is carrying out its programs, the Agency will use maximum contaminant levels (MCLs) under the Safe Drinking Water Act, as "reference points" for water resource protection efforts when the ground water in question is a potential source of drinking water. Water quality standards, under the Clean Water Act, will be used as reference points when ground water is closely hydrologically connected to surface water ecological systems. Where MCLs are not available, EPA Health Advisory numbers or other approved health-based levels are recommended as the point of reference. If such numbers are not available, reference points may be derived from the health-effects literature where appropriate. In certain cases, maximum contaminant level goals (MCLGs) under the Safe Drinking Water Act, or background levels may be used in order to comply with Federal statutory requirements. Reference points are to be applied differently for prevention and cleanup purposes.

- Prevention: Best technologies and management practices should be relied on to protect ground water to the maximum extent practicable. Detection of a percentage of the reference point at an appropriate monitoring location would then be used to trigger consideration of additional action (e.g., additional monitoring; restricting, limiting use or banning the use of a pesticide). Reaching the MCL or other appropriate reference point would be considered a failure of prevention.

- Cleanup: Remediation will generally attempt to achieve a total lifetime cancer risk level in the range of 10-4 to 10-6 and exposures to non-carcinogens below appropriate reference doses. More stringent measures may be selected based on such factors as the cumulative effect of multiple contaminants, exposure from other pathways, and unusual population sensitivities. Less stringent measures than the reference point may be selected where authorized by law, based on such factors as technological practicality, adverse environmental impacts of remediation measures, cost and low likelihood of potential use.

SAFETY SERIES No

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SAFETY FUNDAMENTALS

The Principles of Radioactive Waste Management

A PUBLICATION
WITHIN THE RADWASS PROGRAMME

A-95-12
Y-A-10

EPA/AIR DOCKET
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account recommendations of international bodies such as the ICRP and the IAEA, notably the concept of optimization of radiological protection.

313. In the case of normal release, potential release or migration of radionuclides across national borders, the country of origin could choose to find agreement regarding elaboration of this principle, for example, through exchange of information or arrangements with neighbours or affected countries.

314. Import and export of radioactive waste is the subject of the IAEA "Code of Practice on the International Transboundary Movement of Radioactive Waste", which states in part that a State should receive radioactive waste for management or disposal only if it "has the administrative and technical capacity and regulatory structure to manage and dispose of such waste in a manner consistent with international safety standards".

Principle 4: Protection of future generations

> **Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.**

315. This principle is derived from an ethical concern for the health of future generations. In the establishment of acceptable levels of protection, the latest recommendations of international organizations, for example the ICRP and the IAEA, are typically taken into account.

316. While it is not possible to ensure total isolation of radioactive waste over extended time-scales, the intent is to achieve reasonable assurance that there will be no unacceptable impacts on human health. This is typically achieved by applying the multibarrier approach in which both natural and engineered barriers are utilized. The existence of suitable natural barriers is usually determined within a siting process. Furthermore, account should be taken of possible future exploration for, or exploitation of, valuable natural resources that could potentially result in adverse effects on the isolation capability of a disposal facility. In the implementation of radioactive waste management, particularly for disposal, uncertainties in long term safety assessment due to the inherent difficulty in predicting impacts far into the future should be taken into account.

Principle 5: Burdens on future generations

> **Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.**

317. Consideration for future generations is of fundamental importance in the management of radioactive waste. This principle is based on the ethical consideration that the generations that receive the benefits of a practice should bear the responsibility to manage the resulting waste. Limited actions, however, may be passed to succeeding generations, for example, the continuation of institutional control, if needed, over a disposal facility.

318. The responsibility of the present generation includes developing the technology, constructing and operating facilities, and providing a funding system, sufficient controls and plans for the management of radioactive waste.

319. The timing and implementation of disposal of individual radioactive waste types will depend on scientific, technical, social and economic factors such as the availability, acceptability and development of suitable sites and the decrease of radioactivity levels and heat generation during interim storage.

320. The management of radioactive waste should, to the extent possible, not rely on long term institutional arrangements or actions as a necessary safety feature, although future generations may decide to utilize such arrangements, for example to monitor radioactive waste repositories or retrieve radioactive waste after closure has been effected. The identity, location and inventory of a radioactive waste disposal facility should be appropriately recorded and the records maintained.

Principle 6: National legal framework

> **Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.**

321. Countries in which radionuclides are being produced or used should develop a national legal framework providing laws, regulations and guidelines for radioactive waste management, taking into account overall national radioactive waste management strategies. The responsibilities of each party or organization involved should be clearly allocated for all radioactive waste management activities that take place in a country.

UNITED STATES

NUCLEAR WASTE TECHNICAL REVIEW BOARD

1995 FALL BOARD MEETING

STRATEGIC CONCERNS, TOTAL
SYSTEM PERFORMANCE ASSESSMENT

October 17, 1995

Arlington Renaissance Hotel
920 N. Stafford Street
Arlington, Virginia 22203

BOARD MEMBERS PRESENT

Dr. John E. Cantlon, Chairman, NWTRB
Dr. Clarence Allen
Mr. John W. Arendt
Dr. Jared L. Cohon
Dr. Edward J. Cording
Dr. Donald Langmuir
Dr. John J. McKetta
Dr. Jeffrey J. Wong

CONSULTANTS

Dr. Patrick A. Domenico
Mr. Richard Grundy
Dr. Richard Parazek
Dr. Ellis D. Verink

think that it will be very hard to implement a standard that goes out without any time limits.

We feel it's ultimately a policy matter as to what the time limits should be or the time one should take into consideration. We think that we should take into consideration how other standards are regulated. If you look at other hazards, they generally go between 1,000 and 10,000 years for other EPA regulations. As was alluded to this morning, the general standard for disposal of waste which applies to WIPP and would apply to any other geologic repository if there ever was one has a 10,000 year period of performance.

That does not mean one would not do these evaluations for longer time periods for the insights and the design considerations and those kinds of aspects.

[Slide.]

BROCOUM: We are also concerned with the quantitative treatment of human intrusion impacts.

The National Academy recommended comparing these impacts with the limit for the undisturbed repository performance.

We feel that in essence the human intrusion scenario would in effect become the controlling scenario, assuming that this scenario doesn't behave as well as the undisturbed one. So in a hearing or in the process that one goes through there would be a lot of focus in this area.

We still feel that human intrusion should be handled by some qualitative approach and requirements, such as design requirements and passive institutional controls.

[Slide.]

BROCOUM: The approach to calculation of risk to critical group to some of the people in DOE appears to be very complicated.

Appendix C gives a very prescriptive approach to making those calculations and may not be easily understood or comprehended by the public. Some of us felt the Appendix D approach was more straightforward and is kind of more consistent with the way other radionuclide regulations have been in the past.

[Slide.]

BROCOUM: We think that as we go into rulemaking the critical issues for EPA and the other parties to consider are these:

The level of risk that is considered acceptable.

The time frame for the quantitative compliance demonstrations, the standard that you are held to.

The definition of a reference biosphere, including the critical group and exposure scenarios. This is very important because, depending on the assumptions and how you define these, the site can either pass or fail.

Finally, the treatment of human intrusion, as I mentioned in the early slide.

[Slide.]

BROCOUM: What are some of the potential impacts to the project if these recommendations were implemented in a standard?

There might be increased emphasis on measures that would reduce the long-term dose. It was mentioned earlier today, well, if we are only worried abóut the period of greatest risk, maybe we could do away with the waste package. As you will hear later from Jean, we are taking almost a two-pronged approach. We are taking a containment approach for the operational and the early preclosure up to several thousand years and a different approach which consists of slow release, diffusion and dilution of the radionuclides for a longer term period.

There was also increased emphasis of a calculation of a long-term dose/risk:

Waste form dissolution.

And, of course, saturated zone hydrology, which in the days we wrote the SEP was not considered very important. That has become more important over the years as we realize we may be going to a dose or a risk-based standard.

[Slide.]

BROCOUM: Other potential impacts.

There might be a decreased emphasis on explicitly demonstrating compliance with any subsystem requirements. You'd still have defense-in-depth because you would have multiple barriers, but the focus would be on how the individual subsystems contribute to the overall and total system performance, not how the subsystems contribute through some arbitrary subsystem requirement.

There would also be a decreased emphasis on site characterization data that do not impact long-term doses. For example, pathways for and release of gaseous radionuclides.

[Slide.]

BROCOUM: We are planning to provide informal comments to the EPA. The EPA did issue a Federal Register notice on September 11. They asked for informal comments by October 26. We have those comments in draft form.

They also had a meeting in Amargosa Valley and several meetings in Las Vegas where they got oral and written public comments.

We anticipate EPA moving out expeditiously on the rulemaking and us working with EPA and the NRC during the rulemaking process.

The resulting standard, in our view, has to be implementable. When I say implementable, it has to lead down one of several paths.

The first path would be it would have to eventually lead to a license application. If it successfully went beyond the license application, then have the ability to construct and operate the closed repository.

The other path is it would have to lead to a decision that Yucca Mountain isn't suitable as opposed to constantly being on a treadmill with no discernible progress.

That's kind of how I'm defining implementable here.

We feel as an agency that we offer a unique perspective because we are the agency that will have to demonstrate compliance with whatever standard is eventually promulgated.

Those are our preliminary comments on the proposed standard.

CANTLON: Thank you, Steve.

Questions from the Board? Ed?

CORDING: Steve, the comment on "NAS recommends comparing these impacts with the limit for undisturbed repository performance," could you clarify what is meant there by the limit?

BROCOUM: Whatever the overall risk that is allowed, whatever that risk limit is, which will be decided in a rulemaking process, they recommended that you have at least one stylized human intrusion case that you use to compare that limit to how robust the repository design is. I believe that was the point of the recommendation.

What DOE is saying is that might become the controlling case, because most likely the repository system will perform worse with some sort of a stylized intrusion than it would if it was undisturbed. That's the point I was trying to make. The limit would be they would have the same standard for the human intrusion case as they would for the undisturbed case.

I hope I'm saying that correctly. I'm looking back at the National Academy people.

CORDING: You had no note on the increased emphasis on measures that would reduce long-term dose, and there you are talking about the engineered barrier system. The focus on the engineered barrier system, you were commenting, was several thousand years. Are you looking at it to do something for you?

BROCOUM: The point I was trying to make is something Chris Whipple said earlier. He said that, well, we hope that people don't say just because we recommend you focus on the period of greatest risk that we don't just get rid of the robust waste package.

The point I was trying to make is when you hear the presentation on our waste site selection strategy, we do

STATEMENT FOR THE RECORD
PRESENTATION TO THE U.S. NUCLEAR REGULATORY COMMISSION
STATUS OF THE CIVILIAN RADIOACTIVE WASTE
MANAGEMENT PROGRAM
BY
DANIEL A. DREYFUS, DIRECTOR
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
U.S. DEPARTMENT OF ENERGY
January 30, 1996

Introduction

Chairman Jackson and Commissioner Rogers:

A lot has happened since I last spoke with you in June of last year regarding the Civilian Radioactive Waste Management Program. We are now four months into the new fiscal year, operating under a reduced budget that required us to restructure our geologic disposal program and to terminate a large portion of our waste acceptance activities. We are, as yet, without agreement between the Administration and Congress on new policy direction on our role in the near-term management of spent nuclear fuel. Congress is continuing to consider legislation to initiate construction of an interim storage facility. If such legislation is enacted, we will need to further redirect our program.

To the best of my ability at this point, I will share with you our planning for the future of the program, considering the funding and the direction the Congress has provided through the appropriations bill enacted for the current fiscal year. I will also discuss our contingency planning in the event that the Administration and Congress agree on new policy direction for interim storage.

Fiscal Year 1995 Accomplishments

In my briefing to you in December 1994, I outlined our targets for implementing the program approach, which was described in the Program Plan we issued that same month. At that time, I noted the importance of gaining agreement by Congress to the 40 per cent increase in funding requested by the Administration for fiscal year 1995.. The program approach was endorsed by Congress as a basis for 1995 funding. It also was generally supported by the Commission and other program stakeholders.

Almost all of the increase in funding for fiscal year 1995 was allocated to, and utilized by the Yucca Mountain Project, which completed the fiscal year with very little carry over and with accomplishments that often exceeded our targets. For example, we overcame startup difficulties

Yucca Mountain Standards

At present, there are no environmental standards for protection of the public from the radioactive waste that might be disposed of in a geologic repository at the Yucca Mountain site. The uncertainty associated with this situation requires some flexibility in defining our strategy and plans. The Energy Policy Act of 1992 directed the Environmental Protection Agency to promulgate new standards for a repository at the Yucca Mountain site based on and consistent with the recommendations developed by the National Academy of Sciences. The 1992 law also directed the Commission to modify its requirements to be consistent with the new standards.

National Academy of Sciences Report

The National Academy of Sciences formed the Committee on Technical Bases for Yucca Mountain Standards to prepare its recommendations to the Environmental Protection Agency. The Committee's report was submitted to the Agency in August 1995.

The Committee's report observes that there are both technical and institutional dimensions to the development and approval of a geologic repository. This observation is consistent with our view, and what we believe is the Commission's view, that science cannot provide unqualified assurances over many thousands of years. The ultimate decisions regarding disposal will involve societal and economic, as well as technical elements. We believe that the Committee's report basically reaffirms the feasibility of geologic disposal. The report also recognizes that policy makers need to make decisions regarding a number of issues that lack a definitive scientific basis. Through its recommendations, the report puts the question of how society and policy makers should deal with inter-generational equity on the table for discussion.

The report notes that predictions of human behavior, even for hundreds of years in the future, have no scientific basis. At the same time, however, the report goes on to recommend compliance assessments against quantitative standards for geologic disposal that would apply for hundreds of thousands of years into the future, to include the peak annual risk, whenever it occurs. It is not clear that quantitative predictions for a period of up to one million years can be defended in a licensing environment, especially if the attendant uncertainties are not explicitly recognized and the standard is based on a risk limit that is overly conservative in light of these uncertainties. A quantitative standard that focuses the licensing debate upon highly speculative calculations of exposures as much as one million years into the future, it seems to me, is more likely to obscure than enlighten the societal decision on the acceptability of geologic disposal at Yucca Mountain.

In the absence of a scientific basis for predictions about human behavior and the biosphere as they relate to the evaluation of individual risk in the far future, the Committee declared that it is really a policy issue. The Committee suggested that appropriate (but certainly hypothetical) assumptions for such evaluations should be made, based on current population and living habits, and incorporated in the rulemaking. We believe that this approach is implementable, provided that the required hypothetical assumptions are explicitly defined in the standard.

In developing its recommendations, the Committee also made several technical assertions that should be carefully evaluated during the rulemaking process. For example, the Committee concluded that the geologic framework at Yucca Mountain was either geologically stable or was expected to vary in such a way as to be predictable over a period on the order of a million years. We are not certain that it is reasonable to expect that science can demonstrate and that we can defend that contention in the licensing process as the basis for conclusions about compliance. In general, we believe that some of the technical assertions made by the Committee are also inherently a matter of judgement and will have to be determined by policy decisions at the appropriate stage in the rulemaking process and stipulated in the standard or the Commission's implementing regulation.

Consequently, we believe that great care needs to be taken by the Environmental Protection Agency and the Nuclear Regulatory Commission in addressing the Committee's recommendations in their subsequent rulemaking actions. Whatever standard results from this process must protect public health and safety and the environment. It must also be implementable. That is, demonstrating compliance with the standard should not require a greater degree of scientific proof than can reasonably be provided and should not leave policy judgements to be defended in a licensing process as if they were technical judgements supported by factual analyses. Promulgating a standard that cannot be implemented may result in the de facto rejection of the Yucca Mountain site, or even a rejection of the option of geologic disposal. Such rejection will not avoid the consequences of long-term radioactive waste management, it will simply require society to resort to a different, and currently undetermined, long-term approach.

We are pleased to note that your staff has established a liaison with the Environmental Protection Agency and a task force to follow the Agency's rulemaking activities. Since the Department will ultimately have to demonstrate compliance with whatever standard is promulgated, we also intend to be very involved in the rulemaking process. We provided our comments on the Committee's report and our recommendations to the Environmental Protection Agency in November 1995. We will follow the rulemaking process closely and comment when appropriate. We believe that the critical policy issues for rulemaking are: 1) the level of risk that is considered acceptable and whether that level of risk should depend on the time frame; 2) the time frame for quantitative compliance assessment and demonstration; 3) the definition of the reference biosphere, including the critical group and exposure scenarios; and 4) how human intrusion will be treated.

Revisiting the Regulatory Basis for Geologic Disposal

Although Congress has directed that repository licensing activities should be deferred, the long-range goal of submitting a successful license application to the Commission remains central to the Program's mission. We believe that the program should include a plan and target date for the submittal of a license application. It is apparent from recent developments, however, that any such plan must recognize the budgetary realities or it will have little possibility of being implemented.

As you may recall, the Program Approach for the Yucca Mountain Project that we adopted in fiscal year 1995 reduced the previously projected cost to submittal of a license application by about $1 billion. That plan, which we were pursuing in fiscal year 1995, still contemplated the expenditure of an additional $3.2 billion on Yucca Mountain from fiscal year 1996 through submittal of the license application in 2001. We are now expecting to spend only about $1 billion through fiscal year 1998.

The implication of these numbers is that, based upon the 1995 program approach, the completion of a license application would entail an additional $2.5 billion of expenditures after 1998, if the cost of extending the schedule is considered. It is clear to me that the Congress will be reluctant to provide those resources, even if the outlook from the viability assessment is promising.

It should be possible to move directly and efficiently from the viability assessment to a license application, if we find that a repository at Yucca Mountain is indeed viable. Our objective should be to design a repository that is compatible with the geologic setting and to develop a safety case to support a proposal to construct that repository. The licensing process should then focus on examining the safety case to determine if public health and safety and the environment are adequately protected.

I believe that it is both possible and necessary to revisit the regulatory basis and the related expectations that have given rise to our earlier work plans. Most of the scientific factors central to those work plans have, or will have, been addressed by 1998. Testing related to long term performance can be done as part of the performance confirmation program during construction and operations, prior to closure of the repository. Much of the cost subsequent to 1998 is expected to be associated with the documentation, presentation, and defense of the results. In my view, that cost can be significantly reduced if the focus of the licensing review is on the safety case we make for a specific repository design and its predicted performance in the geologic setting, rather than on a comprehensive evaluation of all possible aspects of the site.

With a licensing process that concentrates on the adequacy of a specific proposed facility, we can aspire to reestablish a target date for a license application soon after the year 2000 at a sustainable level of funding. I believe this is the only way the program can command the resources needed to retain geologic disposal as a national strategy. We intend to explore this approach and we are considering the revisions to our regulations that would be needed to clarify our intentions. We intend to keep the Congress, our stakeholders and oversight groups, and, of course, the Commission, advised of our evaluation.

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

Advisory Committee on Nuclear Waste

SUBJECT: DOE PERSPECTIVE ON TIME FRAME OF COMPLIANCE

PRESENTER: Dr. Stephan J. Brocoum

PRESENTER'S TITLE AND ORGANIZATION: Assistant Manager for Suitability & Licensing
Yucca Mountain Site Characterization Office

TELEPHONE NUMBER: (702) 794-7971

March 27, 1996

Background

- April 1994: DOE provided recommendations on various issues to NAS
- November 1995: Comments provided to EPA on NAS report, "Technical Bases for Yucca Mountain Standards"
- March 1996: Additional recommendations provided to EPA

Overview of DOE Perspective

- The EPA standard and NRC implementing regulation must be:
  - Understandable
  - Implementable
  - Consistent with other radiation standards and regulations
- Technical assumptions and policy judgments must be clearly specified in the regulations
- The regulations should not require a degree of proof beyond what science can reasonably provide and defend in a licensing environment

Overview of DOE Perspective

(Continued)

- The regulatory framework should not preclude DOE's ability to provide the information needed for NRC to make a reasonable assurance finding
- The longer the compliance time frame, the more difficult it will be to defend such a finding

DOE Position on Compliance Time Frame

(Continued)

- 10,000 years was endorsed by EPA's Science Advisory Board (SAB) in 1984
  - SAB recognized that larger radionuclide releases may occur past 10,000 years
  - However, they recommended that such post 10,000-year estimates be used in comparative analyses for selecting sites

Summary

- Compliance time frame should be limited to no more than 10,000 years
  - Requiring quantitative compliance for periods past 10,000 years could significantly affect the viability of geologic disposal
- Calculations past 10,000 years could be used to gain insight into system performance

UNITED STATES

NUCLEAR WASTE TECHNICAL REVIEW BOARD

SPRING FULL BOARD MEETING

OCRWM Program Planning and Integration

April 30, 1996

Austin, Texas

BOARD MEMBERS PRESENT

Dr. John E. Cantlon, Chairman, NWTRB
Mr. John W. Arendt
Dr. Garry D. Brewer
Dr. Jared L. Cohon, Afternoon Session Chair
Dr. Edward J. Cording
Dr. Donald Langmuir
Dr. John J. McKetta
Dr. Jeffrey J. Wong

CONSULTANTS

Dr. D. Warner North
Dr. Dennis Price
Dr. Robert Williams
Dr. Richard Parizek
Dr. Patrick Domenico
Dr. Ellis D. Verink

SENIOR PROFESSIONAL STAFF

Dr. Sherwood Chu
Dr. Carl Di Bella
Dr. Daniel Fehringer
Mr. Russell McFarland
Dr. Victor Palciauskas
Dr. Daniel Metlay
Dr. Leon Reiter

The exploratory tunnel is a key aspect of the program. We're now over three miles into the mountain. The tunnel itself is not as important as the science that takes place behind the tunnel. It's basically just a conveyance mechanism to allow the science to go on within the mountain. As we anticipated, we are finding many interesting things as the scientists get into the mountain and do experiments in the mountain itself and take samples out from the repository horizon.

An example of that is the Chlorine 36 that you may have heard about. There are indications from some of the samples that some of the Chlorine 36 found down at the repository depth is of fairly recent age, meaning less than 50 years, and Dennis Williams will be talking to you more about that on Wednesday.

Even with that information and other information, we still believe that the results that we're finding within the mountain supports our hypotheses as we continue forward on determining the performance of the mountain.

Rick Craun will be going through and explaining more about the tunnel, but here's just the coming out of the curve at the tunnel. We're also in the process of digging out those. We've now started our sixth alcove. That's the first Ghost Dance Fault alcove. It was started on this Saturday, and Rick will tell you more about that later.

Now, the plans for Yucca Mountain for '97, we expect to complete the tunnel and daylight the tunnel boring machine, winter this sometime. There's some uncertainty on what the ground conditions will be. I think as you probably know, at the south end of the repository horizon, it goes back from Category 1 to Category 4. The last time I knew, we were in Category 1, but it shifts. And coming back up the south ramp, if we encounter some of the soft ground like we did in the north ramp, it may be slower. So there's some uncertainty as to when we will daylight the machine.

It has been a struggle in the reduced funding that we have to keep that machine running all year. The initial plans were last fall, was to shut that machine down in the month of March because of funding, but we have been constantly looking in every nook and cranny for money to shift to the machine to keep that machine running. And it is our current plans to be able to continue running the machine the full three shifts the rest of the year.

The test alcoves are rapidly being constructed. We intend to start the thermal mechanical tests this summer in the heater alcove and the large scale drift testing in '97. The information in preparing the scientific program today will lead to the information that will be available for the viability assessment in September of 1998. This will provide crucial information on the repository performance, the constructability of the repository and the cost to continue the repository program on through licensing and construction and through its closure.

The NEPA activities would resume with a final environmental impact statement in the year 2000, which would accompany the site recommendation on the suitability to the president in 2001. Along that line, we're starting to revise the DOE regs, 10 CFR 960, to focus on the isolation and performance of Yucca Mountain and to delete the aspects in the regulation as they relate to comparison of various sites, because that has not been changed since the amendments of '87.

If the science confirms our hypotheses and if the funding permits and if we have reasonable EPA, NRS regulatory criteria, we could submit a license application to the NRC in March of '02, would be our milestone that we would plan against and track against. And then this would allow emplacement in the year 2010, which is the date that we have had. So we believe that we can compress it back up with a little bit of a stutter step we've had in '96, and still maintain a 2010 waste emplacement in the drifts.

Now, let me shift away from Yucca Mountain to the front end of the program. We have completed fabrication and testing of the half scale advanced technology truck cask. Westinghouse has submitted the design for the multi-purpose canister systems, the large and the small. Those design presentations are going on as we speak back in Vienna. We have submitted burn-up credit topical report to the NRC, and we've been working on the institutional issues of the 180 C funding to the states and to the Indian tribes. So activity continues there.

As I mentioned, the shift to the market-driven approach for waste acceptance is a major activity there. This is a creative innovative approach in concert with the DOE re-engineering activities that the Secretary and Vice-President Gore have directed that we do. This would be a major shift that would place greater reliance upon the marketplace to furnish the necessary management, hardware and transportation services to receive the fuel and transport it to the federal facility. That federal facility could be the repository or it could be an interim storage facility.

We will engage the NRC in pre-licensing discussions to shorten the time period from when a site is specified through the political process, to fuel receipt.

Again, another item that I'm especially proud of as we've searched for money to keep the tunnel boring machine going, we've also been able to free up sufficient funds to start activities for a Topical Safety Analysis Report for a Phase I safety analysis to submit to the NRC. We've started that work this month down at Duke Engineering, with Duke and

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: OVERVIEW OF THE REVISED YUCCA MOUNTAIN PROJECT

PRESENTER: STEPHAN J. BROCOUM

PRESENTER'S TITLE AND ORGANIZATION: ASSISTANT MANAGER FOR SUITABILITY AND LICENSING
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT OFFICE
LAS VEGAS, NEVADA

TELEPHONE NUMBER: (702) 295-9611

AUSTIN, TEXAS
APRIL 30 - MAY 1, 1996

Regulatory Initiatives
(Continued)

- In response, DOE has taken the following actions:
  - Recommendations to the EPA on a revised standard
    - » Clearly define policy and technical considerations
    - » Provide appropriate degrees of conservatism to protect public health and safety
  - Plan to propose changes to 10CFR960 that focus on system performance
  - Planning to discuss with the NRC
    - » Possible changes to 10CFR60
    - » Process of regulatory reviews

DOE Recommendations to EPA

- DOE recommends a site-specific standard
  - Time frame for compliance
    - » 10,000 years
  - Exposure Limit
    - » Risk limit based on 10^{-4} to 10^{-5} fatal cancers per year
    - » Dose limit on the order of 100 mrem/year
  - Define reference biosphere
    - » Critical population based on current characteristics

Potential 10CFR960 Revisions

- Streamline compliance process to focus on aspects most important to protect health and safety at Yucca Mountain
- Focus on system performance guideline approach
  - Postclosure systems guideline
  - Preclosure radiological safety

PRESENTATION TO THE
NUCLEAR WASTE TECHNICAL REVIEW BOARD

STATUS OF THE CIVILIAN RADIOACTIVE WASTE
MANAGEMENT PROGRAM
BY
LAKE H. BARRETT, ACTING DIRECTOR
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
U.S. DEPARTMENT OF ENERGY
OCTOBER 22, 1997

Introduction

Chairman Cohon and Members of the Board:

Thank you for the opportunity to appear here today to provide my perspective on the status of the Civilian Radioactive Waste Management Program and our plans for the coming year. When I spoke to you in June, I discussed the progress we had made in implementing our Revised Program Plan and noted the importance of adequate funding to complete the Viability Assessment and maintain the momentum toward a national decision on geologic disposal.

Current Status

Budget

Congress has completed work on our fiscal year 1998 appropriation. We received $346 million for the Program, which was $34 million less than the President's budget request. The appropriation does not include funds for oversight by the State of Nevada, although $5 million is provided for the local counties. Congress stipulated that $12 million of the budget reduction be taken from science activities at Yucca Mountain and $16 million be taken from program management, cooperative agreements, and other programs not directly associated with site characterization and interim storage activities. The remaining $6 million is a $2 million reduction left to the discretion of the Program and the $4 million for U.S. Nuclear Regulatory Commission's
(NRC) certification of multi-purpose canister designs that was line item vetoed by President Clinton last Friday.

The reductions in our 1998 budget affect ongoing and proposed scientific work related to the Viability Assessment at Yucca Mountain. These reductions are causing some delays in the schedule for collection of the scientific data from several areas including the East-West drift. We have been able, however, to sustain construction and basic construction science for the East-West drift. The program direction cut affecting contractual services has adversely impacted

Additionally, the Program recently submitted to the Commission a Topical Report on Burn-up Credit for Actinide Elements. We hope to have feedback on the report from Commission staff by the middle of next year.

Plans for 1998

This year will be a particularly important one for the Program as we complete the Viability Assessment of Yucca Mountain as directed by the President and Congress. Susan Jones, the Acting Deputy Project Manager for the Yucca Mountain Site Characterization Project, will discuss the Project activities supporting the completion of the Viability Assessment following my talk. I intend to use my time on the agenda to provide you my perspective on the strategic significance of this milestone.

One of the foremost challenges in a complex, first-of-a-kind endeavor is to converge on a working concept and to define the additional information required to implement that concept. The Viability Assessment is a management tool that accomplishes this for the geologic disposal program. Its completion will culminate a three-year effort by the Program to assemble the information collected during site characterization into a workable repository concept for Yucca Mountain and to focus the Program on the key remaining technical issues. The Program has shared its plans for completing the Viability Assessment with the Board and other interested parties over the last year. Much of the attention has been appropriately focused on the design, performance assessment, and supporting science activities. We recognize that the products associated with these efforts will not be sufficient for licensing. Their completion, however, will help integrate the ongoing activities and help guide the completion of site characterization by identifying those areas where additional scientific or technical work is required to evaluate the site or prepare a complete, defensible license application.

We have previously noted that the completion of the Viability Assessment will give all parties a clearer understanding of the information gained from site investigations and the remaining work required to support national decisions on geologic disposal at Yucca Mountain. The license application plan will describe this work and provide an estimate of its cost. This plan will identify the work that the Program believes is necessary to complete the site recommendation process and prepare a license application within the cost and schedule constraints imposed by an ever-tightening Federal budgetary situation. General agreement between the Program and its overseers and regulators on this remaining work is central to the continuation of the geologic disposal program. We would appreciate the Board's views on this effort to ensure that we have identified tests and activities that are appropriate for the task at hand and that can be conducted within the constraints on the Program.

Regulatory Standards

Yesterday, this Board held a panel meeting regarding the performance standards for a repository at Yucca Mountain. The regulatory standards for a geologic repository have been the subject of much debate since the Program's inception. It would be timely for the Board to examine the issues associated with the standard and provide its views and insights. I would like to provide a few thoughts on those regulatory standards from my perspective.

Our Revised Program Plan recognized the need to update the regulatory framework for the repository to reflect the policy changes since the enactment of the Nuclear Waste Policy Act, the realities of the budget constraints on the Program, and, in particular, the understanding gained in more than 15 years of site investigations. We have considered these factors in the proposed amendments to our siting guidelines. It is similarly important that these factors be considered by the Environmental Protection Agency and the Nuclear Regulatory Commission, respectively, in developing radiation protection standards and revising the licensing criteria for a repository at Yucca Mountain.

The Department believes that the regulatory framework for the repository should focus on issues central to protecting public health and safety, and be implementable in a contentious licensing environment. That is, demonstrating compliance with the standard should not require a degree of proof that is beyond what science and engineering can reasonably provide. The National Academy of Sciences' report and subsequent discussions regarding the Yucca Mountain Standard indicate that the level of protection provided by the repository standard should be commensurate with existing facilities. We certainly agree that the future generations should be afforded the same protection as current populations. This standard, however, will be applied to estimates of repository performance thousands of years in the future, which involve an unprecedented level of uncertainty. Much of this uncertainty is irreducible within the bounds of a rational site characterization program and approach to design. Consequently, the regulations associated with repository development must maintain a degree of flexibility to accommodate the inherent uncertainty in the results of site characterization and performance assessment. The Board's views regarding the acceptability of this residual uncertainty will be significant to the rulemaking process and to the subsequent national decisions on geologic disposal.

Yesterday's discussions addressed the biosphere assumptions that the Department will use to evaluate repository performance. Many of the key issues associated with the repository standard relate to these biosphere assumptions that provide the context in which to evaluate repository performance. Since the future behavior of society cannot be predicted with scientific certainty, these assumptions are ultimately policy decisions. We agree with the view expressed by the National Academy of Sciences in its report that these assumptions should be defined in the rulemaking process. We must be careful to define reasonable assumptions because they are central to the implementability of the standard. We believe that the biosphere assumptions should be based on the current conditions surrounding Yucca Mountain and not speculation about future populations or other regulatory precedents. It is incumbent upon all knowledgeable participants in this process to ensure that the regulatory framework for the repository provides a reasonable basis to assess whether a Yucca Mountain repository will adequately protect public health and safety and is not constructed so as to defeat the Nation's policy of geologic disposal.

Conclusion

The Program is continuing to implement its Revised Program Plan and looks forward to completing the Viability Assessment this fiscal year. This milestone is important to the Nation's geologic disposal program and will represent the culmination of a significant effort by all Program participants. We intend that this assessment will provide an unbiased, technically sound analysis of a Yucca Mountain repository. We look forward to the Board's review of this effort.

Thank you for the opportunity to brief the Board today and I would be happy to answer any questions you may have.

INF

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JOINT CONVENTION ON THE SAFETY OF SPENT FUEL MANAGEMENT AND ON THE SAFETY OF RADIOACTIVE WASTE MANAGEMENT

1. The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management was adopted on 5 September 1997 by a Diplomatic Conference convened by the International Atomic Energy Agency at its headquarters from 1 to 5 September 1997. The Joint Convention was opened for signature at Vienna on 29 September 1997 during the forty-first session of the General Conference of the International Atomic Energy Agency and will remain open for signature until its entry into force.

2. Pursuant to article 40, the Joint Convention will enter into force on the ninetieth day after the date of deposit with the Depositary of the twenty-fifth instrument of ratification, acceptance or approval, including the instruments of fifteen States each having an operational nuclear power plant.

3. The text of the Convention, as adopted, is attached hereto for the information of Member States.

CHAPTER 1. OBJECTIVES, DEFINITIONS AND SCOPE OF APPLICATION

ARTICLE 1. OBJECTIVES

The objectives of this Convention are:

(i) to achieve and maintain a high level of safety worldwide in spent fuel and radioactive waste management, through the enhancement of national measures and international co-operation, including where appropriate, safety-related technical co-operation;

(ii) to ensure that during all stages of spent fuel and radioactive waste management there are effective defenses against potential hazards so that individuals, society and the environment are protected from harmful effects of ionizing radiation, now and in the future, in such a way that the needs and aspirations of the present generation are met without compromising the ability of future generations to meet their needs and aspirations;

(iii) to prevent accidents with radiological consequences and to mitigate their consequences should they occur during any stage of spent fuel or radioactive waste management.

ARTICLE 2. DEFINITIONS

For the purposes of this Convention:

(a) *"closure"* means the completion of all operations at some time after the emplacement of spent fuel or radioactive waste in a disposal facility. This includes the final engineering or other work required to bring the facility to a condition that will be safe in the long term;

CHAPTER 2 SAFETY OF SPENT FUEL MANAGEMENT

ARTICLE 4. GENERAL SAFETY REQUIREMENTS

Each Contracting Party shall take the appropriate steps to ensure that at all stages of spent fuel management, individuals, society and the environment are adequately protected against radiological hazards.

In so doing, each Contracting Party shall take the appropriate steps to:

(i) ensure that criticality and removal of residual heat generated during spent fuel management are adequately addressed;

(ii) ensure that the generation of radioactive waste associated with spent fuel management is kept to the minimum practicable, consistent with the type of fuel cycle policy adopted;

(iii) take into account interdependencies among the different steps in spent fuel management;

(iv) provide for effective protection of individuals, society and the environment, by applying at the national level suitable protective methods as approved by the regulatory body, in the framework of its national legislation which has due regard to internationally endorsed criteria and standards;

(v) take into account the biological, chemical and other hazards that may be associated with spent fuel management;

(vi) strive to avoid actions that impose reasonably predictable impacts on future generations greater than those permitted for the current generation;

(vii) aim to avoid imposing undue burdens on future generations.

ENVIRONMENTAL RADIATION PROTECTION STANDARDS FOR YUCCA MOUNTAIN: CONSIDERATIONS ON ISSUES

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202-564-9198

for Waste Management '98 Tucson, Arizona March 1998

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ABSTRACT

The Energy Policy Act of 1992 (EnPA) directed the Environmental Protection Agency (EPA) "to set generally applicable standards for the Yucca Mountain site...for protection of the public from releases from radioactive materials stored or disposed of in the repository at the Yucca Mountain site." It also directed EPA to contract with the National Academy of Sciences (NAS) to "conduct a study to provide [to EPA]...findings and recommendations on reasonable standards for protection of the public health and safety...." Upon receipt of the NAS Report, the Agency immediately began preparation of the proposed standards. This included holding public meetings, establishing official dockets and an information file in Washington, DC and Nevada; and meetings with many stakeholders including Federal agencies, the State of Nevada (Governor's office and legislature), Nevada counties, and industry, environmental, and public interest groups. Comments have been compiled and are being considered as the Agency proceeds. As a result of this process, there are several major issues which are being investigated and considered. These issues are critical group, form of the standard, level of protection, reference biosphere, negligible incremental risk, time frame, human intrusion, assurance requirements, and protection of ground water. This paper discusses some of the factors which the Agency has considered in formulating the standards for Yucca Mountain relative to these issues and updates the status of the rulemaking.

INTRODUCTION

As a result of the Energy Policy Act of 1992 (EnPA) (1), the Agency has requested and received technical recommendations from the National Academy of Sciences (NAS) regarding the establishment of environmental radiation protection standards for Yucca Mountain, Nevada (the NAS Report) (2). Since receiving those recommendations, the Environmental Protection Agency (EPA) has been preparing the standards. This preparation has included holding public meetings, establishing official dockets and an information file in Washington, DC and Nevada; and conducting meetings with many stakeholders including Federal agencies, the State of Nevada (Governor's office and legislature), Nevada counties, and industry, environmental, and public interest groups. This process has resulted in a number of issues which have been central in the Agency's deliberations. The major issues are critical group, form of the standard, level of protection, reference biosphere, negligible incremental risk, compliance period, human intrusion, assurance requirements, and protection of ground water. The following sections will describe many of the factors which the Agency has considered in formulating the standards. All issues have included consideration of comments received from all parties throughout the process even though all parties are not necessarily noted in all sections. Further, this is not intended to be an exhaustive listing of all factors under consideration but rather it is an attempt to discuss the general factors which have been involved in the Agency's process of addressing these issues. As of this writing, no final decisions have been made regarding these issues and, therefore, the discussions should not be interpreted to be a final decision or the Agency's final position simply because of the contents or lack thereof.

CRITICAL GROUP

The NAS recommended protecting individuals and to do so by using the critical-group approach (2). The critical-group approach involves the assessment of the dose received by the exposed population and then determining which subset of that population would be most exposed, i.e., the critical group. The individual doses received within the critical group would then be averaged in a prescribed manner and the average dose would be compared with the regulatory limit to determine compliance. In previous Federal radiation-related standards and regulations, the critical-group approach has not been used. This is also true within EPA for any type of standard or regulation be it for radioactive or chemically hazardous pollutants. Therefore, the Agency has examined use of this concept and has discussed it in the context of its policy implications. There are other approaches which have been used, for example, protection of the most exposed individual in the general population and the adoption of an approach which has been used in regulating some chemical hazards, i.e., a reasonably maximally exposed individual. Under the most-exposed-individual approach, a person would be a hypothetical individual who would be assumed to have characteristics and be in circumstances which would result in that individual receiving more dose than any other member of the general population. Historically, this has been the most common form of radiation standards and regulations. This approach has the advantage of protecting all individuals in a population to a set level. However, it has been criticized frequently as resulting in projected doses than would not occur in reality and, therefore, resulting in unnecessary protective measures. The regulatory scheme used in some of EPA's chemically related regulations uses a projected individual dose which is intended to be representative of the highest of all doses received by the general population but to allow use of less than the absolutely highest values of the parameters used to estimate doses. In other words, most of the parameters would be held to their highest values but some of them could be reduced a reasonable amount. The purpose of this approach is to arrive at a dose which would be the highest for at least 95% of the population but would not be the absolutely, highest theoretical dose, i.e, it is a dose which could reasonably be expected to be the highest in the population. This approach has the attractiveness of attempting to be cautiously realistic but could, theoretically, result in some doses being above the regulatory limit. Another factor is the lifestyle of the group or individual. The NAS suggested two starting points (2). One was a statistically generated group which would take into account a spectrum of lifestyles, e.g., from people who eat, drink, and live only in the contaminated area to those who only live in the contaminated area but there food and water are from non-contaminated areas. The other NAS suggestion was the use of a so-called "subsistence farmer" who would only use water from the contaminated area for both domestic and farming uses and eats only food grown using contaminated water. There have also been suggestions that there are possibilities of assuming an individual or group that lives in the area and raises some of its own food and drinks from the aquifer but also "imports" food and fluids from other sources. The Agency has studied a number of possibilities within the bounds of these suggestions.

FORM OF THE STANDARD

There are two basic choices being considered as a result of the EnPA and the NAS Report, i.e., dose and risk limits (1, 2). The choices are brought about simply because in section 801 of the EnPA is the direction that EPA's standards "shall prescribe the maximum annual effective dose equivalent to individual members of the public...." while in the NAS Report is the recommendation that the standard for the protection of individuals be stated in terms of the risk of developing a fatal cancer. A difficulty has arisen out of an inconsistency which is because of another provision in the EnPA and an action of NAS. In section 801, is a phrase which states that the EPA standards shall be "based upon and consistent with the findings and recommendations of the National Academy of Sciences...." (1) Therefore, the Agency is faced with Congressional guidance to set a standard in terms of dose and to be consistent with the recommendations of the NAS. However, the NAS has recommended setting a standard stated in terms of risk (2). Technically, dose and risk can be interchanged with approximate parity. However, these conflicting requirements have been a source of legal and policy discussion.

LEVEL OF PROTECTION

The NAS stated that the level of protection is a matter of public policy which should be reached through a public rulemaking conducted by EPA. However, the NAS recommended a starting point for their risk recommendation, 10-5to 10-6/yr (i.e., an annual risk of one in 100,000 to one in 1,000,000) of developing a fatal cancer (2). The Agency estimates this risk range to correspond with an annual dose range of 200 to 20 microsieverts (μSv). The NAS pointed out that this level is consistent with existing levels which have been set by radiation regulatory authorities both inside and outside the United States (2). For example, EPA's generic standards for the disposal of spent nuclear fuel, high-level and transuranic radioactive wastes limits doses incurred by individuals to 15 μSv per year (3). Some groups have commented that an annual dose of 1 mSv is considered to be safe by national and international authorities, including EPA. However, the Agency has proposed that dose as an acceptable level for members of the public exposed from all sources except background and medical exposures (4). The EPA, and international guidance, then requires that this overall dose be apportioned among actual and currently known potential sources and future exposures. In the vicinity of Yucca Mountain are several potential sources of exposure for a critical group, for example, the waste disposal site in Area 5 and the weapons testing areas on the Nevada Test Site, the commercial low-level radioactive waste disposal site near Beatty, Nevada, and a potential interim storage site for spent nuclear fuel.

REFERENCE BIOSPHERE

In the preamble to 40 CFR Part 191 (3), the Agency stated that, on a generic basis, it considered it more important to center analyses of a disposal system's performance on factors such as geology, hydrology, and general climate change. The nearly infinite ways in which people, technology, and society could change over very long periods lead to such speculative gambits that it is not possible to reasonably model those changes. The NAS stated that there was no scientific basis for estimating such changes and suggested using a fixed, or reference, biosphere (2). However, the Agency is also aware that other countries have examined a number of possible future biospheres which are then postulated in considering future performance of a disposal system.

NEGLIGIBLE INCREMENTAL RISK

The NAS adapted the National Council on Radiation Protection's (NCRP) concept of "negligible incremental dose" to their suggestion of using a risk-type limit to arrive at the concept of "negligible incremental risk." The NAS stated, "The negligible individual dose is defined as a level of effective dose that can, for radiation protection purposes, be dismissed from consideration." (2) The public comment period brought strong reaction from most commenters who were not in favor of this being used for the Yucca Mountain standards. Much of the reason that such a concept arises is that there is debate in the scientific community about how much small increments of radiation exposure above the natural background can change the risk of causing adverse effects in people. The current position of the Agency is that it is prudent to assume that any amount of radiation carries a risk of causing an effect. The word "prudent" is used since there is no direct, epidemiological data which can conclusively show what, if any, effect there is at low doses, i.e., at levels similar to background doses and dose rates but in addition to background exposures. It is possible that there is a level below which no effects occur or there could be greater than a linearly proportionate effect occurs since the current estimates are based upon extrapolation of effects seen at much higher doses. That is why EPA has, in the past, assumed a linearly proportionate risk from any size of radiation exposure. The Agency is examining the NAS recommendation, the public reaction, and its previous position in determining its proposed position for this issue relative to this rulemaking.

COMPLIANCE PERIOD

The compliance period is the time set forth in the standards for which performance of the disposal system must meet the standards. The recommendation from the NAS has caused much discussion both within and outside the Agency. The NAS found no scientific basis, based upon geology, that the time frame needed to be less than the period during which the geology would be stable in and around the Yucca Mountain site; the finding was that such stability is on the order of one million years (2). With the exception of standards in which no compliance period is stipulated, this is by far the longest compliance period which has been suggested in the United States for the disposal of radioactive waste. In 1985, the Agency stipulated that the generic compliance period be 10,000 years which was criticized in most quarters as being too long (2). Since that time, this period has become generally accepted in similar programs where long-term performance is a concern. Of course, there was also concern that 10,000 years was not long enough since the waste would still be "hazardous." On the other hand, some chemical waste disposal regulations specify periods as short as 30 years. Therefore, the Agency is faced with a spectrum of potential compliance periods. A central concern has been the capability of current science and technology to be able to project performance within uncertainty bounds which will result in meaningful estimates for decisionmakers. Thus, the Agency is examining such capabilities and the inherent uncertainties in reaching what it considers to be an appropriate compliance period.

HUMAN INTRUSION

The NAS recommended that human intrusion not be included in the same performance standard in which all other types of disruption to the repository are analyzed (2). In its generic 40 CFR Part 191 standards, human intrusion was included in its probabilistic risk assessment (3). The NAS believed that there was no scientific justification to hypothesize human behavior by trying to project how many and what type of intrusion would or could occur during the performance period. Rather, the NAS suggested that, for Yucca Mountain, the Agency assume that a drilling-type intrusion will occur and to specify the scenario under which it occurs. Further, no effects should be calculated to the drillers or to the public as a result of waste brought to the surface (2). In the past, EPA has not attempted to protect the drillers because the Agency believes that the purpose of deep geologic disposal is to contain the waste in a limited area for as long as reasonably possible (3). To assume otherwise, would invoke an impossible situation where containment and dispersion of the waste were simultaneous goals.

ASSURANCE REQUIREMENTS

In addition to quantitative limits, the Agency has considered including several qualitative principles called assurance requirements. Such requirements would be intended to compensate for the uncertainties inherent in projecting the effects of releases from radioactive waste over long periods and, therefore, to add confidence that the disposal system would be able to achieve the level of protection established in the quantitative standards. Assurance requirements were included in 40 CFR Part 191. They dealt with use of active and passive institutional controls, monitoring, use of multiple barriers, the ability to locate and remove the waste after it is disposed, and consideration of the presence of natural resources (3). In discussing the need for such requirements for Yucca Mountain, the Agency has considered whether there are site-specific conditions which would make them unnecessary or if those conditions might require the use of assurance requirements that are considerably different than the generic requirements. The NAS recognized the need for protection beyond that inherent in the disposal system when it addressed institutional controls in its report and the public generally supported the use of such requirements (2). However, another consideration is that the increase of protection, or benefits, brought by assurance requirements cannot be precisely quantified.

PROTECTION OF GROUND WATER

In its report, the NAS recognized that 40 CFR part 191 addressed ground-water protection separately from individual-dose protection even though both use an individual-dose limit (3). Also, the NAS identified the ground-water pathway as an important pathway for defining who was to be protected by an individual-protection standard (3). However, the NAS provided no recommendation for including or excluding separate ground-water protection requirements Ground water is a valuable resource with many potential uses. In 40 CFR Part 191, the ground-water protection standards protected ground water that is used as drinking water by restricting contamination to the maximum contaminant levels (MCLs) which have been established under the authority of the Safe Drinking Water Act. In addition to drinking, ground water may be a source of radiation exposure when used for irrigation, stock watering, food preparation, showering, or when incorporated into various industrial processes. In addition, ground-water contamination is of concern to EPA because of potential adverse impacts upon ecosystems, particularly sensitive or endangered ecosystems. However, the primary purpose of such standards is to prevent contamination of drinking-water resources. This prevents the need to decontaminate that water in the future which, if not done, would place the burden on future generations to implement expensive clean-up or treatment procedures. Therefore, it is prudent to protect drinking water from contamination through prevention rather than rely upon treatment. Another possibility is that the disposal system itself could become subject to clean-up by future generations.

STATUS OF THE RULEMAKING

The Agency is evaluating and discussing issues. Efforts are continuing to gather and analyze information on the disposal system and the environment outside the Yucca Mountain site. The proposed standards will be sent to the Office of Management and Budget (OMB) for review prior to proposal. Following release from OMB, there will be a public-comment period and hearings. It is planned to propose the standards in mid-1998. Final standards and support documents will be issued as soon as possible thereafter.

REFERENCES

1. Energy Policy Act of 1992, Public Law 102-486, 106 Stat. 2921.

2. Technical Bases for Yucca Mountain Standards, National Research Council, National Academy Press, Washington, DC, 1995.

3. Part 191 of Title 40 of the Code of Federal Regulations, Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste.

4. Proposed Federal Radiation Protection Guidance for Exposure of the General Public, Federal Register, Vol. 59, No. 246, December 23, 1994.

Background Information Document

Yucca Mountain Standards

Below is a list of the major segments of the *Public Health and Enviornmental Radiation Protection Standards for Yucca Mountain, NV: Background Information Document for 40 CFR Part 197* [EPA 402-R-01-004], which are linked to the text. All sections of the BID are presented in portable document format (pdf)[about pdf format].

Appendices

* Please note that Figure 7-27, Potentiometric Surface in the Amargosa Desert, in this version, is a slightly different format that the one appearing in the BID placed in the docket. has been replaced with an equivalent version that is more easily viewed on the Web and reproduced in printed copies.

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EXECUTIVE SUMMARY

ES.1 INTRODUCTION AND BACKGROUND

The U.S. Environmental Protection Agency (EPA) is responsible for developing and issuing environmental standards and criteria to ensure that public health and the environment are adequately protected from potential radiation impacts from waste stored or disposed in Yucca Mountain, Nevada. The Yucca Mountain site is located in Nye County, approximately 150 kilometers (90 miles) northwest of Las Vegas, Nevada, and on the southwestern boundary of the Nevada Test Site. Yucca Mountain is an irregularly shaped elevated land mass six to 10 km wide (four to six miles) and about 40 km (25 miles) long. A waste repository would be about 300 meters (one thousand feet) below the crest of Yucca Mountain and about the same distance above the water table under the mountain.

The EPA is promulgating, in 40 CFR Part 197, site-specific environmental standards to protect the public from releases of radioactive materials disposed of or stored in the potential repository to be constructed at Yucca Mountain.[1] These standards provide the basic framework to control the long-term storage and disposal of three types of radioactive waste:

- Spent nuclear fuel (SNF), if disposed of without reprocessing
- High-level radioactive waste (HLW) from the reprocessing of spent nuclear fuel
- Other radioactive materials that may be placed in the potential repository

The other radioactive materials that could be disposed of in the Yucca Mountain repository include highly radioactive low-level waste, known as greater-than-Class-C waste, and excess plutonium resulting from the dismantlement of nuclear weapons. However, the plans for placement of these materials are uncertain and therefore, for the purpose of the present rulemaking, the information presented in this Background Information Document (BID) is limited to spent nuclear fuel and high-level radioactive waste.

[1] It is important to note that no decision has been made regarding the acceptability of Yucca Mountain for storage or disposal. However, for the purposes of this document, the description of Yucca Mountain as "potential" will generally not be used but is intended.

ES.1.1 Purpose And Scope of The Background Information Document

The BID presents the technical information used by EPA to understand the characteristics of the Yucca Mountain site and to develop its rule, 40 CFR Part 197. Most of the technical information discussed in the BID is derived from investigations sponsored by the Department of Energy (DOE). However, where appropriate, information from other sources, such as the Electric Power Research Institute (EPRI) and U.S. Nuclear Regulatory Commission (NRC), and Nevada state and local agencies is presented to supplement the DOE data base, to fill data gaps, and to illustrate alternative conceptualizations of geologic processes and engineered barrier performance.

The scope of the BID encompasses the conceptual framework employed by the Agency for assessing radiation exposures and associated health risks. In general terms, this assessment discusses the radioactive source term characterization, movement of radionuclides from the repository at Yucca Mountain through the appropriate environmental exposure pathways, and the estimates of potential doses to members of a representative group of people living in the region around the repository site. It is not intended to be a technical critique of the investigations conducted by DOE and other parties. Nor is it a regulatory compliance or criteria document. The BID is simply a summary of the technical information considered by EPA in developing the rationale for, and specifics in, 40 CFR Part 197.

This executive summary highlights key chapters of the BID, particularly information concerning efforts in other nations to develop deep geological repositories (Chapter 3); current efforts to develop a repository at Yucca Mountain (Chapter 4); the types and inventories of waste likely to be disposed in Yucca Mountain (Chapter 5); geologic and hydrogeologic characteristics of the repository site and anticipated repository performance (Chapter 7); and pathways for human exposure to radionuclides potentially released from the site (Chapter 8). The reader is referred to the full text of the BID for information regarding ways in which radiological dose and risk are estimated (Chapter 6); potential exposure scenarios and compliance assessment issues for the Yucca Mountain repository (Chapter 9); and the comparative radiological risks associated with deep geological disposal and surface storage of spent nuclear fuel (Chapter 10).

ES.1.2 EPA's Regulatory Authority For The Rulemaking

The standards governing environmental releases from the potential Yucca Mountain repository have been developed pursuant to the Agency's responsibilities under the Energy Policy Act (EnPA) of 1992 (Public Law 102-486). Section 801 of this Act directed EPA to promulgate standards to ensure protection of public health from releases of radioactive material in a deep geologic repository to be built in Yucca Mountain by setting standards to protect individual members of the public. The EnPA also required EPA to contract with the National Academy of Sciences (NAS) to advise the Agency on the technical bases for the Yucca Mountain standards. The EnPA directed that these standards will apply only to the Yucca Mountain site and are to be based upon and consistent with the findings and recommendations of the NAS:

- *...the Administrator shall, based upon and consistent with the findings and recommendations of the National Academy of Sciences, promulgate, by rule, public health and safety standards for protection of the public from releases from radioactive materials stored or disposed of in the repository at the Yucca Mountain site. Such standards shall prescribe the maximum annual effective dose equivalent to individual members of the public from releases to the accessible environment from radioactive materials stored or disposed of in the repository.*

ES.1.3 The National Academy of Sciences Recommendations

In the EnPA, the Congress asked the Academy to address three issues in particular:

- *Whether a health-based standard based upon doses to individual members of the public from releases to the accessible environment will provide a reasonable standard for protection of the health and safety of the general public;*

- *Whether it is reasonable to assume that a system for post-closure oversight of the repository can be developed, based upon active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered or geologic barriers or increasing exposure of individual members of the public to radiation beyond allowable limits; and*

- *Whether it will be possible to make scientifically supportable predictions of the probability that the repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years.*

To address these questions, the Academy assembled a committee of 15 persons representing a range of scientific expertise and perspectives. The committee conducted a series of five technical meetings at which more than 50 nationally and internationally known scientists and engineers were invited to participate. In addition, the committee received information from the NRC, DOE, EPA, Nevada State and county agencies, and private organizations, such as the Electric Power Research Institute.

The committee's conclusions and recommendations are contained in its final report, entitled *Technical Bases for Yucca Mountain Standards*, which was issued on August 1, 1995. In this report, the committee addressed the key issues posed by Congress and reached the following conclusions:

- *...an individual-risk standard would protect public health, given the particular characteristics of the site, provided that policy makers and the public are prepared to accept that very low radiation doses pose a negligibly small risk.*

- *...it is not reasonable to assume that a system for post-closure oversight of the repository can be developed, based on active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered barriers or increasing the exposure of individual members of the public to radiation beyond allowable limits.*

- *...it is not possible to make scientifically supportable predictions of the probability that a repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years.*

In addition, the report offered the Agency several general recommendations as to the approach EPA should take in developing 40 CFR Part 197. Specifically, the NAS recommended:

- *...the use of a standard that sets a limit on the risk to individuals of adverse health effects from releases from the repository.*

- *...that compliance with the standard be measured at the time of peak risk, whenever it occurs. (Within the limits imposed by the long-term stability of the geologic environment, which is on the order of one million years.)*

- *...that the consequences of an intrusion be calculated to assess the resilience of the repository to intrusion.*

The EPA does not believe it is bound to adopt all of the positions advanced by the NAS in the Yucca Mountain rulemaking. The Agency has used the NAS report as the foundational starting point for the rulemaking. The Agency has carefully considered the recommendations of the NAS, but the role of the NAS recommendations is not to replace the rulemaking authority of the

Agency. The Agency will tend to accord greatest deference to the judgements of NAS about issues having a strong scientific component, the area where NAS has its greatest expertise. The EPA will reach final determinations that are congruent with the NAS analysis whenever it can do so without departing from the Congressional delegation of authority to promulgate, by rule, health and safety standards for protection of the public. The Agency believes that such determinations require the consideration of public comments and the Agency's own expertise and discretion.

ES.1.4 Prior Agency Action

In December 1976, EPA announced its intent to develop environmental radiation protection criteria for radioactive waste to ensure the protection of public health and the general environment. These efforts resulted in a series of radioactive waste disposal workshops, held in 1977 and 1978. Based on issues raised during workshop deliberations, EPA published a *Federal Register* notice on November 15, 1978 of intent to propose criteria for radioactive wastes and to solicit public comments on possible recommendations for Federal Radiation Guidance. In March 1981, EPA withdrew the proposed "Criteria for Radioactive Wastes" because it considered the implementation of generic disposal guidance too complex given the many different types of radioactive waste.

In 1982, Congress enacted the Nuclear Waste Policy Act (NWPA), which established the current national program for the disposal of SNF and HLW. The Act assigned to DOE the responsibility of siting, building, and operating an underground geologic repository for the disposal of these wastes and directed the EPA to "promulgate generally applicable standards for the protection of the general environment from off-site releases from radioactive material in repositories." In that same year, under the authority of the Atomic Energy Act (AEA), the EPA proposed a set of standards under 40 CFR Part 191, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." After a number of public hearings and comment periods, the EPA issued the final rule under 40 CFR Part 191 on August 15, 1985. Sections of this rulemaking were remanded by a Federal Court in 1987 and repromulgated by EPA in 1993.

In December 1987, Congress enacted the Nuclear Waste Policy Amendments Act (NWPAA). The 1987 Amendments Act redirected the nation's nuclear waste program to evaluate the suitability of the Yucca Mountain site as the location for the first SNF and HLW repository. Activities at all other potential sites were to be phased out.

In October 1992, the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA) was enacted. While reinstating certain sections of the Agency's 1985 disposal standards, the Act had the effect of exempting the Yucca Mountain site from these generic disposal standards. However, also in October 1992, the EnPA directed the EPA to promulgate site-specific radiation protection standards for the Yucca Mountain disposal system.

ES.2 CURRENT U.S. PROGRAMS FOR YUCCA MOUNTAIN

The DOE, NRC, and EPA each have legislatively defined roles in the management and disposal of SNF and HLW at the proposed Yucca Mountain disposal site. As stated in the NWPA, DOE is responsible for developing, constructing, and operating repositories for disposal of these wastes. The NRC has responsibility to license the repository and related facilities, and EPA is to promulgate radiation protection standards which the NRC is to adopt as the basis for its licensing actions. Affected state and local governments and Native American tribes have an oversight role in the program. The NWPAA designated the Yucca Mountain site in Nevada as the only site to be evaluated by DOE as a potential location for disposal of SNF and HLW, and established the Nuclear Waste Technical Review Board (NWTRB) to provide oversight of the DOE program.

ES.2.1 The Department of Energy

The DOE's Office of Civilian Radioactive Waste Management (OCRWM) was established by Congress in the NWPA specifically to provide management for the disposal of SNF from commercial nuclear power reactors. Under a 1985 Presidential Executive Order, the repository established by DOE is also to be used for disposal of HLW from DOE operations. The OCRWM charter includes responsibility for receipt of SNF from reactors at the reactor sites; interim storage of received SNF, as necessary, prior to disposal; transport of SNF to the site(s) for interim storage and disposal; and siting, design, licensing, and operation of a central interim storage facility and disposal facilities. In addition to its work at Yucca Mountain, DOE has developed alternative designs for a central interim storage facility (known historically as a Monitored Retrievable Storage (MRS) facility), but, as of March 2000, the Department has not established a site for such a facility.

In accord with the NWPAA, DOE has been evaluating Yucca Mountain as the disposal site for SNF and HLW. Characterization of the site is proceeding with surface-based and sub-surface activities. Design concepts for the engineered features of the repository are being developed. Recent DOE activities produced the Viability Assessment (VA) report, which is a Congressionally mandated appraisal of the viability of the Yucca Mountain project for geologic disposal of nuclear wastes. The VA report contains:

- A site description and a design for engineered features of the repository and waste package
- A Total System Performance Assessment, based on available data, describing the probable safety performance of the VA reference design (TSPA-VA)
- A plan and cost estimate for completing the license application (LA) to NRC for repository construction
- Cost estimates for constructing and operating the repository

The VA report was published in December 1998. It was followed by a draft environmental impact statement (DEIS) in 1999 and a final EIS is planned for late in 2000. The site-suitability recommendation, required by the NWPA, is planned to be submitted to the President in 2001 and a License Application (LA) would be submitted to NRC in 2002 if the site is found suitable for disposal. Significant recent accomplishments of the DOE program include:

- Completion of the Exploratory Studies Facility (ESF) and Cross Drift tunnels for gathering experimental data at the proposed repository horizon
- Initiation of various types of experiments in the tunnel alcoves and niches
- Completion of the Viability Assessment in December 1998
- Issuance of the DEIS in August 1999
- Selection of an improved repository design, EDA II, based on TSPA-VA results

ES.2.2 The Nuclear Regulatory Commission

The NRC is responsible for licensing and regulating the receipt and possession of SNF and HLW, at privately owned facilities and at certain facilities managed by DOE. This licensing responsibility includes the waste management and disposal facilities at Yucca Mountain. The NRC currently licenses temporary storage facilities at reactor sites, as well as commercial storage facilities at West Valley, New York, and Morris, Illinois.

NRC licensing of a repository at Yucca Mountain will be accomplished through review of a License Application (LA) submitted by DOE after completion of site approval procedures set forth in the NWPA. If the LA is found acceptable for review, NRC would review it to determine if there is reasonable assurance of compliance with regulatory standards. If expectation of compliance is established, DOE will be authorized to construct the repository. Subsequently, the LA will be amended to seek approval to receive and emplace wastes for disposal. Confirmatory testing is expected to continue throughout construction and disposal operations. After disposal is completed (a process expected to span about 50 years), the LA would be amended to request closure of the repository. After closure is authorized, post-closure monitoring would be expected to be required.

The NWPA requires both EPA and NRC to publish radiation-protection standards and regulations, for the storage and disposal of HLW. As previously noted, the EnPA directed the EPA to develop radiation protection standards for the Yucca Mountain site and for the NRC to develop implementing regulations that conform to the EPA's Yucca Mountain standards. The NRC's proposed (February 1999) 10 CFR Part 63 regulations require use of multiple barriers (natural and engineered) to achive compliance with regulatory standards, and implement the Commission's principles of defense-in-depth and risk-informed regulation. The proposed rule addresses licensing procedures, radiation exposure standards, criteria for public participation, records and reporting, monitoring and testing programs, performance confirmation, quality assurance, personnel training and certification, and emergency planning.

The NRC's proposed 10 CFR Part 63 regulations would be modified as necessary to conform to EPA's 40 CFR Part 197 standards after they are established.

ES.2.3 Nuclear Waste Technical Review Board

The NWPAA established the Nuclear Waste Technical Review Board comprised of eleven members recommended by the NAS and appointed by the President. These individuals are experts in the fields of science, engineering, or environmental sciences and represent a broad range of scientific and engineering disciplines, including hydrology, underground construction, hydrogeology, and physical metallurgy. No member of the Board may be employed by DOE, its contractors, or the National Laboratories. The current Board is composed of individuals with academic and public and private sector experience. The Board's mandate is to evaluate the technical and scientific validity of activities undertaken by DOE, regarding various aspects of the U.S. SNF and HLW management. For example, the NWTRB provided comments in April 1999 on DOE's Viability Assessment in a report entitled *Moving Beyond the Yucca Mountain Viability Assessment - A Report to the U.S. Congress and the Secretary of Energy.*

The NWTRB meets periodically in open public meetings. The Board reports to Congress and to the Secretary of Energy at least twice a year on technical issues associated with the Nation's SNF and HLW disposal program.

ES.2.4 State Governments and Native American Tribes

In both the NWPA and the NWPAA, the Congress provided for active State and Native American tribe participation in the Yucca Mountain site evaluation process. The legislation provides for financial assistance to the State of Nevada, and for affected tribes and units of local government, for participation in program activities. The State of Nevada and affected tribes or units of local government may also request assistance to mitigate any economic, social, public health and safety, and environmental impacts that are likely to result from site characterization activities at Yucca Mountain.

The Nevada legislature created the State's Nuclear Projects/Nuclear Waste Project Office (NWPO) in 1985 to oversee Federal high-level nuclear waste activities in the State. Since then, the NWPO has dealt primarily with the technical and institutional issues associated with DOE's efforts to characterize the Yucca Mountain site. In addition, the counties contiguous to Nye County, the host county for Yucca Mountain, have been determined to be affected parties and are participating in program oversight.

ES.3 SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE DISPOSAL PROGRAMS IN OTHER COUNTRIES

As in the United States, other countries that use nuclear power are establishing long-term programs for the safe management and disposal of SNF and HLW. These countries include Belgium, Canada, France, Germany, Japan, Spain, Sweden, Switzerland, and the United Kingdom. Management strategies of these countries may include SNF storage at and away from reactor sites, SNF reprocessing, HLW vitrification and storage, partitioning and transmutation of the waste into short-lived or stable forms, and disposal in deep geologic media.

Deep geologic disposal is considered by the international scientific community to be the most promising method for disposing of long-lived nuclear waste. As a consequence, all of the countries discussed in this document envision emplacing solid radioactive waste in a deep geologic formation located within their national borders.

Only the United States and Germany have identified candidate locations for disposal of HLW, i.e., the Yucca Mountain site in Nevada and the Gorleben site in Germany. Other countries are to varying degrees engaged in technical evaluations of the potential suitability of indigenous geologic formations for disposal. Some nations, such as France, have several geologic formations such as clay and granite, that might be used for disposal, and each alternative is being evaluated. Others, such as Canada, have focused on one type of geologic formation. (Canada is evaluating a crystalline rock formation in a setting with low seismic activity.) In addition, several countries, such as Canada and Sweden, have established underground research laboratories (URL's) and extended their research programs to include participation by other nations with similar candidate geologies.

The disposal strategies of all nations assume that waste isolation will be maintained by reliance on a combination of engineered and natural barriers between the emplaced waste and the environment. Currently the United States is, as a result of site characterization data interpretations, placing increasing emphasis on the role of engineered barriers in a potential repository site at Yucca Mountain. This is, in part, due to the unique repository environment and associated disposal strategy. Other countries, because of the characteristics of their available geologic formations, are also placing emphasis on engineered barrier systems and are designing these systems to ensure their long-term performance as a barrier to radionuclide release.
Table ES-1 summarizes the characteristics of disposal programs in other nations.

Table ES-1. Programs for HLW and SNF Disposal in Other Nations

COUNTRY	ESTIMATED WASTE AMOUNTS	MANAGEMENT ORGANIZATIONS	PROGRAM STATUS	PRIMARY REGULATORY AGENCY	TIME FRAME
Belgium	2,500 MTHM by 2000	National Agency for Radioactive Waste and Fossil Materials (ONDRAF)	Conducting studies at the Mol-Dessel Underground Research Lab (URL)	Federal Nuclear Inspection Agency (AFCN)	Operation around 2030
Canada	34,000 MTHM by 2000	Atomic Energy of Canada Ltd. (AECL)	Conducting studies at Whireshell URL	Atomic Energy Control Board (AECB)	Repository established by about 2025
Finland	2,440 MTHM	Posiva Oy	Investigating three potential sites	Finnish Centre of Radiation and Nuclear Safety	Repository operation expected around 2020
France	Not available	National Radioactive Waste Management Agency (ANDRA)	Working to identify suitable site locations	Directorate for Safety of Nuclear Installations (DSIN)	Repository operations not expected before 2020
Germany	9,000 MTHM by 2000	Institute for Radiation Protection	Selected potential repository site at Gorleben	Federal Ministry for Environment, Protection of Nature and Reactor Safety	Repository construction to begin around 2000
Japan	20,000 MTHM by 2000	Steering Committee on High-Level Radioactive Waste	Experiments being conducted at Tono uranium mine and Kamaishi iron ore mine	Atomic Energy Commission	Repository operation expected by 2035 to 2045
Spain	5,200 MTHM (vitrified waste)	Spanish National Radioactive Waste Company (ENRESA)	Developing conceptual design	Spanish Nuclear Safety Council	Not available
Sweden	8,000 MTHM by 2010	Swedish Nuclear Fuel and Waste Management Company (SKB)	Conducting feasibility studies; operates URL at Apsö	Ministry of the Environment and Natural Resources	Repository operation by 2008
Switzerland	1,800 MTHM by 2000	National Cooperative for the Storage of Radioactive Waste (NAGRA)	Considering appropriate repository medium	Nuclear Safety Division with the Federal Department of Transport, Communications, and Energy	Repository viability to be determined by 2000; commissioning of repository will not occur before 2020
United Kingdom	4,000 m^3 by 2000	British Nuclear Fuels, plc (BNFL)	Concentrating on deep disposal of low to intermediate level waste	Nuclear Installations Inspectorate; Radiochemical Inspectorate; Ministry of Agriculture, Fisheries, and Food; UK Atomic Energy Authority; Secretaries of State for Scotland and Wales	Need for repository not expected before 2040

Various nations and international agencies, in addition to the United States, have begun to give consideration to regulations and regulatory standards for SNF and HLW disposal. Some nations have developed broad risk or dose criteria, and some have supplemented such criteria with additional qualitative technical criteria concerning features of the disposal system. International organizations, such as the Nuclear Energy Agency, provide opportunities for discussion of regulatory criteria and also provide programs on issues of common interest.

Although the performance standards and the criteria for the various national regulations are similar, each nation has established specific requirements to meet its needs. Current information concerning the provisions of national and international criteria and objectives for the safety of long-lived radioactive waste disposal is presented in Chapter 3 along with a summary of the waste management programs of Belgium, Canada, Finland, France, Germany, Japan, Spain, Sweden, Switzerland, and the United Kingdom.

ES.4 WASTE CHARACTERISTICS

Current national plans call for existing and yet-to be-produced inventories of SNF and HLW to be disposed of in a Yucca Mountain geologic repository if it is approved for disposal. Each of these waste forms is described below.

ES.4.1 Spent Nuclear Fuel

Spent nuclear fuel is defined as fuel that has been withdrawn from a nuclear reactor following irradiation and whose constituent elements have not been separated by reprocessing. Generators of SNF include: commercial nuclear power reactors, which consist of pressurized water reactors (PWR) and boiling water reactors (BWR); reactors which are used in government-sponsored research and demonstration programs in universities and industry; experimental reactors, e.g., liquid-metal, fast-breeder reactors (LMFBR) and high-temperature gas-cooled reactors (HTGR); DOE Naval and nuclear-weapons production reactors; and Department of Defense (DOD) reactors.

Commercial power reactors are by far the largest source of SNF. Approximately 98 percent of the SNF from these reactors is stored at the reactor sites where it was generated. Spent nuclear fuel from government research and production reactors is currently stored at various DOE facilities. The fuels at these DOE facilities are Government-owned and, like commercial fuels, there are no plans for reprocessing.

The fuel for commercial nuclear reactors consists of uranium dioxide pellets encased in zirconium alloy (Zircaloy) or stainless steel tubes. During reactor operation, fission of some of the uranium produces energy, neutrons, and radioactive isotopes known as fission products. The neutrons cause further fission reactions and thus sustain the nuclear chain reaction. In time, the uranium, is depleted to such a level that power production becomes inefficient. Once this occurs, the fuel bundles are deemed "spent" and are removed from the reactor. Reprocessing of commercial SNF to recover the unfissioned uranium and the by-product plutonium for reuse as a fuel resource is currently not taking place in the United States.

The radioactive materials associated with SNF fall into three categories: (1) fission products; (2) actinide elements (atomic numbers of 89 and greater); and (3) activation products. Typically, fresh SNF contains more than 100 radionuclides as fission products. Fission products are of particular importance because of the quantities produced, their high radiological decay rates, their decay-heat production, and their potential biological hazard. Such fission products include: strontium-90; technetium-99; iodine-129 and -131; cesium isotopes; tin-126; and krypton-85 and other noble gases.

Activation products include tritium (hydrogen-3), carbon-14, cobalt-60, and other radioactive isotopes created by neutron activation of reactor components, fuel assembly materials, and impurities in cooling water or in the fuel pellets. The actinides include uranium isotopes and transuranic elements, such as plutonium, curium, americium, and neptunium. The exact radionuclide composition of a particular SNF sample depends on the reactor type, the initial fuel composition, the length of time the fuel was irradiated (also known as "burnup"), and the elapsed time since its removal from the reactor core.

As of January 1999, SNF from commercial reactor operations in inventory at various locations amounted to 37,700 metric tons of initial heavy metal (MTIHM)[2]. Based on the DOE/EIA Low Case assumptions of nuclear power capacity through the year 2030, the SNF inventory is

[2] Commercial SNF reported in certain DOE documents is in units of metric tons of *initial* heavy metal (MTIHM) to avoid difficulties arising from the need to estimate ranges of varied heavy-metal content that result from different levels of enrichment and reactor fuel burn up. A metric ton (tonne) is 1,000 kilograms, corresponding to about 2,200 pounds.

expected to increase to 87,900 MTIHM. This is the amount that would be produced by existing commercial reactors under current licenses.

ES.4.2 Defense High-Level Radioactive Waste

High-level radioactive wastes are the intensely radioactive materials resulting from the reprocessing of SNF, including liquid waste produced directly in reprocessing, and any solid material derived from such liquid waste. High-level waste is generated by the chemical reprocessing of spent research and production reactor fuel, irradiated targets, and fuel from U.S. Naval propulsion reactors. The fission products, actinides, and neutron-activated products of particular importance are the same for HLW as for SNF assemblies.

Historically, weapons program reactors were operated mainly to produce plutonium. Reprocessing to recover the plutonium was an integral part of the weapons program. Naval propulsion reactor fuel elements were also reprocessed to recover the highly enriched uranium that remained after use. DOE decided in 1992 to phase out the domestic reprocessing of irradiated nuclear fuel of defense program origin, so only minimal amounts of HLW are expected to be added to the current inventory.

High-level radioactive waste that is generated by the reprocessing of SNF and targets contains more than 99 percent of the nonvolatile fission products produced in the fuel or targets during reactor operation. It generally contains about 0.5 percent of the uranium and plutonium originally present in the fuel. Most of the current HLW inventory, which is the result of DOE national defense activities, is stored at the Savannah River Site (126,300 m^3), the Idaho National Engineering and Environmental Laboratory (INEEL) (11,000 m^3), and the Hanford Site (239,000 m^3). A limited quantity of HLW is stored at the West Valley Demonstration Project (2,180 m^3). The HLW has, to date, been through one or more treatment steps, e.g., neutralization, precipitation, decantation, or evaporation. It is currently planned that this HLW will be solidified, using a vitrification process, for disposal. Vitrification of HLW is in progress at West Valley and the Savannah River Site. A vitrification facility for HLW at Hanford is being designed.

The DOE defense HLW at INEEL results from reprocessing nuclear fuels from naval propulsion reactors and special research and test reactors. The bulk of this waste has been converted to a stable, granular solid (calcine). At the Savannah River and Hanford Sites, the acidic liquid waste from reprocessing defense reactor fuel is or has been made alkaline by the addition of caustic soda and stored in tanks. During storage, this alkaline waste separates into three phases: liquid, sludge, and salt cake. The relative proportions of liquid and salt cake depend on how much water is removed by waste treatment evaporators during waste management operations.

Both alkaline and acidic HLW was generated at West Valley. The alkaline waste was generated by reprocessing commercial power reactor fuels and some Hanford N-Reactor fuels. Acidic waste was generated by reprocessing a small amount of commercial fuel containing thorium.

Projecting DOE defense HLW inventories is based on specific assumptions and may be subject to change. New treatment methods and waste forms are possible and may affect the future projections. Since all DOE defense production sites are progressing toward closure, there should be minimal amounts of waste added to the current inventory. Interim storage of DOE HLW will be required and will most likely continue to be at the site where the waste is produced. Current DOE policy states that DOE HLW will not be accepted at the geologic repository until six years after initial receipt of commercial SNF.

ES.4.3 Significant Radionuclides Contained in Spent Nuclear Fuel and High-Level Waste

Of the 70,000-tonne capacity limit for Yucca Mountain set by the NWPA, about 40,785 MTHM and 22,210 MTHM represent spent PWR and spent BWR fuel, respectively. About 7,000 MTHM of vitrified defense HLW and SNF represents the balance of the total specified repository inventory. For the Yucca Mountain site, radionuclide-specific activity levels are estimated by assuming that all spent nuclear fuel had been removed from the reactors 30 years before emplacement with burn-ups of 39,651 MWd/MTHM for PWR fuel and 31,186 MWd/MTHM for BWR fuel. Although the burn-up of SNF from which HLW is derived is generally uncertain, this is thought to affect the adjustment for decay only marginally. In addition, the radionuclide inventories in a repository at Yucca Mountain stemming from defense HLW are expected to be much less than those from commercial SNF.

The radionuclide inventory of the repository will change with time due to radioactive decay and ingrowth of radioactive decay products. For example, inventories of the initially prominent fission products cesium-137 and strontium-90, which have approximately 30-year half-lives, will decay to insignificant levels within 1,000 years, while some decay products, such as neptunium-237 with a half life of 2.1 million years, will not contribute significantly to doses until about

50,000 years after repository closure. Activity levels for very long-lived radioisotopes will be low but nearly constant for periods on the order of a million years. Overall, the radioisotope inventory of the wastes placed in the repository will decrease by about five orders of magnitude during the first 100,000 years after closure, and remain virtually constant thereafter.

ES.5 CURRENT INFORMATION ON A POTENTIAL WASTE REPOSITORY AT YUCCA MOUNTAIN

ES.5.1 Geologic Features of the Yucca Mountain Site

In terms of geologic designations, the site is situated in the southern section of the Great Basin, which is characterized by north-south mountain ranges separating narrow, flat valleys. As is typical of mountains in the region, Yucca Mountain is essentially a tilted fault block, with the west side steep and nearly vertical and the east side sloping to the adjacent valley floor. The crest elevation of the mountain is on the order of 1,500 to 2,000 meters (5,000 to 6,000 feet) above sea level and is about 650 meters (2,000 feet) above the adjacent valley floors.

The geologic features of the southern Great Basin are highly complex and varied, with rock formations ranging in age from 500 million to less than 400,000 years. The geologic structure at Yucca Mountain is dominated by a series of layers of rocks that were produced by explosive volcanic eruptions and are known as tuffs. The tuff layers have widely varying physical characteristics and are on the order of 10 to 15 million years old. The host rock of the potential repository is known as Topapah Spring tuff, which is a hard, fractured rock about 13 million years old.

Geologic features of the region that are important to the integrity of a radioactive waste repository in Yucca Mountain include faulting, seismicity, volcanism, and stability of the geologic regime.

ES.5.1.1 Major Fault Features of the Yucca Mountain Area

The geologic formations, of which Yucca Mountain is a part, contain numerous major faults as a result of deformation caused by tectonic movement. The faults are indicative of past and potential movement of the geologic structures and they are potential pathways for water to transport radioactivity released from the repository to the biosphere. The location of faults and the extent of recent movement along the faults are important to the location and design of surface facilities at the disposal site and to the design of the underground facilities into which the wastes would be placed for disposal.

There are more that 80 known or suspected Quaternary faults and fault rupture combinations within 100 kilometers (km) of the Yucca Mountain site. The DOE has determined that 38 of these faults are capable of generating a peak acceleration of one-tenth the acceleration of gravity (0.1 g) or greater at the ground surface of the proposed repository site; these are classified as relevant earthquake sources. An updated compilation of faults prepared by the U.S. Geological Survey identifies 67 faults with demonstrable or questionable evidence of Quaternary movement and capability for accelerations of at least 0.1 g at an 84 percent confidence limit. The NRC-supported program of the Center for Nuclear Waste Regulatory Analyses (CNWRA) has identified 52 Type I faults within a 100-km radius of the mountain. Eleven known or suspected Quaternary faults exist within 20 km (12 miles) of Yucca Mountain.

The three major faults in the immediate vicinity of the proposed disposal site are the Ghost Dance fault, which passes through Yucca Mountain; the Bow Ridge fault, which is just to the east of the mountain; and the Solitario Canyon fault, which is just to the west of the mountain. According to DOE's interpretation of available data, no movement on any of these faults has occurred during the past 10,000 years.

ES.5.1.2 Seismology of the Yucca Mountain Area

The fault systems and the seismic history of the Yucca Mountain area are the result of regional tectonics, which are dominated by the interaction of the North American and Pacific plates. The tectonic processes that are stretching the Great Basin and produced its major land forms are the result of the Pacific Plate moving northwest relative to the North American plate; the typical geologic structures of the region were developed on the order of 11 million years ago. The relative plate movements produced the past and recent seismic activity characteristics of the region, outlined below.

Seismicity in the region of Yucca Mountain is concentrated in several zones. The Southern Nevada Transverse Zone (SNTZ) is nearest to the Yucca Mountain site and is the most significant to repository performance. Historic earthquakes in the SNTZ have been of moderate magnitude with no documented surface rupture. The most recent earthquake in the vicinity of

Yucca Mountain was the Little Skull Mountain event, of Richter magnitude 5.6, in June 1992. This earthquake was centered 20 km southeast of Yucca Mountain and was associated with the Landers, California earthquake earlier that year. It caused minor structural damage to the Yucca Mountain project field office near the mountain but had no apparent effect on geologic features near the mountain. It was the largest earthquake ever recorded in the vicinity of the site, based on nearly 100 years of records.

Assessments of available data indicate that Yucca Mountain has not been subject to ground accelerations at the surface in excess of 0.2 g for over several tens of thousands of years. At the proposed waste emplacement depth of about 300 meters, the effects of ground motion are expected to be insignificant. Empirical evidence of damage to 71 rock tunnels in Alaska, California, and Japan resulting from earthquake shaking indicates that tunnel damage does not occur at peak surface accelerations of less than approximately 0.2 g and only minor tunnel damage occurs when the peak surface acceleration is between 0.2 and 0.5 g. Since ground acceleration is not expected to impose significant design demands on either the underground repository or surface facilities at Yucca Mountain, DOE does not consider seismicity to be a significant factor in repository performance.

The Department also believes that future tectonic events are unlikely to significantly alter the hydrologic characteristics of the Yucca Mountain site. This position is based on the assumption that the current state of faults and fractures at the site is the result of cumulative past tectonic events. The CNWRA has proposed, however, that a single tectonic event can cause significant changes in hydrologic characteristics. Currently, there are five alternative tectonic models which may form the basis for future assessment of relationships between tectonic phenomena and the hydrologic regime.

ES.5.1.3 Volcanism

Yucca Mountain is composed of layers of volcanic rocks which originated in silica-rich eruptions at what is now the Timber Mountain volcanic basin complex starting about 10 km north of Yucca Mountain. The principal eruptions took place approximately 11 to 15 million years ago, and ceased about 7.5 million years ago. After the silicic volcanism ended, there were two episodes of basaltic volcanic rock formation. The most recent of these, which produced minor ash deposits in the Lathrop Wells area to the southwest of Yucca Mountain, ended about 9,000 years ago.

DOE and NRC agree that a future occurrence of silicic volcanism is highly unlikely; the consequences of such an event, therefore, do not need to be considered in assessments of a waste repository at Yucca Mountain. The Department and the NRC have also recently reached agreement on the likelihood of future basaltic volcanic events and their possible consequences. One of the phenomena potentially associated with basaltic volcanism is sheet-like intrusion of molten or liquid basaltic rock along fractures in the overlying rocks, i.e., the formation of dikes. Given the history of volcanism in the Yucca Mountain region, there is some potential for magma from a basaltic volcanic event to either intersect the repository footprint and directly affect the waste or to form a nearby intrusive dike that might affect the waste isolation capability of the natural system. If such intrusions occur, they could mobilize wastes and/or alter ground water pathways. DOE and NRC are currently developing a mutually acceptable approach to estimating the likelihood and consequences of such intrusions.

ES.5.1.4 Geologic Stability

The NAS report, "Technical Bases for Yucca Mountain Standards," recommended that assessments of compliance with the Yucca Mountain standards be conducted for the time at which the greatest risk occurs, within the limits imposed by long-term stability of the geologic environment. The report also stated that long-term geologic stability for time periods on the order of one million years can be expected; i.e., the contribution of geologic and hydrologic features to overall repository system performance can be assessed for time periods of this duration. The NAS report concluded that there is no technical basis for selecting a shorter compliance period, such as 10,000 years. However, the NAS also stated that EPA may select a shorter period based on policy considerations.

The concept of geologic stability does not imply absence of geologic activity or absence of change in geologic processes. Rather, the concept implies that processes and events such as climate change, tectonic movement, and earthquakes will occur as in the past, and that variations within these processes and events will be boundable. The NAS report does not explicitly justify the assertion of million-year stability by providing a synopsis and interpretation of the documented geologic record. Some of the references cited in the report contain information about the geologic record, but none of the cited references interprets the record to indicate a million-year stability of the geologic regime or the processes associated with it. Until recently, DOE documents containing information about the geologic features of the Yucca Mountain site anticipated that performance assessments for a disposal system at the site would be evaluated in terms of EPA's 40 CFR Part 191 regulations, which require evaluation of performance for a period of 10,000 years. The 40 CFR Part 197 regulations specify the same time period.

The 10,000-year time frame for compliance with EPA's 40 CFR Part 191 regulations, which applied to Yucca Mountain until Yucca Mountain was exempted by the WIPP Land Withdrawal Act of 1992, was selected by the Agency because it was relatively brief compared to the time frame for long-term factors, such as tectonic motion, that might affect the natural environment and are not reasonably predictable over that period. On the other hand, the time period was long enough to bring into consideration factors such as degradation of engineered barriers and earthquakes that might affect disposal system performance and allow radionuclides to reach the accessible environment.

Available information generally supports the NAS assertion that the fundamental geologic regime at Yucca Mountain will remain stable over the next one million years. The overall picture that emerges from available information is that the site and region had a highly dynamic period of volcanism, seismicity, and tectonic action during the past, but that this very dynamic situation has matured into one where the magnitudes, frequencies, locations, and consequences of such phenomena relevant to long-term future disposal system performance can be bounded and projected with reasonable confidence.

Performance assessments define the expected behavior of the waste isolation system over time. Within the framework of expected repository performance, it is convenient to characterize future repository conditions over three time periods. A similar breakdown was presented by DOE in its 1998 Viability Assessment. In the first, short-term period, lasting about 100 to 1,000 years, the repository is characterized by intact waste canisters, high temperatures, and temperature gradients which serve as driving forces for transients such as chemical reactions, and the retention of short-lived and long-lived radioactivity in the canisters. Percolation water may or may not contact the canisters, depending on local conditions determined by the arrangement of waste packages in the repository and the pattern of percolation into the repository.

In the intermediate period, with a duration between 1,000 and 10,000 years, temperature gradients are diminished or gone and the engineered features of the repository start to degrade. During this time, canisters begin to corrode and only long-lived radioactivity remains; some of the radioactivity is released from a few canisters which are penetrated by water, but most is retained within the repository. Percolation water contacts and transports radioactive waste. Releases are dominated by technetium-99 and iodine-129.

In the long-term period, from 10,000 years to 1,000,000 years, the repository gradually evolves into an assemblage of the oxides, hydroxides, or carbonates of waste-package and waste-form materials at ambient conditions. Percolation water seeps through the repository level and transports radionuclides that can be mobilized to the environment, where the radionuclide concentrations are diluted and dispersed by ground water flow processes. Potential for radiation doses is dominated by neptunium-237 released from the repository.

ES.5.2 Hydrologic Features of the Yucca Mountain Site

The proposed repository depth in Yucca Mountain (about 300 meters or 1,000 feet) would locate it in a geologic formation not fully saturated with water (the unsaturated zone). The unsaturated zone depth to the water table beneath the repository horizon is variable but is on the order of 300 meters. Water that infiltrates into the mountain, percolates through the repository, and moves through the matrix of the geologic formations in the unsaturated zone will travel slowly, thereby delaying entry of radionuclides released from the repository into the saturated zone and ground water system. Fractures in the rocks within the unsaturated zone can act as conduits for relatively rapid movement of ground water through Yucca Mountain. Some radionuclides may be chemically trapped in rock formations in the unsaturated zone.

ES.5.2.1 Characteristics of the Unsaturated Zone

Water flows slowly through the pore space in the matrix of partially saturated rock (the degree of saturation in the Yucca Mountain formations is on the order of 80 to 90 percent) because there is little areal recharge. If the pore space becomes saturated, the water will flow more quickly under the existing hydrologic conditions. Also, water may flow quickly and preferentially through fractures in the rock matrix. There is experimental evidence of "fast paths" for flow in some rock fractures at Yucca Mountain. The fraction of total flow through these fast paths is uncertain, may be episodic, and may be a small percentage of the total ground water moving through the repository host rock. There is also evidence that some faults and fractures are barriers to flow because of solids deposited along the fractures which block potential flow paths.

The complexity of the geologic structures in the unsaturated zone and the complexity of flow in partially saturated media make it difficult to develop accurate models to predict flow rates and flow paths in the unsaturated zone below the proposed repository location. Water flow and storage in the unsaturated zone is three-dimensional and is controlled by structural, stratigraphic, thermal, and climatological features of the system. The presence of features such as fractured porous media, layered geologic units with widely varying hydrologic properties, tilted rock units, and bounding faults can be expected to result in phenomena such as flow in both the fractures and the matrix, diversion of flow by capillary barriers, lateral flow along discontinuities, perched ground water zones, and vapor movement.

Water quantities that enter the mountain from precipitation and that percolate through the geologic structures are spatially and temporally variable. The amount of water that percolates along different paths is highly variable. Infiltration pathways depend on variations in the properties of geologic units, the intersections of faults with the surface, and the presence of local fracturing in individual rock units. Variations in the time it takes water to infiltrate are related to the seasonality and relative infrequency of precipitation at Yucca Mountain. Over long time frames, variations will occur because of climate changes. The interplay of all of these factors may act to even out downward movement of ground water in the unsaturated zone with increasing depth from the surface. There is evidence of rapid movement of infiltrating waters along fracture zones in the rock.

Quantities of water that percolate through the mountain at the proposed repository depth cannot be measured directly. Recent estimates, based on analysis of site characterization data, place the percolation rate in the range of one to 10 mm/yr. Base-case performance assessments for the TSPA-VA used a range of three to 23 mm/yr, with an expected value (60 percent probable) of 7.7 mm/yr. Values in this range are as much as two orders of magnitude higher than values previously estimated using more limited data. The TSPA-VA also used a model of future climate involving "long-term average" conditions, with an expected infiltration rate of 42 mm/yr, and "superpluvial" conditions with an expected infiltration rate of 110 mm/yr.

Models of water flow in the unsaturated zone take into account potential for flow in both the matrix and fractures, the relative distribution depending on the quantities of ground water available. For example, at high percolation rates, a larger fraction may be transported laterally and/or transported in fractures, including fast-path fractures. The models also take into consideration the possibility that radionuclides may be removed from water that is intercepted by geologic media having a high capacity to chemically absorb and retain some radionuclides, such as the zeolite materials in the Calico Hills formation.

Using uncertainty distributions for the flow parameters, models are used to estimate values for performance factors, such as the time necessary for water to move through the unsaturated zone. Results of studies to date show that radionuclides, carried by water through fractures, cross the unsaturated zone much more rapidly than those in water that travels through the rock matrix. Similarly, radionuclides strongly sorbed on rocks, such as the Calico Hills zeolites, have transit times through the unsaturated zone 50,000 times longer than for radionuclides that are soluble and travel with the water. The conceptual models and transport parameters for water flow and radionuclide transport in the unsaturated zone, and the results obtained from use of the models, will be refined by DOE as additional data concerning the unsaturated zone are obtained from future site characterization work.

ES.5.2.2 Characteristics of the Saturated Zone

Water that percolates through the repository and the unsaturated zone below will enter the saturated zone where ground water fills the pore spaces and fractures within these rocks. The saturated zone at Yucca Mountain is located at depths on the order of 300 m below the repository horizon. Radionuclides transported to this zone will move toward the environment away from Yucca Mountain through ground water. Radionuclide concentrations in the saturated zone will be reduced by dilution caused by dispersion as radionuclides are transported away from the repository at rates and in directions according to the flow characteristics of the hydrologic regime. The saturated zone is, like the unsaturated zone, composed of numerous layers of rocks with widely different characteristics and complex structures resulting from the dynamic geologic history of the region . Flow rates and directions are of interest for evaluating compliance with EPA's standards, as are the locations at which radionuclides would be accessible to human use and the radionuclide concentrations at those locations.

The sequence of volcanic rocks within and below Yucca Mountain has been described hydrologically in terms of four hydrologic units characterized by their ability to transmit water. Beneath the volcanic rocks, at depths on the order of 2,000 meters at some locations, are older rocks which contain the Lower Carbonate Aquifer. The volcanic hydrologic units and the lower carbonate aquifer may all have a role in transporting radionuclides from the repository to the surrounding areas.

The thicknesses of the rock formations and the depth to water in the saturated zone vary significantly with distance and direction from the proposed repository location. For example, the volcanic rock units are believed to thin out and disappear to the south of Yucca Mountain where they are covered by the alluvial deposits of the Amargosa Desert. In this region, as illustrated by Figure ES.5-1, the formations containing the Lower Carbonate Aquifer are near the surface. Depths to ground water currently used for human consumption and activities such as irrigation are shallow in this area, i.e., on the order of a few tens of meters. Consequently, human habitation and water supply wells are currently located in this area.

Available data indicate that much of the outflow from the volcanic aquifers moves laterally into the alluvial aquifer as the volcanic rock formations thin out below it. The alluvial aquifer may also be receiving water from the carbonate aquifer. The data are not sufficient to indicate where and how these flow transitions occur. Comparison of recent water-level altitude maps with those completed in the 1950s indicates that aquifer development may have had a significant impact on water levels and flow directions. Pumping of the alluvial aquifer may have induced upward flow from the lower carbonate aquifer into the alluvial system.

Discharge from the alluvial aquifer system can occur by interbasin flow, leakage to underlying units, evaporation, and extraction for human use. Available data indicate that the major discharge area for the alluvial aquifer system is Alkali Flat, known also as the Franklin Lake Playa. The estimated discharge rate in this area is 10,000 acre-feet per year, primarily based on bare-soil evaporation. Some of the alluvial aquifer flow may also move further to the southwest and discharge in the Death Valley region, but the extent of this is unknown.

Estimates of rates and quantities of ground water flow in the saturated zone are based on estimates of values for hydraulic conductivity, hydraulic gradient, and effective porosity of the formations through which the water is flowing. Hydraulic gradient (i.e., the change in water level between two locations) is generally the parameter best known and most easily measured. In the Yucca Mountain region, three regions with distinct hydraulic gradients, designated as small, moderate, and large, have been identified. Their extent and characteristics are governed by the complexity and characteristics of the geologic formations.

Of particular interest to repository performance at Yucca Mountain is the high-gradient area, located about two miles north of the mountain. The cause of the gradient, in which water levels

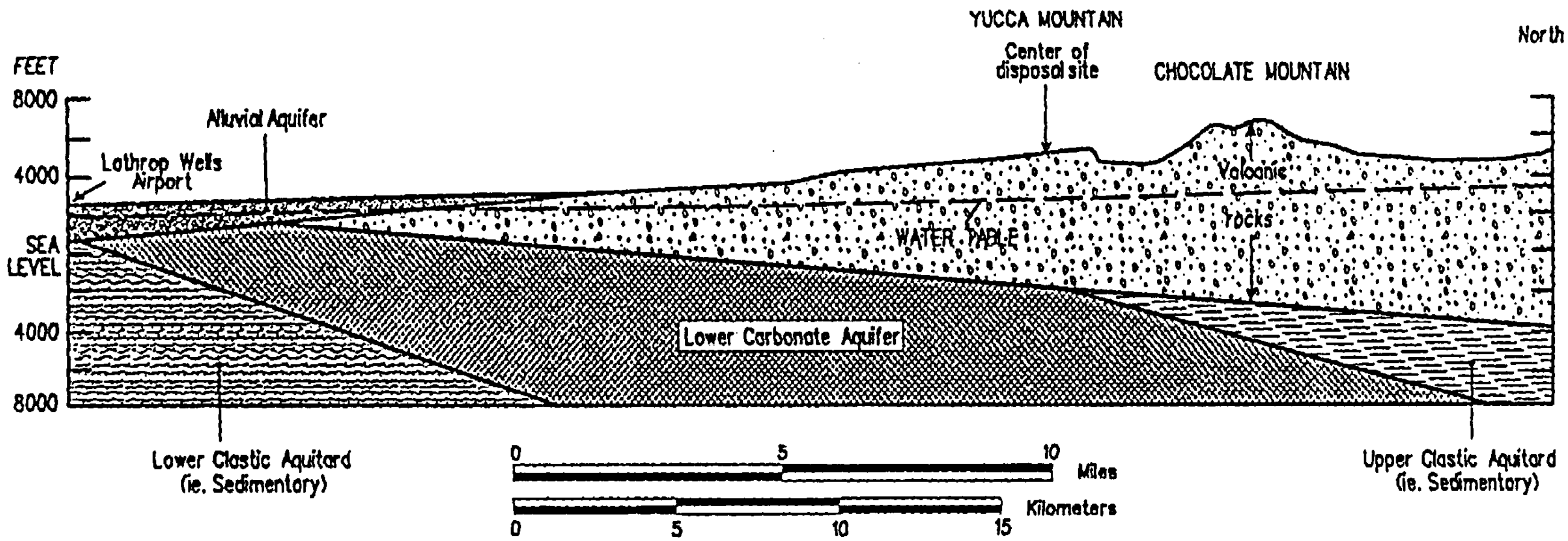

Figure ES.5-1. Schematic North/South Cross-Sectional Illustration of Thinning of Volcanic Units Beneath the Amargosa Desert [U.S. Geological Survey, *Structure of Pre-Cenozoic Rocks in the Vicinity of Yucca Mountain, Nye County, Nevada*, USGS Survey Bulletin 1647, 1985] decline by more than 900 feet over a distance of about a mile, is unknown. Possible causes include a flow barrier, a fault, an intrusive dike from volcanic rock flow, or changes in the detailed structure of the rocks. If the gradient is caused by a flow barrier of some type, a loss of this barrier due to future geologic movements could cause a rise in the water table in the area of the proposed repository. A rise in the water table would not be expected to intercept the repository, but it would decrease the thickness of the unsaturated zone and decrease the radionuclide travel time from the repository to the environment.

Ground water flow rates, like flow directions and quantities, are at present highly uncertain because of limited data and the complexity of the geologic structures that create the hydrologic regime. Flow rates in the alluvial aquifer, the volcanic rock aquifers, and the lower carbonate aquifer will differ because of the different rock characteristics for these geologic regimes. Ground water movement in the volcanic rocks of the saturated zone was estimated by DOE in 1993 to be in the range of 5.5 to 12.5 meters per year. A more recent estimate concluded that a flow rate of five meters per year is in the middle of the range of reasonable estimates. However, recent data from the Exploratory Studies Facility tunnel into Yucca Mountain suggest the existence of "fast paths" through the unsaturated zone that can allow water to move from the surface to depths as far as 300 m in 50 years. At present, DOE believes that only a small fraction of percolating water is transported to the repository level through these pathways. Flow rates in the lower carbonate aquifer have been estimated to be in the range of three to 3,000 meters per year, depending on location. Pressure gradients are such that water flow from the volcanic aquifers to the lower lying carbonate aquifer presumably does not occur. While reliable estimates of flow rates in the alluvial aquifers are not available, flow rates in these strata are believed to be lower than in the carbonate strata. This has the effect of preventing radionuclide from moving into the higher flow rate paths in the carbonate aquifer. The areal extent of the region where upward flow comes from the carbonate aquifer is highly uncertain.

If ground water containing radionuclides flows at a rate of five meters per year, it would take 1,000 years for the ground water to travel a distance of five kilometers and 4,000 years to travel a distance of 20 kilometers. Concentrations of soluble radionuclides in the ground water at these distances from the repository would depend on the initial concentration at the boundary of the repository, the dilution that occurs as a result of mixing of water from various sources, and the dispersion of radionuclides. Overall, the mixing, dilution, and dispersion processes have been estimated potentially to reduce radionuclide concentrations at distances on the order of 20 kilometers from the repository by a factor of 10 in comparison with the initial concentration.

Estimation of dispersion on a kilometer scale is difficult. The DOE used expert elicitation to fix this parameter. The experts estimated that the parameter could vary from 1 to 100 with an average assumed value of 10. The amount of concentration reduction that occurs may depend on the direction of flow (i.e., as a result of dispersion being controlled by rock structures along the flow path) as well as the distance over which flow has occurred.

Nye County, NV is currently drilling a series of 20 deep and shallow wells south of the Yucca Mountain site and in Amargosa Valley to monitor the behavior of the saturated zone. Some of the wells will measure hydraulic parameters of the alluvial and tuff aquifers. Other deep monitoring wells will be installed to measure the properties of the carbonate aquifer and to define how this aquifer connects with the shallower tuff and alluvial aquifers. These data will support modeling of the saturated zone flow and transport on both site-scale and regional-scale. Results to date indicate that the alluvium is complex and layered.

ES.5.3 Climate of the Yucca Mountain Region

The region surrounding Yucca Mountain currently has an arid climate, with total annual precipitation on the order of 170 mm (six inches) of water. Precipitation rates vary throughout the year, averaging about 18 mm/month during the fall and winter months and nine mm/month during the spring and summer months. Current climate conditions have apparently prevailed during the past 10,000 years, i.e., since the last ice age. Prior to the ice age, the climate cycled between wet and dry; during the wet periods, many of the valleys that are now dry contained lakes.

Future variations of precipitation and temperature are climate factors of considerable interest for predicting the performance of a repository at Yucca Mountain. These factors influence the percolation rate of water through the repository and the transport of radionuclides released from the repository to the environment.

Current arid conditions are expected to persist well into the future. These conditions are associated with the rain shadow caused by the Sierra Nevada Mountains to the west, which are still rising. In addition, increases in greenhouse gases and global warming may affect general atmospheric circulation and local climate conditions at Yucca Mountain. A panel of experts, convened by the CNWRA, estimated that an enhanced greenhouse effect would probably produce warmer conditions than have been experienced during the past few thousand years, with a likely increase in the upper limit of temperature in the Yucca Mountain region on the order of two to three degrees Celsius. The time period during which these elevated temperatures would persist would depend on assumptions about future human use of fossil fuels. In general, increased temperatures would be accompanied by lower precipitation rates and, therefore, lower rates of percolation through the repository. Opposite changes could occur, however, especially in connection with any future glacial periods.

Performance assessments in the Department's TSPA-VA assumed that the climate alternates between the present (dry) climate, a long-term average climate during which the precipitation rate is twice the current rate, and a superpluvial climate during which the precipitation rate is three times the current rate. The expected duration of the initial dry climate was 5,000 years. Subsequent dry periods would have an average duration of 10,000 years. The expected duration of the long-term average periods was 90,000 years. Two superpluvial periods of 10,000 years each were assumed to occur over the 1,000,000-year model period. About 90 percent of the 1,000,000-year model period was characterized as having long-term average climate. Climatic fluctuations were predicted to have virtually no impact on repository performance assessments over a 10,000-year time frame. Over the longer term, climate assumptions affect the time at which the peak dose rate occurs but not its magnitude.

ES.5.4 Repository Design Concepts Under Consideration for Yucca Mountain

Design concepts for a potential waste repository at Yucca Mountain have evolved significantly in response to information from sources such as site characterization data, repository system performance assessments, external technical reviews, and refinement of a waste isolation strategy. The original design concept envisioned vertical emplacement of simple steel canisters in individual boreholes; current plans call for end-to-end horizontal emplacement of large, complex waste packages in parallel, excavated drifts. Design details are expected to continue to evolve until a final design is selected for the License Application, if the site is approved for disposal.

The repository design can be characterized as a multi-barrier system that functions to delay the failure of the waste package, delay the release of radionuclides from the waste package, and mitigate the effects of radionuclide release. Key design factors important to repository performance and radionuclide release potential include the corrosion resistance of the waste package wall material; the use of techniques to deflect or delay contact of percolating water with the waste packages; and the use of techniques to stop or delay migration of releases to the environment.

One technique to delay waste package failure is to emplace the packages so that heat from the wastes will keep temperatures in the repository high enough to vaporize percolation water, for as long as possible. Corrosion by liquid water is thereby delayed until the heat emissions decrease to levels such that water can enter the repository. Another technique for delaying waste package failure is to use shields that deflect water dripping into the emplacement tunnels from contact with the packages. In general, various technologies and concepts are available for each of the basic functions for delaying waste package failure and decreasing radionuclide releases.

Key features of the design used by DOE in the recently completed TSPA for Site Recommendation issued in December 2000 include the following:

- Horizontal emplacement of 7,642 commercial SNF and 2,858 HLW canisters positioned end-to-end in parallel, excavated, concrete-lined drifts, with an initial thermal loading (to vaporize percolation water) on the surroundings corresponding to emplacement of 85 MTHM/acre of reference spent commercial reactor fuel

- Emplacement of waste canisters only between the Ghost Dance fault and the Solitario Canyon fault

- Disposal of 63,000 MTHM of spent commercial fuel and 7,000 MTHM equivalent of defense HLW in 120 miles of tunnels and drifts, over 840 acres of emplacement area, at depths on the order of one-eighth to one-quarter of a mile

- Construction of 29 surface buildings encompassing 800,000 square feet of floor space and serving the operational needs of 300 underground drift excavation personnel and 600 surface and subsurface operational personnel

- Use of commercial spent fuel waste packages that are two meters in diameter, six meters in length, with an Alloy 22 corrosion-resistant waste container.

- Protection of the waste containers using titanium drip shields, which decrease contact with water and extend the lifetime of the Alloy 22 containers.

Waste types to be disposed would include commercial SNF fuel in bare assemblies; canistered commercial SNF; canisters of vitrified defense HLW; SNF from nuclear defense programs; and other DOE-owned SNF such as unprocessed fuel from Hanford's production reactors.

A plan view of the repository layout for the TSPA-VA is shown in Figure ES.5-2. In this diagram, the dense array of parallel lines in the subsurface emplacement block represents the drifts where the waste canisters would be emplaced. The waste package design features shown in Figure ES.5-3 are representative of those used in the VA reference design.

In the TSPA-VA, DOE evaluated several design options as variants to the base case. The options considered included use of backfill; use of drip shields to preclude water from impinging on the waste packages; use of a ceramic coating on the waste packages to defer corrosion; and whether or not to take credit for fuel rod cladding as a barrier to radionuclide mobilization and transport.

During early 1999, DOE evaluated alternative repository designs based on, and evolved from, the Viability Assessment design. These alternative designs were intended to reduce uncertainties in performance identified in the TSPA-VA analysis. DOE has selected, as the reference design for the Site Recommendation, a design whose key features include an area mass loading of 60 MTU/acre, drift spacings of 81 m, waste packages with 2 cm of Alloy 22 over 5 cm of 316L stainless steel, use of steel ground support, and use of drip shields. These design features significantly reduced uncertainties and technical issues associated with the VA reference design. The demonstration of this improved performance was conducted as the TSPA-SR. Engineered design concepts may continue to evolve to the design selected for the LA.

ES.5.5 Repository System Performance Assessments

Assessments of future repository system performance are currently used by DOE to aid repository design and, in association with the license application, will be used to demonstrate compliance with regulatory standards. The assessments are done using analytical models of factors that affect performance, such as the waste package corrosion rate, and computer codes that combine the models of performance factors with performance parameter values and modeling assumptions.

The NRC is developing independent capability to perform performance assessments in order to be able to review DOE's license application. In addition, the Electric Power Research Institute has developed performance assessment methods that are used in its oversight of the government program, and EPA has developed methods that are used in support of its promulgation of the Yucca Mountain standards.

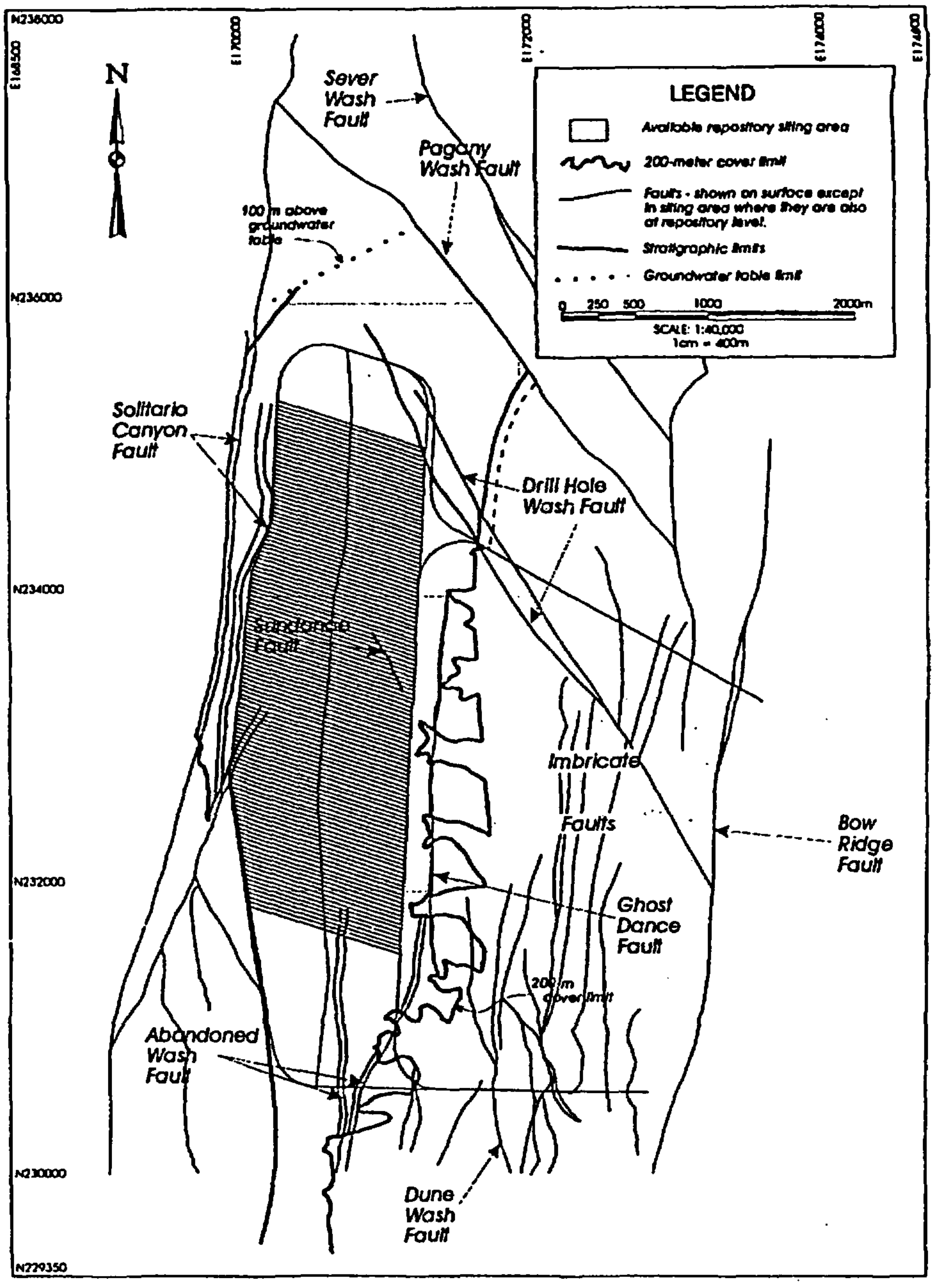

Figure ES.5-2. Repository Layout for the TSPA-VA Design

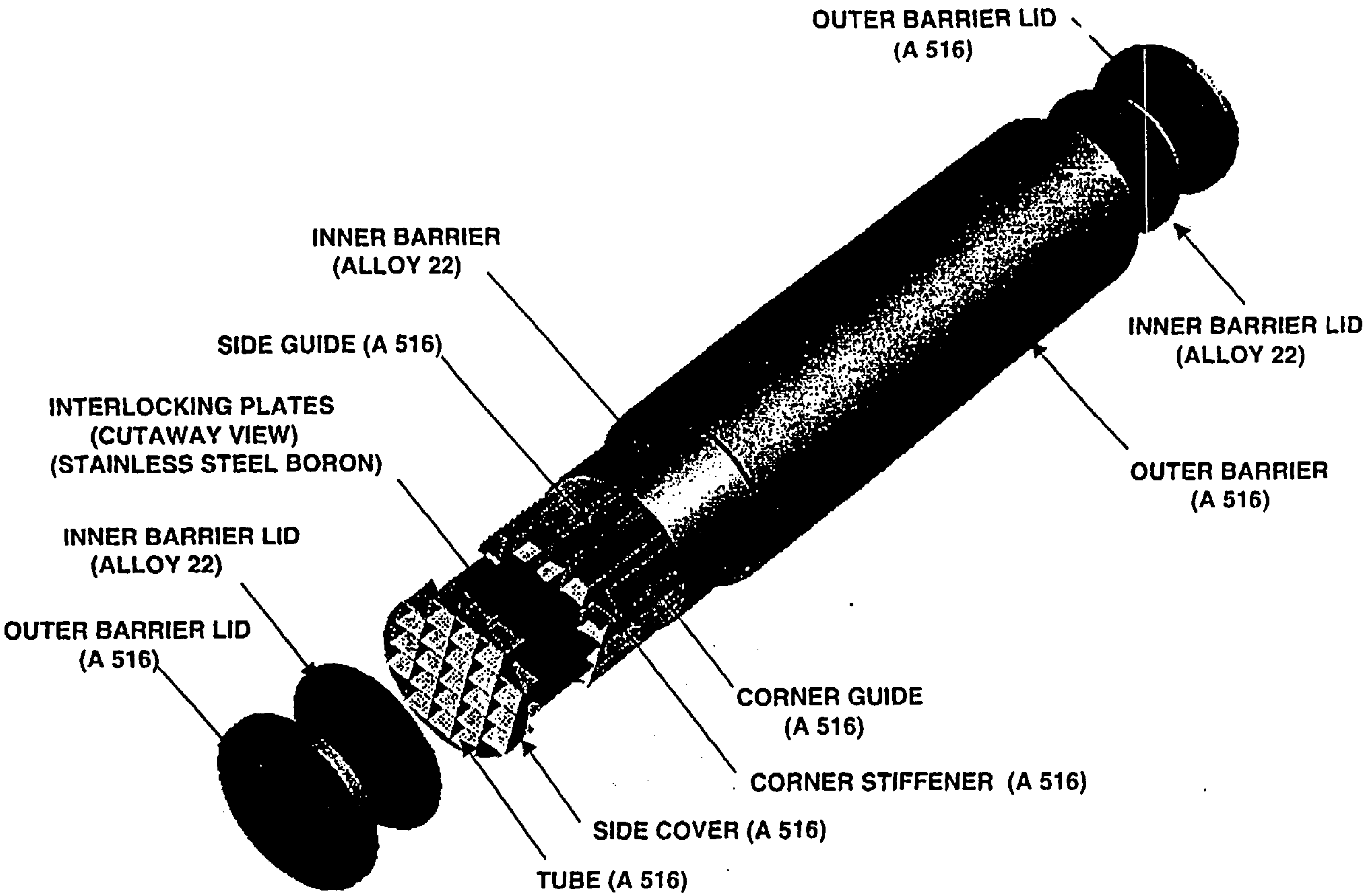

Figure ES.5-3. Waste Package for 21 PWR Uncanistered Fuel Assemblies

Prior to the TSPA-VA, DOE issued reports on its total system performance assessments in 1991, 1993, and 1995. They also serve as precursors of the TSPA results that will be submitted with the License Application to demonstrate compliance with regulatory requirements. The expected performance of the repository will be strongly dependent upon the combination of engineered barriers finally selected by DOE.

The performance assessment models and codes address engineered design features that affect repository system performance. They also consider geologic and hydrologic features that can affect performance, such as those discussed in Sections 4.1 and 4.2 of this BID, and uncertainties in these factors that affect uncertainties in demonstrating compliance with regulatory requirements. Types of uncertainties that are considered include uncertainties in measured values of performance parameters such as corrosion rates and hydrologic parameters; spatial variability of parameters such as percolation rate and temperatures around the repository; temporal variability of factors such as annual variation of precipitation and future climate change; and uncertainties in the analytical models as a result of simplifications or imperfect knowledge of the processes simulated by the models.

These uncertainties are taken into consideration by the codes used in TSPAs through use of probabilistic techniques in selecting the model parameters for the calculations. The numerical values for uncertain performance parameters used in the TSPA codes are characterized using a range of possible values. Calculational techniques are used to sample values from the distributions to produce a large number of individual TSPA results which collectively characterize the uncertainty in the overall system performance as a result of uncertainties in the individual factors. DOE uses the computer code GOLDSIM as the integrating shell to link the various component codes. GOLDSIM includes parameter sampling capability to assess uncertainty in dose rates as a function of uncertainty in the component models, and permits flexible implementation of alternative conceptual models are part of its framework.

During the first 10,000 years, based on the TSPA-SR nominal scenario assumptions, there are no releases from the repository. However, the TSPA-SR also accounts for the potential for disruption of the repository by igneous activity. Two scenarios are evaluated in the TSPA-SR. In the first igneous scenario, magma intrudes into the repository, completely destroying waste packages it encounters, carrying waste to the surface, where a violent eruption occurs. Waste materials, in this scenario, are then distributed along with the ash plume created by the eruption. In the second igneous scenario, magma intrudes into the repository, destroying waste packages it encounters, but does not progress to the surface. In this scenario, the damage to the repository permits water to contact the waste, leading to early releases from the repository. These two igneous scenarios are the only mechanisms in the TSPA-SR leading to releases in the first 10,000 years. The mean dose rate from these scenarios reached a maximum of 0.1 mrem/yr in the first 10,000 years.

Inadvertent drilling intrusion as a result of searching for water was assumed to occur at 100 or 10,000 years. The former value is based on the proposed NRC guidance for 10 CFR 63, and the latter reflects EPA's proposed position in the draft 40 CFR 197 that the waste package must degrade for a period of time before it would be unrecognizable to a driller. The mean peak dose calculated in the TSPA-SR for either intrusion time is 0.01 mrem/yr; there is virtually no difference between the mean peak dose for the two assumptions.

The NRC is developing its own performance assessment models and codes for use in pre-licensing technical exchanges with DOE, and, ultimately, for performing reviews of DOE's license application for a repository at Yucca Mountain. The NRC models are similar in concept and content to the DOE models in that they include models of the various factors relevant to disposal system performance and have the capability to address uncertainties. NRC's recent modeling has shown results similar to those developed by DOE in the TSPA-VA, even though significant differences in underlying assumptions exist between the two approaches. NRC has not yet updated their TSPA to reflect comparable conditions to the TSPA-SR.

The NRC has estimated that the 10,000-year dose rate is about 0.003 mrem/yr as compared to the equivalent TSPA-VA dose rate of 0.04 mrem/yr. At 100,000 years the NRC calculated dose rate is 0.2 mrem/yr while the equivalent value in the TSPA-VA is 5 mrem/yr. Reasons for the differences are not readily apparent because the parameters and modeling approaches used by the two agencies differed markedly. For example, the NRC did not assume credit for fuel rod cladding as an engineered barrier while in the TSPA-VA DOE did take credit for Zircaloy cladding. The NRC assumed that dilution of ground water radionuclide concentrations occurs during pumping by the dose receptor; the DOE assumed that this dilution did not occur.

The Electric Power Research Institute has also conducted performance assessments using models and codes which address the same general features and processes as those modeled by DOE. However, the codes differ in approach and detail from those used in the TSPA-VA. Differing parameters are also used by the two organizations. In spite of these differences, 10,000-year performance assessment results were in reasonable agreement. The 10,000-year dose calculated by EPRI was 0.08 mrem/yr as compared to the DOE TSPA-VA estimate of 0.04 mrem/yr. After 100,000 years the EPRI dose rates were about two orders of magnitude lower than the TSPA-VA results due, at least in part, to differing assumptions about the available inventories of iodine - 129 and technicium-99.

ES.6 BIOSPHERE PATHWAYS LEADING TO RADIATION EXPOSURE

In order to evaluate compliance of the repository system performance with regulatory requirements, potential radiation doses to humans from repository releases must be calculated. This evaluation requires estimating radionuclide releases; modeling their movement through the environment; selecting and characterizing the person(s) for whom the potential radiation dose is to be evaluated; and characterizing the pathways by which the person(s) receives the dose.

This estimation also requires assumptions concerning the location and exposure scenarios of an individual or group of individuals likely to be at greatest risk from potential radionuclide releases after repository closure and removal of institutional controls. Prior to closure, such assumptions are unnecessary because possible contamination levels can be measured with considerable accuracy both within and outside the repository.

Releases of radionuclides from the repository are not expected to occur sooner than several thousands of years in the future; the start of release might be deferred much longer if certain repository design features are used (i.e., those aimed at delaying the start of release, such as corrosion-resistant drip shields and waste packages). After release from the repository, the radioactivity would migrate through environmental pathways until it reaches the location of the person(s) selected for the evaluation of potential doses. Thus, radiation doses might first be incurred many thousands of years in the future, when locations and lifestyles of humans in the vicinity of Yucca Mountain might differ from those of the present. Human locations and lifestyles far in the future cannot, however, be reliably estimated. Therefore, evaluations of future potential radiation doses are based on an understanding of current patterns of human habitation, physiology, and activities as well as current technology. This approach to addressing future states was affirmed by the NAS who concluded in their study mandated by the EnPA that:

- *...based on our review of the literature we believe that no scientific basis exists to make projections of the nature of future human societies to within reasonable limits of uncertainty*

- *... it is not possible to predict on the basis of scientific analyses the societal factors required for an exposure scenario. Specifying exposure scenarios therefore requires a policy decision that is appropriately made in a rulemaking process conducted by EPA.*

ES.6.1 Current Demographics and Land and Water Use

The boundaries of the unincorporated town of Amargosa Valley (the closest population center to the repository site) encompass almost 500 square miles of the Amargosa Desert. The boundaries of the town include all of the area in which the highest potential doses from a repository at Yucca Mountain are anticipated. The remoteness and arid climate of the area are reflected by its population of only about 1,000 residents. Only about 11 percent of the land is held privately; the remainder is under Federal control.

Currently, agricultural activities in the Yucca Mountain region are restricted to the Ash Meadows area and the southern portion of Amargosa Valley. Two commercial alfalfa farms, a dairy farm, and one commercial sod farm operate full-time in the Valley; most other farms in the area operate on a part-time basis. Despite some difficulties, a wide range of crops and livestock can be raised. Alfalfa, hay and grass, wheat, fruits and melons, vegetable, cotton, nuts, poultry, beef cattle, dairy cattle, and fish are being or have been grown on farms and ranches in Amargosa Valley. However, because of local conditions, the population in the region does not currently grow significant quantities of leafy vegetables, root vegetables, and fruit and grain crops for its own use. Presently, no farming occurs closer than about 23 kilometers south of the repository site.

Primary uses of water in the Amargosa Valley include domestic, industrial, agricultural, mining, and recreational. Most residences are supplied by individual wells, though some trailer parks, public facilities, and commercial establishments are served by small private water companies. A number of springs also supply water, primarily to the resort area in Death Valley.

Water use data for Hydrographic Basin 230 (Amargosa Desert) in 1997 was 940 acre-feet for domestic, quasi-municipal, and commercial uses exclusive of mining and irrigation. As such, the usage is typical of a small rural residential community. The average per person use rate was 0.8 acre-feet per year. Since no major demographic changes are expected, these values should be representative of future communities in the regions.

At the present time nine farms varying in size from 65 to 800 acres are cultivating alfalfa in the area. It is estimated that a total of 2,500 acres is being cultivated in 1999 and that water usage for alfalfa irrigation is, as limited by current allocations, 5 acre-feet per acre. The nine alfalfa-growing operations have an average size estimated to be 255 acres. This results in an average annual water use for irrigation of 1,275 acre-feet per year. The domestic use of water by a small farming community of 25 people is estimated to be 10 acre-feet per year, so the average volume of water that would supply the annual water needs of a hypothetical future agricultural small community would be 1,285 acre-feet.

ES.6.2 Radiation Protection of Individuals

According to current understanding, contaminated ground water is the principal pathway by which a release of radionuclides from a repository at Yucca Mountain could cause radiation exposures to humans. Figure ES.6-1 illustrates the ground water pathway leading to human exposure from an undisturbed repository at Yucca Mountain. The major reservoirs (source terms) containing radionuclides at various times following closure are depicted as rectangles.

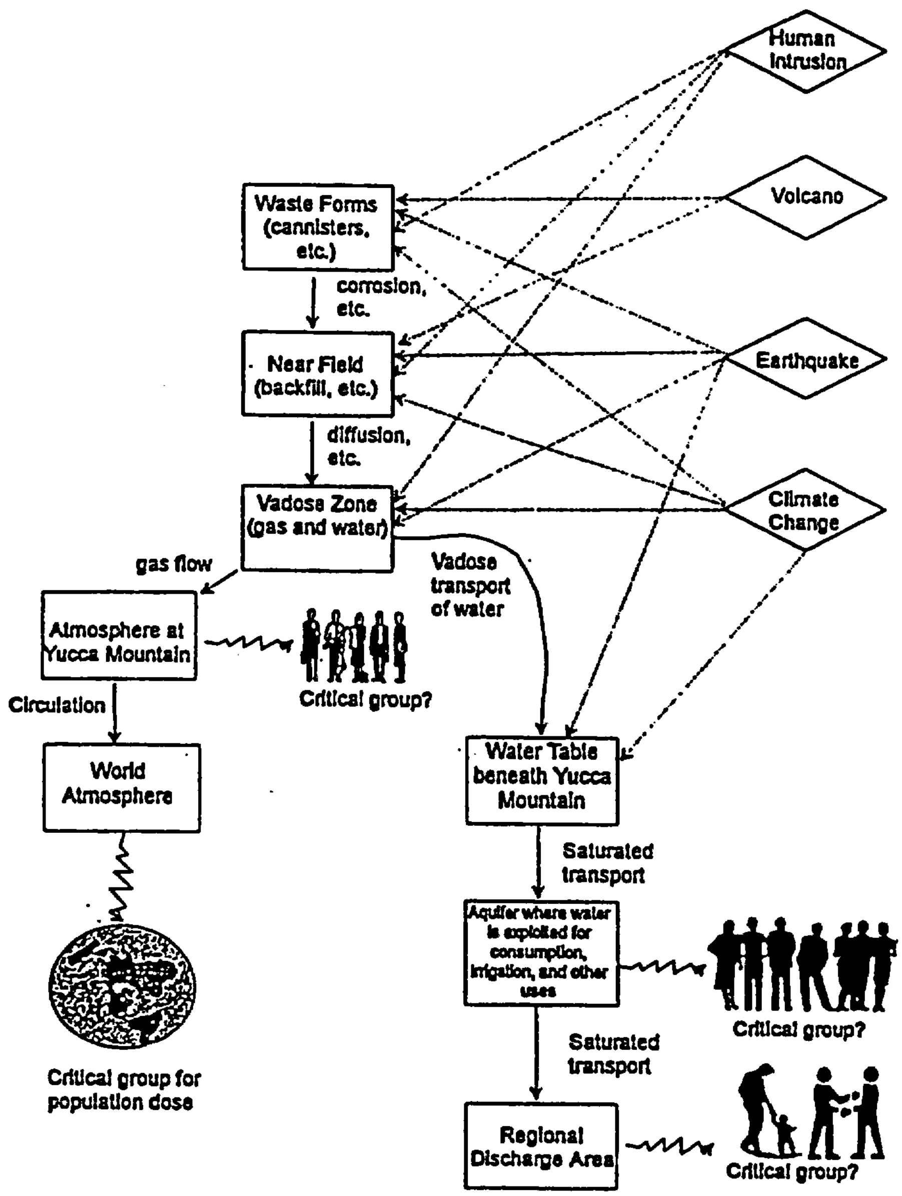

Figure ES.6-1. Schematic Illustration of the Major Pathways from a Repository at Yucca Mountain to Humans (copied from the NAS report, 1995)

Solid arrows between reservoirs represent the probable processes by which radionuclides are transported from one reservoir to another in an undisturbed repository. Major processes and events with the potential to modify normal behavior or drastically alter the physical integrity of reservoirs are shown in the figure as diamonds. These modifiers are connected by dashed lines to those reservoirs most likely to have the most significant impact.

Individuals in a human population may have greatly different responses to radiation exposure reflecting differences in factors such as age, life style, and family history. In addition, their potential exposure to radiation released from a repository at Yucca Mountain will depend on factors such as where they live and what they eat and drink. A wide range of radiation exposures and effects is therefore possible. Because of these variations, some specification of the exposure conditions to be considered in measuring compliance must also be part of the regulations. Specifying some variables in the compliance evaluations would provide a means to narrow and characterize the range of conditions for which evaluations of compliance are to be made. More than one approach is possible for assessing potential radiation doses to individuals down the hydrologic gradient from the repository.

ES.6.3 Dose Estimation Approaches

To determine the risk to exposed individuals resulting from contaminated ground water requires the development of a comprehensive exposure scenario that specifies discrete pathways and quantifies the intake of individual radionuclides. Pathways for human exposure from contaminated well water include internal exposure from the ingestion of drinking water, vegetables, fruits, dairy products, and meats. For persons engaged in agricultural activities, internal exposure may also result from the inhalation of airborne contaminants resuspended from soil irrigated with contaminated water. Over time, the buildup of soil contaminants could reach levels that also give significant external doses.

The implementation of an exposure scenario appropriate for a specified population requires a complex array of pathway parameter values that define potential radionuclide concentrations in various media to which individuals may be exposed. Exposure scenarios must also provide quantitative descriptions that include where individuals live, what they eat and drink, and what their sources of food and water are. Many key parameters needed to model human exposures at Yucca Mountain are highly site-specific and reflect the desert conditions of the sparsely populated Amargosa Valley. For example, the combined impacts of low rainfall, desert temperatures, and soil quality mandate extensive irrigation of farm crops and use of local ground water for cattle. Under these conditions, contaminated well water has the potential for developing unusually high radionuclide concentrations in all locally grown food products.

The Cricial Group Approach to Chatacterization of the Dose Receptor

The NAS report recommended the use of the critical group concept for the development of environmental standards. The critical group concept was first introduced by the International Commission on Radiation Protection (ICRP) in order to account for the variation in dose in a given population which may occur due to differences in age, size, metabolism, habits, and environment. This concept was adopted in total by the NAS panel, although the Academy differs from ICRP in the implementation of the concept. The ICRP defines the critical group in dose terms, while the NAS adapted the concept to individual risk. The critical group is defined by the ICRP as a relatively homogeneous group of people whose location and lifestyle are such that they represent those individuals expected to receive the highest doses (or be at highest risk) as a result of radioactive releases. As part of the critical group definition, the ICRP specifies the following additional criteria (also adopted by the NAS panel):

- <u>Size</u> - The critical group should be small in number and typically include a few to a few tens of persons.

- <u>Homogeneity among members of the critical group</u> - There should be a relatively small difference between those receiving the highest and the lowest doses. It is recommended that the range between the low and high doses not differ by more than a factor of ten or a factor of about three on either side of the critical group average.

- <u>Magnitude of dose/risk</u> - It is suggested that the regulatory limit defined by a standard exceed the calculated average critical group dose by at least a factor of ten.

- <u>Modeling assumptions</u> - In modeling exposure for the critical group, the ICRP recommends that dose estimates be based on cautious, but reasonable assumptions.

The ICRP does not, however, prescribe the lifestyle, habits, or conditions of exposure that may define a critical group into the future. Its generic recommendations suggest use of current knowledge and cautious, but reasonable, assumptions for characterizing future exposure scenarios.

To account explicitly for future uncertainties, the NAS report offered two probabilistic modeling approaches. The first, described in Appendix C of the NAS report, A Probabilistic Critical Group Approach, uses statistical methods and probability values to characterize members of the critical group. The second, The Subsistence-Farmer Critical Group, described in Appendix D of the report, also employs a probabilistic method, but identifies the subsistence farmer as the principal representative of the critical group.

The NAS Subsistence Farmer Critical Group model is quite similar to the RMEI approach (described below) that is used by EPA to characterize the dose receptor for purposes of rulemaking. The model described in Appendix D of the NAS report specifies *a priori* one or more subsistence farmers and makes assumptions designed to define a highly exposed farmer as representative of the critical group. Subsistence farming does not exclude commercial farmers who raise food for personal consumption, in addition to cash farm products. The NAS assumed the subsistence farmer of the future would have nutritional needs consistent with those of a present-day person. Like the subsistence farmer of today, most or all drinking water would be obtained from an on-site well also used in the production of all consumed food. The subsistence farmer is also assumed to live his/her entire life at the same location. Thus, the magnitude of the dose to a subsistence farmer will largely be defined by the radionuclide concentrations in ground water at the point of water withdrawal.

EPA's Reasonably, Maximally Exposed Individual as the Dose Receptor

EPA has developed a method for estimating potential radiation doses based on the concept of the reasonably, maximally exposed individual (RMEI). The RMEI concept, which involves estimating the dose to a person assumed to be at high risk based on reasonable (i.e., not overly or insufficiently conservative) assumptions, has been used in previous agency programs and guidance.

The total population that might be exposed from ground water pathways is very small. There are only about ten people living in community of Lathrop Wells in Amargosa Valley about 20 km from the Yucca Mountain site. If this small population was defined as the critical group, the exposure to the group would likely be on the same order as if the exposure was defined based on an RMEI living at that location. Thus, in the Yucca Mountain setting, there is no significant difference between the critical group and the RMEI.

The basic approach for estimating doses to be incurred by the RMEI is to identify and characterize the most important exposure pathway(s) and input parameters. By using maximum or near-maximum (e.g., 95th percentile) values for one or a few of the most sensitive parameters, while assuming average values for others, the resulting dose estimates should reasonably correspond to the near-maximum exposures to any member of the exposed population. The ultimate objective of the approach is to define an exposure well above average exposures, but within the upper range of possible exposures. The RMEI is not intended to represent the most extreme case.

ES.6.4 Exposure Scenarios

The EPA has considered four basic scenarios for estimating potential exposures of the RMEI in the Yucca Mountain area. The scenarios involve characteristics of the region and represent potential human habitation patterns and lifestyles in the Yucca Mountain region based on local climatic, geologic, and hydrologic conditions.

(1) *Subsistence (low technology) Farmer.* In this scenario, the farmer is assumed to live in the Yucca Mountain area and to be exposed chronically (both indoors and outdoors) to residual concentrations of radionuclides in soil through all exposure pathways. Contaminated water from the aquifer is the only source of water for these individuals. The location and habits of this individual will be consistent with historical locations, and easily accessible water (approximately 30-40 km from the disposal system). All the individual's food and water would come from contaminated sources.

(2) *Commercial Farmer.* Based upon economic factors and current technologies, certain areas around Yucca Mountain are suitable for commercial crop production. These areas are either currently being farmed (approximately 30 km from the Yucca Mountain disposal system) or could be economically viable based upon reasonable assumptions, current technology, and experience in other parts of the arid west. In addition, some parts of the region could possibly support emerging technologies such as hydroponic applications and fish farming. Exposure pathways in this scenario are the same as those described for the subsistence farmer.

(3) *Rural-Residential Person.* In this scenario, individuals are assumed to live closer to Yucca Mountain and to be exposed through the same pathways described for the subsistence farmer in Scenario 1. However, in this case the residents are not assumed to be full-time agricultural

workers. Instead, these individuals work primarily out of the area and engage only in light farming and recreational activities within it. Furthermore, it is assumed that all of the drinking water (2 liters/day) and some of the food production will involve use of water contaminated with radionuclides. This lifestyle is typical of most of the people currently living in the Amargosa Valley.

(4) *Domestic Use of an Underground Drinking Water Supply.* Based upon current water usage in the arid West, there could be an hypothetical water supply which could serve a community living north of Interstate 95 closer to the repository site (inside the Nevada Test Site).

For each of these four scenarios, there are eight exposure pathways to be evaluated:

- External radiation from radionuclides in soil
- Inhalation of resuspended soil and dust containing radionuclides
- Inhalation of radon and radon decay products from soil containing radium
- Incidental ingestion of soil containing radionuclides
- Ingestion of drinking water containing radionuclides transported from soil to potable ground water sources
- Ingestion of home-grown produce contaminated with radionuclides taken up from soil
- Ingestion of meat (beef) or milk containing radionuclides taken up by cows grazing on contaminated plants (fodder)
- Ingestion of locally-caught fish containing radionuclides

ES.6.5 <u>Compliance Evaluation</u>

The above discussion of receptor groups and exposure scenarios illustrates the factors involved in assessing compliance with radiation protection standards. In practice, the critical group and exposure scenarios to be used in assessing compliance with EPA's standards for Yucca Mountain will be implemented under regulations to be developed by the NRC in conformance with the EPA standards. The NRC regulations will be the basis for review of DOE's License Application.

The License Application from DOE will include assessments of potential radionuclide releases from the repository and assessment of compliance with regulatory standards under specified exposure conditions. Because of the long time frames and uncertainties involved in predicting repository performance, DOE will be required to demonstrate "reasonable expectation" of compliance with the standards. The term "reasonable expectation" conveys the concept that absolute numerical proof of compliance with the standards is neither necessary nor likely to be obtainable.

One of the key factors in evaluating compliance with EPA's Yucca Mountain standards is the radiation dose potential associated with each of the exposure pathways used by the receptor. The dose potential is characterized in terms of dose conversion factors, which relate radionuclide concentrations in the pathways for exposure, such as water and food consumed, to dose received. The dose consequence of radionuclides in the environment therefore depends on the relative importance of the various pathways for the exposed individual, which depends, in turn, on the lifestyle of the exposed individual. It is to be expected, for example, that the pathways and dose factors for a farmer residing in an arid environment, such as Yucca Mountain, will differ from those for an urban resident.

Dose conversion factors for assessing compliance with regulatory standards have been evaluated by DOE, EPA, and CNWRA for a wide variety of environmental conditions and receptor lifestyles. The DOE is currently acquiring data to enable characterization of dose factors specifically for environmental conditions and human activities in the Yucca Mountain region. The DOE plans to use site-specific dose conversion factors in the License Application.

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CHAPTER 2

HISTORY OF RADIATION PROTECTION IN THE UNITED STATES AND CURRENT REGULATIONS

2.1 INTRODUCTION

Radiation from cosmic rays and naturally occurring radioactivity contained in the earth make up the natural radiation background environment in which all life forms have evolved. Society's recognition of radiation began in 1895 with the discovery of X-rays; naturally occurring radioactivity was observed in 1896. These discoveries marked the beginning of the study and use of radioactive substances in science, medicine, and industry.

The discovery of radioactivity led rapidly to the development of medical radiology, industrial radiography, nuclear physics, and nuclear medicine. By the 1920s, the use of X-rays in diagnostic medicine and industrial applications was widespread. Radium was being routinely used in luminescent dials and by doctors in therapeutic procedures. By the 1930s, biomedical and genetic research scientists were studying the effects of radiation on living organisms, and physicists were beginning to understand the mechanisms of spontaneous fission and radioactive decay. In the 1940s, research in nuclear physics had advanced to the point where a self-sustaining fission reaction was demonstrated under laboratory conditions. These events led to the construction of the first nuclear reactors and the development of atomic weapons.

Today, the use of radiation, be it naturally occurring or man-made, is widespread and reaches every segment of our society. Common examples include:

- Nuclear reactors used: (1) to generate electricity, (2) to power ships and submarines, (3) to produce radioisotopes used for research, medical, industrial, space and national defense applications, and (4) as research tools for nuclear engineering and physics

- Particle accelerators used to produce radioisotopes and radiation and to study the structure of matter, atoms, and common materials

- Radioisotopes used in nuclear medicine, biomedical research, and medical treatment

- X-rays and gamma rays used as diagnostic tools in medicine, as well as in diverse industrial applications, such as industrial radiography, luggage X-ray inspections, and nondestructive materials testing

- Common consumer products, such as smoke detectors, luminous-dial wrist watches, luminous markers and signs, cardiac pacemakers, lightning rods, static eliminators, welding rods, lantern mantles, and optical glass

It was soon recognized that the use of radioactive materials would have to be controlled to protect the public, workers, and the environment from radiation exposures. The following sections present a brief history of the evolution of radiation protection activities, their principles and concepts, and U.S. regulatory programs and strategies. Included in this discussion is the influence that certain international advisory bodies, such as the International Commission on Radiological Protection (ICRP), have had on the development of U.S. radiation protection policies. Chapter 3 presents a summary of spent nuclear fuel and high-level waste disposal programs in other countries.

2.2 THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, THE NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, AND THE INTERNATIONAL ATOMIC ENERGY AGENCY

Initially, the dangers and risks posed by X-rays and radioactivity were poorly understood. By 1896, however, "X-ray burns" were being reported in the medical literature, and by 1910, it was understood that such "burns" could be caused by radioactive materials. By the 1920s, sufficient direct evidence (from radium dial painters, medical radiologists, and miners) and indirect evidence (from biomedical and genetic experiments with animals) had been accumulated to persuade the scientific community that an official body should be established to make recommendations concerning human protection against exposure to X-rays and radium.

In 1928, at the Second International Congress of Radiology meeting in Stockholm, Sweden, the first radiation protection commission was created. Reflecting the uses of radiation and radioactive materials at the time, the body was named the International X-Ray and Radium Protection Commission. It was charged with developing recommendations concerning radiation protection. In 1950, to better reflect its role in a changing world, the Commission was reorganized and renamed the International Commission on Radiological Protection.
During the Second International Congress of Radiology, the newly created Commission suggested to the nations represented at the Congress that they appoint national advisory

committees to represent their viewpoints before the Commission and to act in concert with the Commission in developing and disseminating recommendations on radiation protection. This suggestion led to the formation of the U.S. Advisory Committee on X-Ray and Radium Protection in 1929. In 1964, the Committee was congressionally chartered as the National Council on Radiation Protection and Measurements (NCRP).

Throughout their existence, the ICRP and the NCRP have worked closely together to develop radiation protection recommendations that reflect the current understanding of the risks associated with exposure to ionizing radiation (ICR34, ICR38, ICR51, ICR60, ICR65). Neither organization has official status, in that they do not have authority to issue or enforce regulations. However, their recommendations often serve as the basis for the radiation protection regulations adopted by the regulatory authorities in the United States and most other nations.

The International Atomic Energy Agency (IAEA) was chartered in July 1957 as an autonomous intergovernmental organization under the aegis of the United Nations. The IAEA gives advice and technical assistance to Member States on nuclear power development, health and safety issues, radioactive waste management, and on a broad range of other areas related to the use of radioactive material and atomic energy in industry and government. As is the case for ICRP and NCRP, Member States do not have to follow IAEA recommendations. However, funding for international programs dealing with the safe use of atomic energy and radioactive materials can be withheld if Member States do not comply with IAEA recommendations. In addition, in matters related to safeguarding special nuclear material, the full weight of the UN can be brought to bear to "enforce" UN resolutions pertaining to the use of nuclear materials for peaceful purposes. Many of the IAEA recommendations adopt ICRP recommendations with respect to the Commission's radiation protection philosophy and numerical criteria.

In 1977, the ICRP released recommendations that are in use today. ICRP Publication No. 26 (ICR77) adopted the weighted, whole-body dose equivalent (defined as the effective dose equivalent) concept for limiting occupational exposures. This approach reflected the increased understanding of the differing radiosensitivities of various organs and tissues and was intended to sum exposures from external sources and from internally deposited nuclides. (Note: The concept of summing internal and external exposures to arrive at total dose had been mentioned as early as ICRP Publication No. 1 [ICR60].)

ICRP No. 26 defined the goal of radiation protection as the prevention or limitation of effects from radiation exposure and the assurance that practices involving radiation exposure are justified. The concept of collective dose equivalent for populations was also discussed. The ICRP No. 26 recommendations represented the first explicit attempt to relate and justify permissible radiation exposures with quantitative levels of acceptable risk. The ICRP concluded that "...the mortality risk factor for radiation-induced cancers is about 10^{-4} per rem, as an average for both sexes and all ages... ." The risks of average occupational exposures (about 0.5 rem/year) are roughly comparable to risks experienced in safe industries, 10^{-4} annually. At the permissible limit of 5 rem/year, the risk is comparable with that experienced by some workers in occupations having higher-than-average risk.

For members of the public, the ICRP considered that an annual risk in the range of 10^{-6} to 10^{-5} would likely be acceptable (ICR77). The ICRP recommended an annual individual dose limit of 100 mrem (1 mSv) from all radiation sources. However, the Commission also recognized that an annual individual dose limit of 500 mrem (5 mSv) may be permissible, provided that the average annual effective dose equivalent over a lifetime does not exceed the principal limit of 100 mrem (1 mSv) (ICR85a). No dose limits for populations were proposed.

In 1979, the ICRP issued Publication No. 30 (ICR79) establishing the Annual Limit on Intake (ALI) system for limiting the intake of radionuclides by workers. The ALI is the activity of a given nuclide that would irradiate a person to the limit set in ICRP No. 26 for each year of occupational exposure. It is a secondary limit, based on the primary limit of equivalent whole-body irradiation, and applies to intake by either ingestion or inhalation. The recommendations of ICRP No. 30 applied only to occupational exposures. In 1983, the ICRP issued a statement (ICR84) clarifying the use of ALIs and Derived Air Concentrations (DACs) for members of the public.

In 1985, the ICRP issued a statement (ICR85a) refining dose limits for members of the public. ICRP No. 26 had endorsed an annual limit of 500 mrem, subject to certain conditions. In making this endorsement, it was assumed that the conditions would, in practice, restrict the average annual dose to about 100 mrem. In its 1985 statement, the Commission stated that the principal limit was 100 mrem, while occasional and short-term exposures up to 500 mrem were thought to be acceptable.

The Commission has also published guidance for waste disposal (ICR85b) and for general radiological protection (ICR91). The first of these, "Radiation Protection for the Disposal of Solid Radioactive Waste," emphasizes an individual-risk approach that considers both the probability of a breach of a disposal site and its consequence upon the critical group.

In 1987, the NCRP issued Report No. 91 (NCR87), which acknowledged the assumptions and the basic thrust of the recommendations in ICRP Reports 26 and 30. In discussing risk estimates, the NCRP noted in its report that new data were becoming available that might require changes in the current estimates. However, the value recommended in ICRP No. 26 of 10^{-4} per rem was retained for a nominal lifetime somatic risk for adults.

The NCRP also noted that continuous annual exposure to 100 mrem gives a person a mortality risk of about 10^{-5} annually, or approximately 10^{-3} in a lifetime (NCR87). Similar to the 1985 ICRP statement, annual limits of 500 mrem were recommended for infrequent exposures and 100 mrem for continuous (or frequent) exposures. These limits do not include natural background or medical exposures.

In 1989, the IAEA issued reports 96 and 99 in its Safety Series (IAE89a, IAE89b). These documents presented criteria and guidance for the underground disposal of nuclear waste. Safety Series No. 99, "Safety Principles and Technical Criteria for the Underground Disposal of High-Level Radioactive Wastes," set out basic design objectives to ensure that "humans and the human environment will be protected after closure of the repository and for the long periods of time for which the wastes remain hazardous." The report went on to state that for releases from a repository due to gradual processes, the dose upper bound should be less than an annual average dose value of 1 mSv (i.e., 100 mrem/yr)[6] for prolonged exposures for individuals in the critical group (defined as the members of the public whose exposure is relatively homogeneous and is typical of individuals receiving the highest effective dose equivalent or dose equivalent from a given radiation source). Finally, it suggested a risk upper bound of 10^{-5} per year for an individual for disruptive events.

In 1990, the ICRP issued Publication 60, which broadened its recommendations to include a wider range of exposure scenarios than had been previously addressed. Publication 60 also gave

[6] The ICRP has adopted the international system of units (SI). Under this system, 1 Sv equals 100 rem. As such, 1 mSv equals 100 mrem.

support to new concepts in the field of radiation exposure protection, most notably the ALARA (as low as reasonably achievable) concept of worker protection optimization. The ALARA principle suggests dose limits should be set at the lowest levels reasonably possible for a given scenario. In recent years, several international organizations, including the Council of the European Communities (CEC) and the Organization for Economic Cooperation and Development/Nuclear Energy Agency's (OECD/NEA's) Committee on Radiation Protection and Public Health (CRPPH), have worked to interpret this principle and develop guidelines for its practical use (NEA94). The formality with which the ALARA principle has been adopted varies widely internationally. In many cases, the ALARA principle is being applied only as part of a nonquantified conceptual framework within which protection measures are implemented; in other countries, the application of the ALARA approach to worker safety is becoming increasingly formalized (OEC95a).

In recent years, the IAEA has been developing new international safety standards and guidance documents. Foremost among these is "International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources," known as BSS (Basic Safety Standards, Safety Series 115-I). The BSS was approved by the IAEA Board of Governors in 1994 and published as an interim document in December 1995. A joint effort of the Food and Agricultural Organization of the United Nations, the International Labor Organization, the OECD/NEA, the Pan-American Health Organization, and the World Health Organization, the BSS is notable primarily for its movement toward an integrated approach to managing exposure risk in which potential but unlikely events (such as accidents) are evaluated along with comparatively normal, likely scenarios for exposure. Previously, safety assessment had focused only on comparatively normal, likely scenarios (OEC95a). IAEA has also been developing a comprehensive set of safety standards for radioactive waste management called Radioactive Waste Safety Standards (RADWASS). RADWASS includes a safety fundamentals document entitled "The Principles of Radioactive Waste Management" and a safety standard document entitled "Establishing a National Safety Standard for Radioactive Waste Management." Both of these were approved by the IAEA Board of Governors and published in October 1995. Three other safety standards (S-2, S-3, and S-6) addressing predisposal management of radioactive waste, near-surface disposal of radioactive waste, and decommissioning are under review (OEC95b). The entire RADWASS series is currently under review to ensure harmonization with Safety Series Publications and BSS documents.

Criteria development is also continuing through an IAEA Working Group on Principles and Criteria for Radioactive Waste Disposal. The working group's focus includes post-closure monitoring, optimization, retrievability, dose vs. risk, and safety indicators under different time frames. The group's first report, entitled *Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories,* was published in 1994 (SNI95).

In recent years, the CEC has been developing directives on radiation safety standards for radiation exposures established under European Atomic Energy Community (EURATOM) agreements. In accordance with ICRP recommendations, the CEC suggested in 1993 that doses to members of the public be limited to 100 mrem per year from all sources except medical and that occupational doses be limited to 2,000 mrem annually. The CEC is also expected to propose criteria for the shipment of radioactive waste among member countries and for the export of radioactive waste to nonmember countries (OEC93).

Finally, in 1989, Radiation Protection and Nuclear Safety authorities in Denmark, Finland, Iceland, Norway, and Sweden developed a set of safety criteria for the disposal of high-level radioactive waste. Revised in 1993 after international review, the Nordic Principles are largely consistent with other criteria developed on the international level. The Principles outline a radiation protection approach employing the concept of optimization and an individual dose limit of 0.1 millisievert (10 mrem) per year. Basic guiding objectives for HLW disposal programs include reduction of burden for future generations, long-term environmental protection, and the use of specific safety assurance measures. Finally, the Principles contain technical recommendations for repository design, site geology, and closure (SNI95).

2.3 FEDERAL RADIATION COUNCIL GUIDANCE

The Federal Radiation Council (FRC) was established in 1959 by Executive Order 10831. The Council arose as a result of new information that became available in the 1950s on the effects of radiation. Before that time, only nongovernmental radiation advisory bodies (i.e., ICRP and NCRP) existed, and their recommendations were not binding on users of radiation or radioactive materials. The FRC was established as an official Government entity and included representatives from all Federal agencies concerned with radiation protection. The Council served as the primary coordinating body for all radiation activities conducted by the Federal Government (FRC60a) and was responsible for:

...advising the President with respect to radiation matters, directly or indirectly affecting health, including providing guidance to all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States... .

The Council's first recommendations concerning radiation protection guidance for Federal agencies were approved by President Eisenhower in 1960 (FRC60b). The guidance established exposure limits for members of the general public. These included the yearly radiation exposure of 0.5 rem per year for the whole body of individuals in the general population and an average gonadal dose of 5 rem in 30 years for the general population (exclusive of natural background and the purposeful medical exposure of patients).

The guidance also established occupational exposure limits, which differed only slightly from those recommended by the NCRP and ICRP at the time (NCR54, NCR59). The guidance included:

- Whole body, head and trunk, active blood-forming organs, gonads or lens of the eyes are not to exceed 3 rem in 13 consecutive weeks, and the total accumulated dose is limited to 5 rems multiplied by the number of years beyond age 18, expressed as 5(N-18), where N is the current age

- Skin of the whole body and thyroid are not to exceed 10 rem in 13 consecutive weeks or 30 rem per year

- Hands, forearms, feet, and ankles are not to exceed 25 rem in 13 consecutive weeks or 75 rem per year

- Bone is not to exceed 0.1 microgram of radium-226 or its biological equivalent

- Any other organs are not to exceed 5 rem in 13 consecutive weeks or 15 rem per year

In addition to the formal exposure limits, the guidance also established as Federal policy that any radiation exposure should be justified and that "...every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable... ." Both of these concepts had previously been proposed by the ICRP. The inclusion of the requirements to consider benefits and keep all exposures to a minimum was based on the possibility that there is no threshold for radiation. The linear, nonthreshold, dose-response relationship was assumed to place an upper limit on the estimate of radiation risk. However, the FRC explicitly recognized that it might also represent the actual level of risk.

Following the issuance of this initial guidance, the FRC continued to provide guidance on a number of radiation protection matters. In 1970, the Council was dissolved, and its functions were transferred to the Environmental Protection Agency under authority of Reorganization Plan No. 3 (NIX70).

2.4 ENVIRONMENTAL PROTECTION AGENCY

Since its creation in 1970, the EPA has issued regulatory standards regarding radiation hazards from a number of different sources, including underground mining (EPA71), the uranium fuel cycle operations (EPA77), uranium and thorium mill tailings (EPA83), radionuclide air emissions (EPA89a), and management and disposal of spent nuclear fuel and high-level and transuranic radioactive wastes (EPA93). Recently, EPA issued compliance criteria for the WIPP (EPA96). EPA is currently developing a standard for the disposal of contaminated soil at decommissioned sites, including Federal facilities.

The Agency has also exercised its authority to issue Federal guidance to limit radiation exposures to workers (EPA87), as well as to the general public. In December 1994, EPA issued proposed Federal guidance to update the previous Federal Radiation Protection Guidance for Exposure to the General Public which was originally adopted in 1960 and 1961 (EPA94). The Agency is now finalizing these new recommendations.

EPA has also provided extensive technical information regarding the assessment of risk from radiation hazards. Specific examples of such information include radionuclide intake limits, occupational radiation doses, biological parameters, and dose conversion factors (EPA88). This information has been used extensively in the development of EPA standards and guidance, as well as specific site assessments.

In addition to its responsibility to provide Federal guidance on radiation protection, the EPA has various statutory authorities and responsibilities for regulating exposure to radiation. The standards and regulations that EPA has promulgated and proposed with respect to controlling radiation exposures are summarized in the following paragraphs. Their applicability to EPA's proposed standards under 40 CFR Part 197 is also discussed.

2.4.1 Environmental Radiation Exposure

The Atomic Energy Act (AEA) of 1954, as amended, and Reorganization Plan No. 3 granted the EPA the authority to establish generally applicable environmental standards for exposure to radiation (AEA54, NIX70). The AEA is the cornerstone of current radiation protection activities and regulations. In 1977, pursuant to this authority, the EPA issued standards limiting exposures from operations associated with the light-water reactor fuel cycle (EPA77). These standards, under 40 CFR Part 190, cover normal operations of the uranium fuel cycle. The standards limit the annual dose equivalent to any member of the public from all phases of the uranium fuel cycle (excluding radon and its daughters) to 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ. To protect against the buildup of long-lived radionuclides in the environment, the standards also set normalized emission limits for krypton-85, iodine-129, and plutonium-239 combined with other transuranics with a half-life exceeding one year. The dose limits imposed by the standards cover all exposures resulting from radiation and radionuclide releases to air and water from operations of fuel-cycle facilities. The development of these standards took into account both the maximum risk to an individual and the overall effect of releases from fuel-cycle operations on the population, and balanced these risks against the costs of effluent control.

2.4.2 Environmental Impact Assessments

In 1969, Congress passed the National Environmental Policy Act (NEPA), which declared a national policy that encouraged a productive and enjoyable harmony between the public and the environment (NEP70). The Act recognized the profound impact of human activity on the interrelations of all components of the natural environment and sought to promote efforts to prevent or eliminate damage to the environment. To this end, the national policy is geared towards increasing the understanding of the ecological systems and natural resources important to the United States. In addition, the Act established a Council on Environmental Quality to assist the President in determining the state of the environment and developing environmental policy initiatives.

The Act also directed all Federal agencies to use a systematic, interdisciplinary approach to ensure the integrated use of natural, social, and environmental sciences in support of plans and decisions that have a potential impact on the environment. Specifically, it mandated that a detailed Environmental Impact Statement (EIS) be submitted for any major action proposed by a Federal agency or for legislation that would significantly affect the quality of the environment. The EIS must describe any adverse environmental effects that the proposal would cause, alternatives to the proposed action, effects of the project on the long-term productivity of the environment, and any irreversible and irretrievable commitment of resources involved in the proposed action. The EIS must also be prepared through consultation with any Federal agency having jurisdiction or special expertise regarding the project and its environmental impact.

The Final EIS prepared by the Department of Energy for the Yucca Mountain site must comply with NEPA requirements.

2.4.3 Ground Water Protection

The Safe Drinking Water Act (SDWA) was enacted to assure safe drinking water supplies and to protect against endangerment of underground sources of drinking waters (USDWs). Under the authority of the SDWA, the EPA issued interim regulations (40 CFR Part 141, Subpart B) covering the permissible levels of radium, gross alpha, man-made beta, and photon-emitting contaminants in community water supply systems (EPA76). Similar to hazardous chemical substances, limits for radionuclides in drinking water are expressed as Maximum Contaminant Levels (MCLs). The current MCL for radium-226 and radium-228 combined is 5 picoCuries per liter (5 pCi/L), and the MCL for gross alpha particle activity (including radium-226, but excluding radon and uranium) is 15 pCi/L. For man-made beta particle- and photon-emitting radionuclides (except tritium and strontium-90), individually or in combination, the MCL is set at an annual dose limit of 4 millirem to the total body or any internal organ. For tritium and strontium-90, the MCLs are 20,000 pCi/L and 8 pCi/L, respectively.

In 1991, the EPA issued a Notice of Proposed Rulemaking (NPRM) under 40 CFR Parts 141 and 142 to update the 1976 interim regulations for radionuclide water pollution control (EPA91). The NPRM, under the SDWA, proposed the establishment of Maximum Contaminant Level Goals (MCLGs) and Maximum Contaminant Levels (MCLs). The MCLGs and MCLs target radium-226, radium-228, natural uranium, radon, gross alpha, gross beta, and photon emitters. As proposed, MCLGs are not enforceable health goals. In contrast, MCLs are enforceable standards. The EPA concluded that radionuclide MCLGs should be set at zero to avert known or anticipated adverse health effects while providing an adequate margin of safety. In setting the MCLGs, the EPA also committed itself to evaluating the feasibility, costs, and availability of water treatment technologies, as well as other practical considerations. The proposed regulations state the following MCLs: radium-226, 20 pCi/L; radium-228, 20 pCi/L; radon-222, 300 pCi/L; uranium, 20 micro g/L; adjusted gross alpha, 15 pCi/L; and beta and photon emitters, 4 mrem ede/yr.

Over the past 20 years, the EPA has used two different methods to calculate radioactivity concentrations for beta particle and photon emitting radionuclides in drinking water corresponding to the MCL of 4 mrem/yr. Each method incorporates successive improvements in the risk models and dose conversion factors for ingested radioactivity recommended by national and international advisory committees on radiation protection and adopted by the Agency.

The first method is a requirement (§141.6(b)) of EPA's 1976 Interim Regulations. It specifies that, with the exception of tritium and strontium-90, the concentration of beta/photon emitters causing 4 millirem (mrem) total body or organ dose equivalent shall be calculated on the basis of a 2 liter per day drinking water intake using the 168 hour data listed in Handbook 69 of the National Bureau of Standards (NBS63). The dose models used in preparing Handbook 69 are based on earlier recommendations of the International Commission on Radiological Protection (ICR60). For tritium and strontium-90, the EPA provides derived activity concentrations in Table A of §141.6(b) based on specific dose models for these nuclides.

The second method is presented in EPA's 1991 proposed rule on final drinking water standards for radionuclides (EPA91). This method is based primarily on the updated dosimetric data in ICRP Publication 30 (ICR79) and uses the Agency's own risk assessment methodology formalized in the RADRISK computer code (DUN80). Under this approach, concentration levels are calculated for each radionuclide individually by limiting the dose to the total body (i.e., the effective dose equivalent or ede) to 4 mrem/yr ede, rather than on a dose rate of 4 mrem/yr to the critical organ. Similar to the first method, the second method assumes continuous intake of activity over a lifetime at a rate of 2 liters of drinking water per day.

2.4.4 Radionuclide Air Emissions

In December 1979, the EPA designated radionuclides as hazardous air pollutants under Section 112 of the Clean Air Act (CAA) Amendments of 1977 (Public Law 95-95) (EPA79). In April 1983, the EPA proposed standards regulating radionuclide emissions from four source categories, one of which included U.S. Department of Energy (DOE) facilities. The rule established annual airborne emission limits for radioactive materials and specified that annual doses resulting from such emissions should not exceed 25 mrem to the whole body and 75 mrem to any critical organ for members of the general public. The EPA also proposed not to regulate several other categories of facilities, including high-level radioactive waste disposal facilities. EPA based its decision with respect to high-level waste disposal facilities on estimated releases from conceptual repositories that indicated that the airborne exposure pathway would not cause doses high enough to warrant regulation.

In October 1984, following a court order, the EPA withdrew the proposed emission standards based on the findings that the control practices already in effect protected the public from radionuclide releases with an ample margin of safety. The Agency also affirmed its position not to regulate other categories of emission sources, including uranium fuel facilities and high-level radioactive waste.

In December 1984, a U.S. District Court found the EPA in contempt of its order and directed the EPA either to issue final radionuclide emission standards or make a finding that radionuclides are not hazardous air pollutants. The EPA complied with the court order in 1985 by issuing standards for selected sources (EPA85a, EPA85b). As a result of the decision in *National Resources Defense Council Inc. v. EPA,* November 1987, the Agency submitted a motion to the court requesting a voluntary remand of its national emission standards for the four original categories of emission sources proposed in April 1983. In December 1987, the Court granted the EPA's motion for voluntary remand and established a schedule to propose new regulatory standards within one year. The Court decision also defined the analytical process under which the EPA was to re-evaluate its standards. Two steps were identified: (1) determine what is safe, based exclusively on health risk, and (2) adjust the level of safety downward to provide an ample margin of safety.

In March 1989, the EPA issued a proposed rule for regulating radionuclide emissions under the CAA following the re-examination of the regulatory issues associated with the use of Section 112 (EPA89a). The rule proposed four policy alternatives to control emissions and risks from 12 categories of sources. Each of the four approaches considered the acceptable risk criterion differently. The four approaches were:

- Case-by-Case Approach: Acceptable risk considers all health information, risk measures, potential biases, assumptions, and quality of the information. The maximum individual lifetime fatal cancer risk must not exceed 1×10^{-4}.
- Incidence-Based Approach: Based on the best estimate of the total incidence of fatal cancer. The proposed acceptable level of incidence must not exceed one fatal cancer per year per source category.
- Maximum Individual Risk Approach (10^{-4} or less): Only risk indicator considered is the best estimate of the maximum individual lifetime risk of fatal cancer. The maximum individual lifetime risk must not exceed 1×10^{-4}.
- Maximum Individual Risk Approach (10^{-6} or less): This approach is similar to the previous one. The maximum individual lifetime risk, however, must not exceed 1×10^{-6}.

Consistent with the two-step process established by the Court, the Agency determined an ample margin of safety after ascertaining a safe level based solely on health risks. In reaching its final decision, the EPA considered all health risk measures, as well as technological feasibility, costs, uncertainties, economic impacts of control technologies, and any other relevant information.

In its radionuclide emission standards, EPA considered a lifetime risk to an individual of approximately 1 in 10,000 as acceptable. The presumptive level provides a benchmark for judging the acceptability of maximum individual risk, but does not constitute a rigid line for making that determination.

In its final rule, EPA concluded that there was no need to establish air emission standards for high-level waste disposal repositories since anticipated operations at the site would be governed by 40 CFR Part 191. Radioactive materials received at such facilities are sealed in containers. Normal operations do not require additional processing or handling because spent nuclear fuel or high-level waste is received and emplaced into the ground in its original containers. Operations at the disposal site, which may require additional waste processing or repackaging before the site is declared a disposal facility, are covered by 40 CFR Part 191 and must comply with Subpart I of the National Emission Standards for radionuclides[7] (EPA89b). Consequently, the Agency believed there is an ample margin of safety since the likelihood of releases, and attendant risks, is very low.

2.4.5 Disposal of High-Level Radioactive Waste and Spent Nuclear Fuel

Congress passed the Nuclear Waste Policy Act (NWPA) of 1982 to provide for the development of repositories for the disposal of high-level radioactive waste and spent nuclear fuel, and to establish a program of research, development, and demonstration regarding this disposal (NWP83). The Act established a schedule for the siting, construction, and operation of repositories that would provide a reasonable assurance that the public and environment would be adequately protected from the hazards posed by high-level radioactive waste. The Secretary of Energy was charged with nominating candidate sites for a repository and following a number of steps through a process of Presidential and Congressional approval, site characterizations, public participation, and hearings. The Act also required the Secretary to adhere to NEPA in considering alternatives and to prepare an EIS for each candidate site.

Initially the Act called for the development of two mined geologic repositories. The first repository was to be selected from nine candidate sites in western states; the second repository was to be located in the eastern United States in crystalline rock. EPA was charged with the responsibility of promulgating generally applicable standards for the protection of public health and the environment from off-site releases from radioactive material in repositories. The NRC, in turn, was responsible for promulgating technical requirements and criteria consistent with EPA's standards to serve as the basis for approving or disapproving applications regarding the use, closure, and post-closure of the repository. The Act also discussed interim waste storage requirements, as well as the payment of benefits to affected States and tribal groups to allow them sufficient resources to participate fully in the process.

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[7] Subpart I of the National Emission Standard can be found in 40 CFR Part 61.101 and is entitled "National Emission Standard for Radionuclide Emissions from Facilities Licensed by the Nuclear Regulatory Commission (NRC) and Federal Facilities Not Covered by Subpart H." Subpart H of the National Emission Standard addresses radionuclide standards for DOE facilities.

In 1987, the NWPA was amended to reflect a redirection of the nuclear waste program. The generic nature of the original act was changed to reflect the selection of the Yucca Mountain site in Nevada as the only candidate site for the repository (NWP87). The State of Nevada was also identified as the affected community. All site-specific activities at other candidate sites were phased out, and the Final EIS, necessary for compliance with the NEPA, was to be prepared specifically for the Yucca Mountain site without further consideration of alternative sites. The redirection charged DOE with reporting to Congress on the potential social, economic, and environmental impacts of locating the repository at Yucca Mountain.

2.4.5.1 Generic Disposal Standards for High-Level and Transuranic Wastes

As discussed in Chapter 1, the First Circuit Court of Appeals remanded Subpart B of EPA's standards for the management and disposal of spent nuclear fuel and high-level and transuranic waste (40 CFR Part 191) in 1987. (See Section 1.3.4 for additional detail regarding the Court's action on 40 CFR Part 191.) The Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA) of 1992 reinstated all of the disposal standards remanded by the First Circuit Court of Appeals in 1987 except the three aspects of the individual and ground water protection requirements that were the subject of the court remand (WIP92). It then put the Agency on a schedule for issuing the final disposal standards. They were published in December 1993. The law also provided an extensive role for EPA in reviewing and approving various phases of DOE activities at the WIPP and required EPA to certify whether the WIPP repository would meet the final 40 CFR Part 191 standards. Finally, and of greatest importance to the current rulemaking, the WIPP LWA exempted radioactive waste disposal activities at Yucca Mountain from compliance with the generic standards set forth under the 40 CFR Part 191 standards.

2.4.5.2 Site-Specific Disposal Standards for High-Level Radioactive Waste

The Energy Policy Act (EnPA) of 1992 addressed energy efficiency throughout the United States in different situations and for various types of fuel. Title VIII of the Act dealt specifically with high-level radioactive waste. Section 801 of the EnPA assigned EPA the responsibility of promulgating public health and safety standards for protection of the public from releases from radioactive materials stored or disposed of in the repository at the Yucca Mountain site. EPA is to prescribe a maximum annual effective dose equivalent to individual members of the public from releases to the accessible environment from radioactive materials stored or disposed of in the repository (EnPA92). The Act also requires that the standards developed be based upon and consistent with the findings and recommendations of the NAS. Specifically, the NAS was charged with considering: the use of a dose-based standard, the reasonableness of post-closure oversight in preventing breaches, and the predictability of human intrusion over a period of 10,000 years. NAS's findings and recommendations were published on August 1, 1995, in its report *Technical Bases for Yucca Mountain Standards* (NAS95). These standards will apply only to Yucca Mountain.

2.4.6 Evaluation of Radiation Dose

The radiation dose incurred by an exposed individual is evaluated using the "committed effective dose equivalent" (CEDE) concept. The CEDE is the weighted sum of the "committed dose equivalent" to specified organs and tissues. The committed effective dose equivalent is the total effective dose equivalent, averaged over a given tissue or organ, that is deposited in the 50-year period following the intake of a radionuclide.

The CEDE approach to dose evaluation therefore takes into account the differing dose effects of various radionuclides in specific parts of the body over time, and the differing dose effects of external exposure to ionizing radiations of different types and energy levels. It accounts, for example, for the fact that some radionuclides that are taken into the body will be rapidly excreted after ingestion or inhalation, so that the dose effect is small. Other radionuclides may be retained indefinitely in specific organs so that if the decay rate is low and exposure continues over time, the body burden of the dose source, and therefore the dose committed to the organ, will continually increase with time. In general, the dose incurred will depend on the types and concentrations of radionuclides present, the conditions and duration of exposure, the biological half-life of the radionuclide in the body, and the effects of exposure on organs and tissues of the body.

Ability to apply the CEDE approach to dose evaluation is the result of a decades-long evolutionary process which has developed a data base for, and an understanding of, the physiological effects of radiation exposure. A brief history of the evolution of information and methodology for radiation dose evaluation, and a description of the CEDE methodology, are set forth in EPA's Federal Guidance Report No. 11 (EPA88). This document also contains tables of values for the committed dose equivalents per unit uptake for various radionuclides taken into the body and for various body organs and tissues.

In 1993, EPA issued a companion report, Federal Guidance Report No.12 (EPA93a), which tabulates dose coefficients for external exposure to photons and electrons emitted by radionuclides distributed in air, water, and soil. The dose coefficient values provided in this document are, like those in Federal Guidance Report No.11, intended to be used by government agencies to calculate the dose equivalent to organs and tissues of the body for given exposure conditions.

2.5 NUCLEAR REGULATORY COMMISSION

The NRC was created as an independent agency by the Energy Reorganization Act (ERA) of 1974 (ERA74), which abolished the AEC and moved the AEC's regulatory function to the NRC. This Act, coupled with the AEA, as amended, provided the foundation for regulation of the nation's commercial nuclear power industry. NRC regulations are issued under the U.S. Code of Federal Regulations Title 10 Chapter 1.

The mission of the NRC is to ensure adequate protection of public health and safety, the national defense and security, and the environment in the use of nuclear materials in the United States. The NRC's scope of responsibility includes regulation of commercial nuclear power reactors; nonpower research, test, and training reactors; fuel cycle facilities; medical, academic, and industrial uses of nuclear materials; and the transport, storage, and disposal of nuclear materials and waste. In addition to licensing and regulating the use of byproduct, source, and special nuclear material, the NRC is also responsible for assuring that all licensed activities are conducted in a manner that protects public health and safety. The NRC assures that none of the operations of its licensees expose an individual of the public to more than 100 mrem/yr from all pathways (NRC91).

The dose limits imposed by the EPA's standards for uranium fuel-cycle facilities (40 CFR Part 190) apply to the fuel-cycle facilities licensed by the NRC. These facilities are prohibited from releasing radioactive effluents in amounts that would result in doses greater than the 25 mrem/yr limit imposed by that standard. Currently, NRC-licensed facilities are also required to operate in accordance with the requirements of the CAA (40 CFR Part 61), which limits radionuclide emissions into the air (EPA89b).[8]

The NRC exercises its statutory authority over licensees by imposing a combination of design criteria, operating parameters, and license conditions at the time of construction and licensing. It assures that the license conditions are fulfilled through inspection and enforcement activities.

2.5.1 Fuel Cycle Licensees

The NRC licenses and inspects all commercial fuel cycle facilities involved in the processing and fabrication of uranium ore into reactor fuel. NRC regulations require an analysis of probable radioactive effluents and their effects on the population near fuel cycle facilities. The NRC also assures that all exposures are maintained as low as reasonably achievable (ALARA) by imposing design criteria for effluent control systems and equipment. After a license has been issued, fuel-cycle licensees must monitor their emissions and set up an environmental monitoring program to assure that the design criteria and license conditions have been met.

2.5.2 Radioactive Waste Disposal Licenses

The NWPA, as amended, specifies a detailed approach for high-level radioactive waste disposal. DOE has operational responsibility and the NRC has licensing responsibility for the transportation, storage, and geologic disposal of the waste. The disposal of high-level radioactive waste requires a determination of acceptable health and environmental impacts that may occur over a period of thousands of years. Current plans call for the ultimate disposal of waste in solid form in a licensed, geologic disposal system. The NWPA, as amended, designates Yucca Mountain, Nevada, as the candidate site for the high-level waste repository.

The EnPA provides additional direction to the NRC as to its role in the licensing of a specific disposal site at Yucca Mountain. Section 801 of the EnPA requires the Commission to modify its technical requirements and criteria under section 121(b) of the NWPA of 1982, as necessary, to be consistent with EPA's standards for the Yucca Mountain site. The NRC's requirements

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[8] Pursuant to Section 112(d)(9) of the CAA Amendments of 1990, EPA is proposing to rescind Subpart I as it applies to NRC-licensed facilities. The NRC is proposing to adopt a constraint level rule which would limit radionuclide airborne emissions to 10 mrem/yr.

and criteria shall assume that engineered barriers and post-closure oversight provided by the DOE will be sufficient to: (1) prevent any activity at the site that poses an unreasonable risk of breaching the repository's engineered or geological barriers and (2) prevent any increase in the exposure of individual members of the public to radiation beyond allowable limits (EnPA92).

NRC's original generic regulations governing deep geologic disposal (which were largely developed prior to the EnPA) are contained in 10 CFR Part 60 entitled *Disposal of High-level Radioactive Wastes in Geologic Repositories* (NRC81, NRC83). However, since the EnPA specifies that sites for consideration be limited to Yucca Mountain and since the legislation specifies the types of standards the Commission is to implement, NRC decided to promulgate site specific standards for Yucca Mountain at 10 CFR Part 63. The proposed rule is entitled *Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada* (*Federal Register*, February 22, 1999). The proposed rule applies only to Yucca Mountain. The generic rule at 10 CFR Part 60 will be modified to indicate that does not apply to Yucca Mountain nor can it be used as a basis for litigation in NRC's Yucca Mountain licensing procedures. The proposed 10 CFR Part 63 regulations are summarized below. In addition, the NRC promulgates (under 10 CFR Part 71) packaging criteria for the transportation of spent nuclear fuel and high-level and transuranic radioactive wastes. Under 10 CFR Part 72, the NRC licenses independent spent nuclear fuel storage facilities (NRC88).

Under the proposed 10 CFR Part 63, DOE is required to conduct site characterization activities prior to submitting a license application and to regularly report on these activities to NRC. When DOE submits the license application it must contain certain prescribed general information and a Safety Analysis Report. The license application must be accompanied by an environmental impact statement. The prescribed general infomation includes:

- A general description of the proposed geologic repository
- Proposed schedules for construction, receipt of waste, and emplacement of wastes
- A detailed plan to provide physical protection of the waste
- A description of the material control and accounting program
- A description of the site characterization work

The Safety Analysis Report is a comprehensive document with 22 prescribed elements including such items as a description and discussion of the engineered barriers system, an assessment of the expected performance after closure, an explanation of how expert elicitation was used, and a description of the quality assurance program.

After review of the license application and the environmental impact statement, NRC may authorize construction of the geologic repository operations area. In deciding whether to provide such authorization to DOE, NRC will examine safety, common defense and security and environmental values in making its determination that construction can begin.

The NRC may subsequently issue a license to DOE to receive nuclear waste if it finds that construction has been substantially completed, that the proposed activities in the operations area are in conformity with the application, that the issuance of a license is not inimical to common defense and security and will not constitute and unreasonable risk to public health and safety, and that adequate protective measures can be taken in the event of a radiological emergency at any time before permanent closure. The NRC license will contain a variety of conditions relating to:

- Restrictions on the physical and chemical form and radioisotopic content of the waste
- Restrictions on the size, shape, and materials and methods of construction of the waste packages
- Restrictions on the volumetric waste loading
- Testing and inspection requirements to assure that any restrictions are met
- Controls to limit access and prevent disturbance of the site
- Administrative controls to assure that site activities are conducted in a safe manner and in accordance with license requirements

Once the waste has been emplaced, DOE is required to file an application to amend the license for permanent closure. The DOE submission shall include, inter alia, a updated performance assessment of the geologic repository, and a detailed plan for post-closure monitoring of the site including land use controls, construction of monuments and preservation of records. Upon completion of permanent closure activities and D&D of surface facilities, DOE can then apply for an amendment to terminate the license.

2.5.3 Repository Licensing Support Activities

The current NRC repository licensing program consists of both proactive and reactive activities. Proactive activities include developing and reviewing regulatory requirements and guidance to identify and resolve regulatory and technical uncertainties. Regulatory uncertainties exist where regulatory requirements are ambiguous and could be subject to various interpretations. Technical uncertainties are related to demonstrating compliance with a particular regulation.

The NRC staff is currently developing and implementing performance assessment models using Yucca Mountain site data. The models will assist the NRC in performing a technical assessment of the site, as well as identifying areas of regulatory and technical uncertainty during the license application review process. The uncertainties identified must be addressed in a timely fashion so that the NRC can meet the three-year license review schedule mandated by the NWPA. Additional details are provided in Chapter 7.

These activities have produced licensing review plans in anticipation of the DOE submissions. They include review of the SCP, Study Plan, and Quality Assurance Plan (QAP).

The major focus of pre-licensing activities has been on 10 key technical issues (KTIs) that NRC has identified as being most important to repository performance. NRC's objective is to seek staff-level resolution of these issues during pre-licensing consultation with DOE although the procedure does not preclude rasing the issues during the licensing process. These issues are:

- Total system performance assessment
- Unsaturated and saturated flow under isothermal conditions
- Evolution of the near-field environment
- Container life and source term
- Repository design and thermal-mechanical effects
- Thermal effects on flow
- Radionuclide transport
- Structural defomation and seismicity
- Igneous activity
- Activities related to NRC high-level radioactive regulations

NRC periodically publishes Issue Resolution Status Reports (IRSRs) which provide DOE with feedback on KTI subissues. For example, NRC published IRSR Revision 1, on total system performance assessment and integration, in November 1998 (NRC98). The report documents the acceptance criteria NRC proposes to use for addressing each identified KTI subissue and the review method NRC plans to use in determining whether or not the each acceptance criterion has been met. As of the November date, 18 subissues relating to total system performance assessment and integration had been resolved and 13 remained open.

Reactive activities of the repository licensing program consist of pre-licensing reviews that follow DOE's sequence and schedule of activities. To date, the NRC has reviewed a number of the QAPs proposed by DOE and its contractors for Yucca Mountain. Any quality assurance issues identified must be resolved before significant data collection activities are performed at the Yucca Mountain site.

The NRC has also provided formal comments to DOE on the 1998 TSPA Viability Assessment (NRC99).

As site characterization activities proceed, the NRC will review DOE's semiannual progress reports on the site characterization program. The review will focus on the resolution of previously identified concerns and will evaluate new information about the site and repository design. In addition, the NRC will review selected DOE study reports and position papers that document the results of work performed to date, and topical and issue resolution reports that summarize the site characterization work for specific licensing topics. These reviews will be used to evaluate compliance with NRC regulations.

All concerns identified by the NRC will be tracked by its staff. The tracking system now being implemented will focus not only on the issues identified, but also on DOE's progress towards their resolution. The system also provides a licensing record of all NRC and DOE actions related to resolving specific issues.

2.6 DEPARTMENT OF ENERGY

DOE operates facilities for the production and testing of nuclear weapons; for the management and disposal of radioactive waste generated in national defense activities; for research and development; and for the storage of spent nuclear fuel. In addition, DOE is conducting several remedial action programs, such as the program for the management of uranium mill tailings and the cleanup of sites formerly used for nuclear activities. These facilities and activities are not licensed by the NRC. However, to protect public health and the environment, DOE has implemented orders and procedures that are consistent with NRC regulations under 10 CFR Part 20 (NRC60), standards promulgated by the EPA, and other applicable Federal regulations and guidelines.

DOE is also responsible for the disposal of spent nuclear fuel from the generation of electricity by commercial nuclear reactors and high-level radioactive waste from defense activities. The facilities developed by the DOE for the management and disposal of these wastes must be licensed by the NRC. The Yucca Mountain site in Nevada is the candidate location for disposal of these wastes.

DOE is responsible for operating its facilities in a manner that is environmentally safe and sound, as stated in DOE Orders 5400.1 (DOE88) and 231.1 (DOE95a). In meeting this mandate, DOE has issued a number of orders specifying environmental standards and procedures. Many of these orders are currently under review to determine their conformance with NRC and EPA regulations and standards and will be revised in accordance with the applicable NRC or EPA guidance. Key DOE orders pertaining to the management of radioactive and hazardous materials include:

- DOE Order 460.1A (DOE96b), which establishes administrative procedures for the certification and use of radioactive and other hazardous materials packaging by the DOE.
- DOE Order 460.2 (DOE95b), which specifies DOE's policies and responsibilities for coordinating and planning base technology for radioactive material and transportation packaging systems. (Cancels DOE Orders 1540.1A, 1540.2, and 1540.3A-Change 1.)
- DOE Order 451.1A (DOE97), which establishes procedures for implementing the requirements of NEPA (NEP70). The order requires new facilities and existing facilities with proposed modifications to submit EISs with their proposed facility design or design modification. In addition, the facilities are subject to extensive design criteria reviews to determine compliance. (Cancels DOE Order 451.1.)

In addition to the above orders, in March 1993, DOE published a Notice of Proposed Rulemaking for 10 CFR Part 834, entitled *Radiation Protection of the Public and the Environment* (58 FR 16268) (DOE93). The proposed rule contains DOE's internal primary standards for the protection of the public and environment against radiation. The requirements would be applicable to control of radiation exposures from normal operations under the authority of DOE and DOE contractor personnel. In December 1996, DOE proposed revisions to its siting guidelines in 10 CFR Part 960 which were specific to the Yucca Mountain site (DOE96a). DOE has not yet taken final action on its proposal.

REFERENCES

AEA54 *Atomic Energy Act*, Public Law 83-703, as amended, 42 USC 2011 et seq., 1954.

DOE88 U.S. Department of Energy, *General Environmental Protection Program*, draft, DOE Order 5400.1, November 9, 1988.

DOE93 U.S. Department of Energy, *Radiation Protection of the Public and the Environment*, 10 CFR Part 834, Federal Register, 58 FR 16268, March 25, 1993.

DOE95a U.S. Department of Energy, *Environmental Safety and Health Reporting*, DOE Order 231.1, September 30, 1995.

DOE95b U.S. Department of Energy, *Departmental Materials Transportation and Packaging Management*, DOE Order 460.2, October 26, 1995.

DOE96a U.S. Department of Energy, *General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories; Proposed Rule and Public Hearing*, 10 CFR Part 960, Federal Register, 61 FR 66158, December 16, 1996.

DOE96b U.S. Department of Energy, *Packaging and Transportation Safety*, DOE Order 460.1A, October 2, 1996.

DOE97 U.S. Department of Energy, *National Environmental Policy Act Compliance Program*, DOE Order 451.1A, June 5, 1997.

DOE98 U.S. Department of Energy, *Viability Assessment of a Repository at Yucca Mountain*, DOE/RW-0508, December 1998.

DUN80 Dunning, D.E. Jr., R.W. Leggett, and M.G.Yalcintas, *A Combined Methodology for Estimating Dose Rates and Health Effects From Exposure to Radioactive Pollutants*, ORNL/TM-7105, 1980.

EnPA92 *Energy Policy Act of 1992*, Public Law 102-486, October 24, 1992.

EPA71 U.S. Environmental Protection Agency, *Radiation Protection Guidance for Federal Agencies: Underground Mining of Uranium Ore*, Federal Register, 36 FR 12921, July 9, 1971.

EPA76 U.S. Environmental Protection Agency, *National Interim Primary Drinking Water Regulations*, EPA 570/9-76-003, 1976.

EPA77 U.S. Environmental Protection Agency, *Environmental Radiation Protection Standards for Nuclear Power Operations*, 40 CFR Part 190, Federal Register, 42 FR 2858-2861, January 13, 1977.

EPA79 U.S. Environmental Protection Agency, *National Emission Standards for Hazardous Air Pollutants, ANPRM*, Federal Register, 44 FR 46738, December 27, 1979.

EPA83 U.S. Environmental Protection Agency, *Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*, 40 CFR Part 192, Federal Register, 48 FR 602, January 5, 1983.

EPA85a U.S. Environmental Protection Agency, *National Emission Standards for Hazardous Air Pollutants, Standards for Radionuclides*, Federal Register, 50 FR 5190-5200, February 6, 1985.

EPA85b U.S. Environmental Protection Agency, *National Emission Standards for Hazardous Air Pollutants, Standards for Radon-222 Emissions from Underground Uranium Mines*, Federal Register, 50 FR 15386-15394, April 17, 1985.

EPA87 U.S. Environmental Protection Agency, *Radiation Protection Guidance to Federal Agencies for Occupational Exposure*, Federal Register, 52 FR 2822-2834, January 27, 1987.

EPA88 U.S. Environmental Protection Agency, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion, Federal Guidance Report No. 11*, Office of Radiation Programs, EPA 520/1-88-020, Washington, D.C., September 1988.

EPA89a U.S. Environmental Protection Agency, *National Emission Standards for Hazardous Air Pollutants: Regulation of Radionuclides*, 40 CFR Part 61, Proposed Rule and Notice of Public Hearing, Federal Register, 54 FR 9612-9668, March 7, 1989.

EPA89b U.S. Environmental Protection Agency, *National Emission Standards for Hazardous Air Pollutants: Regulation of Radionuclides*, 40 CFR Part 61, Final Rule and Notice of Reconsideration, Federal Register, 54 FR 51695, December 15, 1989.

EPA91 U.S. Environmental Protection Agency, 40 CFR Parts 141 and 142, *Proposed Rule, National Primary Drinking Water Regulations; Radionuclides*, Federal Register, 56 FR 33050, July 18, 1991.

EPA93 U.S. Environmental Protection Agency, 40 CFR Part 191, *Proposed Rule, Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, 58 FR 7924 - 7936, February 10, 1993.

EPA93a U.S. Environmental Protection Agency, *External Exposure to Radionuclides in Air, Water and Soil, Federal Guidance Report No. 12*, Office of Radiation and Indoor, EPA 402-R-93-081, September 1993.

EPA94 U.S. Environmental Protection Agency, *Federal Radiation Protection Guidance for Exposure of the General Public; Notice*, Federal Register, 59 FR 66414, December 23, 1994.

EPA96 U.S. Environmental Protection Agency, *Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule*, Federal Register, 61 FR 5224-5245, February 9, 1996.

EPA98 U.S. Environmental Protection Agency, *Health Risks from Low-Level Environmental Exposure to Radionuclides, Federal Guidance Report No. 13*, Part I - Interim Version, Office of Radiation and Indoor Air, EPA 402-R-097-014, January 1998.

ERA74 *Energy Reorganization Act*, as amended, 1974.

FRC60a Federal Radiation Council, *Radiation Protection Guidance for Federal Agencies*, Federal Register, 25 FR 4402-4403, May 18, 1960.

FRC60b Federal Radiation Council, Staff Report No. 1, *Background Material for the Development of Radiation Standards*, May 13, 1960.

IAE89a International Atomic Energy Agency, *Guidance for Regulation of Underground Repositories for Disposal of Radioactive Wastes*, Safety Series No. 96, Vienna, Austria, 1989.

IAE89b International Atomic Energy Agency, *Safety Principles and Technical Criteria for the Underground Disposal of High-Level Radioactive Wastes*, Safety Series No. 99, Vienna, Austria, 1989.

ICR34 International X-Ray and Radium Protection Commission, *International Recommendations for X-Ray and Radium Protection*, British Journal of Radiology 7, 695-699, 1934.

ICR38 International X-Ray and Radium Protection Commission, *International Recommendations for X-Ray and Radium Protection*, American Journal of Roentgenology and Radium, 40, 134-138, 1938.

ICR51 International Commission on Radiological Protection, *International Recommendations of Radiological Protection 1950*, British Journal of Radiology, 24, 46-53, 1951.

ICR60 International Commission on Radiological Protection, *Recommendations of the International Commission on Radiological Protection Report of Committee II on Permissible Dose for Internal Radiation (1959)*, ICRP Publication 2, Pergamon Press, Oxford, 1960.

ICR65 International Commission on Radiological Protection, *Recommendations of the ICRP 1965*, ICRP Publication 9, Pergamon Press, Oxford, 1965.

ICR77 International Commission on Radiological Protection, *Recommendations of the International Commission on Radiological Protection*, ICRP Publication 26, *Annals of the ICRP Vol. 1*, No.3, Pergamon Press, New York, New York, 1977.

ICR79 International Commission on Radiological Protection, *Limits for Intakes of Radionuclides by Workers*, ICRP Publication 30, Part 1, Ann. ICRP 2 (3/4), Pergamon Press, Oxford, 1979.

ICR84 *Annals of the ICRP*, Vol 14, No. 1, 1984, Statement from the 1983 Washington Meeting of the ICRP.

ICR85a *Annals of the ICRP*, Vol. 15, No. 3, 1985, Statement from the 1985 Paris Meeting of the ICRP.

ICR85b International Commission on Radiological Protection, *Radiation Protection Principles for the Disposal of Solid Radioactive Waste*, ICRP Publication 46, Pergamon Press, Oxford, 1985.

ICR91 International Commission on Radiological Protection, *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Pergamon Press, Oxford, 1991.

NAS95 National Academy of Sciences - National Research Council, Committee on Technical Bases for Yucca Mountain Standards, *Technical Bases for Yucca Mountain Standards*, National Academy Press, Washington, D.C., 1995.

NBS63 National Bureau of Standards (1963), *Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure, NBS Handbook 69* as amended August 1963, U.S. Department of Commerce. Revised and republished in 1963 as *NCRP Report No. 22* by the National Committee on Radiation Protection and Measurements.

NCR54 National Council on Radiation Protection and Measurements, *Permissible Dose from External Sources of Ionizing Radiation*, National Bureau of Standards Handbook 59, 1954.

NCR59 National Council on Radiation Protection and Measurements, *Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure*, National Bureau of Standards Handbook 69, 1959.

NCR87 National Council on Radiation Protection and Measurements, *Recommendations on Limits for Exposure to Ionizing Radiation*, NCRP Report No. 91, June 12, 1987.

NEA94 Nuclear Energy Agency, *NEA Annual Report: 1994 Activities*, 1994.

NEP70 *National Environmental Policy Act of 1970*, Public Law 91-190, January 1, 1970.

NIX70 The White House, President R. Nixon, *Reorganization Plan No. 3 of 1970*, Federal Register, 35 FR 15623-15626, October 6, 1970.

NRC60 U.S. Nuclear Regulatory Commission, *Standards for Protection Against Radiation*, 10 CFR Part 20, Federal Register, 25 FR 10914, November 17, 1960, and as subsequently amended.

NRC81 U.S. Nuclear Regulatory Commission, *Disposal of High-Level Radioactive Wastes in Geologic Repositories: Licensing Procedures*, 10 CFR Part 60, Federal Register, 46 FR 13971-13988, February 25, 1981.

NRC83 U.S. Nuclear Regulatory Commission, 10 CFR Part 60, *Disposal of High-Level Radioactive Wastes in Geologic Repositories, Technical Criteria*, Federal Register, 48 FR 28194-28229, June 21, 1983.

NRC88 U.S. Regulatory Commission, 10 CFR Part 72, *Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste*, 53 FR 31658, August 19, 1988.

NRC91 U.S. Nuclear Regulatory Commission, 10 CFR Part 20 et al., *Standards for Protection Against Radiation, Final Rule*, Federal Register, 56 FR 98, May 21, 1991.

NRC98 U.S. Nuclear Regulatory Commission, *Issue Resolution Status Report, Key Technical Issue: Total System Performance Assessment and Integration, Revision 1*, Division of Waste Management, Office of Nuclear Material Safety and Safeguards, November 1998.

NRC99 U.S. Nuclear Regulatory Commission, *Staff Review of the U.S. Department of Energy Viability Assessment for a High-Level Waste Repository at Yucca Mountain, Nevada*, Letter to Lake H. Barrett, OCRWM/DOE from Carl J. Paperiello, ONMSS/NRC, June 2, 1999.

NWP83 *Nuclear Waste Policy Act of 1982*, Public Law 97-425, January 7, 1983.

NWP87 *Nuclear Waste Policy Amendments Act of 1987*, Public Law 100-203, December 22, 1987.

OEC93 Organization for Economic Cooperation and Development/Nuclear Energy Agency, *Nuclear Waste Bulletin: Update on Waste Management Policies and Programs*, No. 8, July 1993.

OEC95a Organization for Economic Cooperation and Development/Nuclear Energy Agency, *Radiation Protection Today and Tomorrow*, 1995.

OEC95b Organization for Economic Cooperation and Development/Nuclear Energy Agency, *Nuclear Waste Bulletin: Update on Waste Management Policies and Programs*, No. 10, June 1995.

SNI95 Snihs, Dr. J.O., "Radioactive Waste Disposal: Radiological Principles and Standards," *IAEA Bulletin*, 1995.

WIP92 *Waste Isolation Pilot Plant Land Withdrawal Act*, Public Law 102-579, October 20, 1992.

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CHAPTER 2

CHAPTER 9

YUCCA MOUNTAIN EXPOSURE SCENARIOS AND COMPLIANCE ASSESSMENT ISSUES

9.1 INTRODUCTION

Chapter 7 described the proposed Yucca Mountain repository in terms of its site characteristics, engineering designs, and current performance assessments. In Chapter 8, derived unit-concentration exposure and risk estimates were presented. These estimates were based on a conceptual model in which radionuclides were released into the biosphere from a repository through the following sequence: degradation and failure of the waste canister(s) through corrosion; release of radionuclides from the waste package into host rock; migration of radionuclides through the unsaturated zone into the aquifer (saturated zone); and dissemination of contaminated ground water to wells used for drinking and agricultural purposes.

This scenario, involving a gradual release from an undisturbed repository, characterizes the most probable events and conditions of future human exposure. It also conforms with the primary objective of deep geological disposal which is to provide long-term barriers that isolate wastes and limit the release of radionuclides into the biosphere by virtue of siting and engineering design. Deep geologic disposal isolates the wastes for a sufficiently long period of time to allow most of the radionuclides to decay to natural background levels. While estimates of dose and risk for this gradual release process cannot be calculated with complete precision, there is a substantial scientific basis for modeling the various processes that take into account parameter variabilities. By means of statistical processes, such as the Monte Carlo method (see Section 8.5), these uncertainties can be minimized, thereby yielding dose/risk estimates that are reasonable.

Figure 9-1 illustrates the major release pathway leading to human exposure which involves ground water from an undisturbed repository at Yucca Mountain. The major reservoirs (source terms) containing radionuclides at various times following closure are depicted as rectangles. These reservoirs do not have discrete physical boundaries, but rather form a continuum. Solid arrows between reservoirs represent the probable processes by which radionuclides are transported from one reservoir to another in an undisturbed repository.

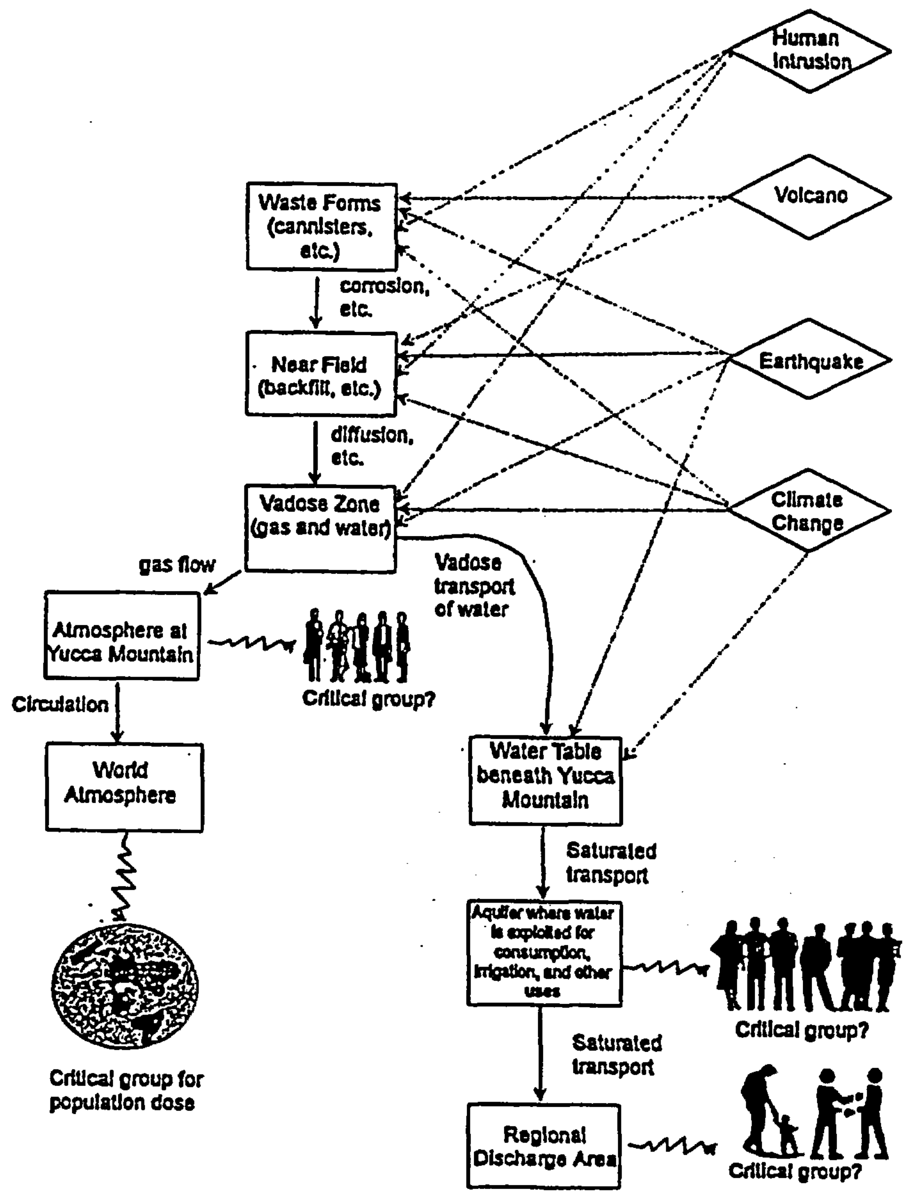

Figure 9-1. Schematic Illustration of the Major Pathways from a Repository at Yucca Mountain to Humans (NAS95)

Major processes and events[27] with potential to modify normal behavior or drastically alter the physical integrity of reservoirs are shown in Figure 9-1 as diamonds. These modifiers are connected by dashed lines to those reservoirs upon which they are likely to have the most significant impact.

To ensure maximum public protection, a standard for a repository at Yucca Mountain must also consider: (1) release pathways other than ground water and (2) improbable conditions that may lead to individual doses and risks well in excess of those specified for the undisturbed repository. A demonstration of compliance with such a standard, therefore, requires estimating potential doses resulting from secondary release pathways and predicting improbable events and processes that may disturb the repository and their corresponding outcomes.

This chapter summarizes issues involved in developing a repository standard that addresses the important exposure pathways and related performance issues that have been identified.

9.2 GASEOUS RELEASES: A SECONDARY PATHWAY FOR HUMAN EXPOSURE

The primary pathway of radionuclide releases from an undisturbed repository involves the introduction of radionuclides into the underlying aquifer, contaminating wells used for drinking or agricultural irrigation. However, as shown in Figure 9-1, humans could also be exposed to radiation as a result of gaseous emissions from the repository. Due to the ease with which gaseous contaminants are distributed in the atmosphere, human exposure would not be limited to the nearfield population but could extend to the world at large. The radionuclide with the highest potential for gaseous release and human exposure is carbon-14.

This section provides a brief overview of the primary parameters affecting the timing and magnitude of gaseous releases and assesses bounding values for human doses.

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[27] The difference between an <u>event</u> and a <u>process</u> is the time interval over which the phenomenon occurs relative to the time frame of interest; events occur over relatively short time intervals and processes occur over relatively long time periods. For example, a disruptive seismic event may occur over minutes, hours, or days. Even a volcanic eruptive cycle that may have time frames extending over several years must be considered an event when judged in context with the lifespan of humans and/or a million-year repository assessment period. Phenomena that exceed human life expectancy or occur over a significant portion of the period of regulatory concern are considered to be processes.

9.2.1 Production and Early Containment of Carbon-14

Carbon-14 is produced in nuclear fuel as a result of neutron absorption by the following reactions: (1) N-14 (n, p) C-14 and (2) O-17 (n, He-4) C-14 (DAV79). Thus, the quantity of C-14 produced is governed by the amount of nitrogen and oxygen contained within the fuel core.

Carbon-14 in oxide fuels is assumed to exist as either CO_2 or low molecular weight hydrocarbons that in time are oxidized to CO_2. The total inventory of C-14 for the 63,000 tons of spent nuclear fuel is estimated to be about 91,000 Ci (DOE94).

When estimating gaseous releases from the repository through the unsaturated zone to the accessible environment, the following parameters should be considered: (1) container performance and (2) the bulk permeability and retardation capability of the tuffs. The retardation of gaseous CO_2 flow is due to its exchange with the relatively immobile bicarbonate (HCO_3^-) in the pore water of the unsaturated zone.

9.2.2 Impacts of Thermal Loading on Gaseous Releases and Transport

The emplacement configuration of heat-generating waste containers is likely to disturb the ambient environment of the repository in a number of ways. Waste-generated heat is expected to enhance vaporization of water within the tuff matrix and, at temperatures above 96°C, completely "dry out" the adjacent host rock and move the water into the surrounding rock.

The impact of thermally-displaced water in the vicinity of the repository has a dual effect on gaseous releases. Since most of the waste-container corrosion processes are known to be temperature and moisture dependent inclusive of: (1) general aqueous corrosion, (2) steam corrosion, (3) pitting corrosion, (4) dry oxidation corrosion, and (5) stress corrosion, the potential impacts of waste emplacement and thermal loading on container failure are highly critical for modeling the time and release fraction of gaseous C-14.

Estimates of travel time for C-14 released from a container into the unsaturated zone are strongly affected by the moisture content. Under conditions of 100 percent humidity, C-14 is assumed to exist for the majority of the time as bicarbonate (HCO_3^-) in the slow-moving aqueous phase (ROS93). Conversely, within the dry-out zone, C-14 can be assumed to exist almost exclusively in the fast-moving gaseous form (CO_2).

9.2.3 Estimates of Travel Time

Estimates of travel time for C-14 released from a failed container to the accessible environment are complicated by the fact that the radionuclide is likely to exist only a small portion of the time in gaseous form as $^{14}CO_2$; the majority of the time, it will exist as bicarbonate (HCO_3^-) in the aqueous phase. In the bicarbonate form, C-14 moves more slowly than in the fast moving uncondensible gaseous form (ROS93). This "slowing," or retardation, must be incorporated into the travel-time calculations by dividing the short-lived gas velocity at each point along the flow path by a retardation factor that accounts for the longer time and limited movement of C-14 in the aqueous bicarbonate phase. Travel-time probability distributions can be determined by coupled calculations of gas and heat flow (i.e., time-dependent temperature distributions in the repository environs).

Because estimates of early waste-container failure and release of C-14 are currently highly uncertain, travel times for release of C-14 have been estimated at 1,000-year intervals following waste emplacement. For example, Figures 9-2 and 9-3 show travel-time histograms for a thermal loading of 57 kW/acre and welded-tuff bulk permeability of 10^{-11} m^2 at 1,000 and 10,000 years (DOE94):

- At 1,000 years, temperature gradients in the vicinity of the repository are high due to the large heat output. Correspondingly, gas velocities in the nearfield ("dry-out zone") are larger than in the far field. Calculated C-14 travel times range from 200 to 600 years.

- At 10,000 years, heat has been conducted outward and temperature gradients have been reduced, resulting in estimated travel times that range from 500 to 1,200 years.

Given this, it appears that the magnitude of potential atmospheric releases would be greatest if containment failure were to occur early. At early times (i.e., 1,000 years), transport velocities can be expected to be maximal and the reduction of C-14 by natural decay is minimal.

It is reasonable, however, to expect that individual container failures will occur over a long period of time. This could substantially broaden the range of C-14 travel times in the unsaturated zone from as little as 200 years to as much as 1,800 years. The period of C-14 release into the accessible environment is further delayed by the fact that, at time of canister failure, only a small percentage of the C-14 inventory has leaked from the fuel matrix into the void spaces of the container for instantaneous release. Barnard et al. (BAR92) estimate that this quick release

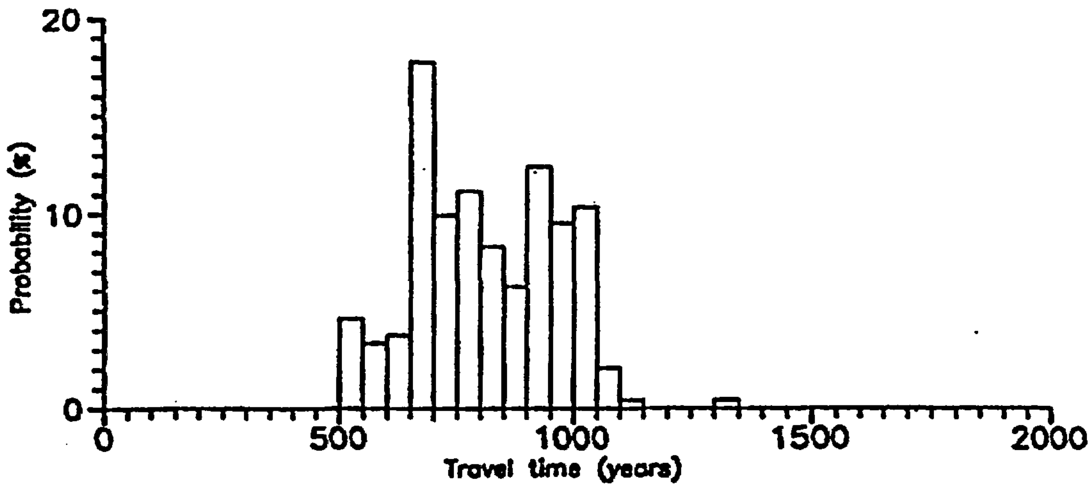

Figure 9-2. Retarded Travel Times of C-14 from the Repository to the Atmosphere for Particles Released at 1,000 Years (DOE94)

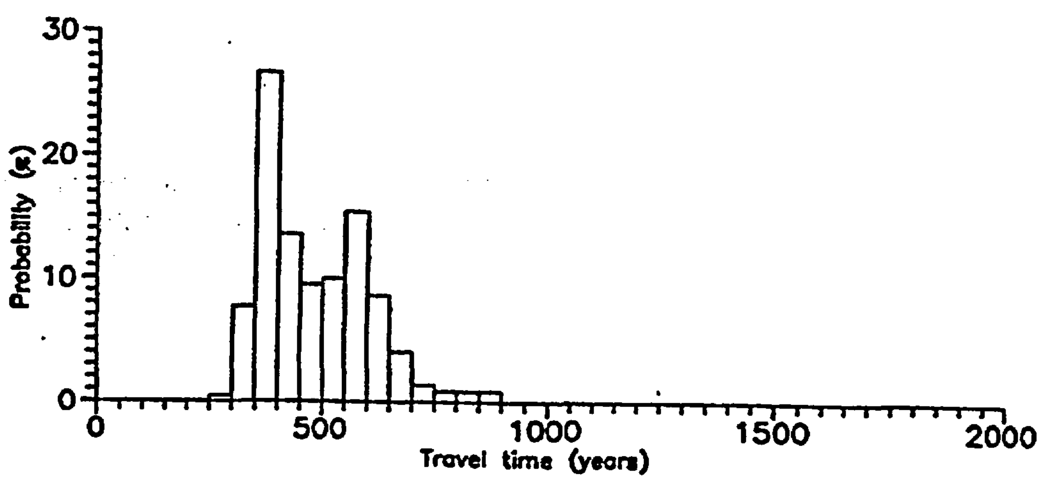

Figure 9-3. Retarded Travel Time of C-14 Particles from the Repository to the Atmosphere for Particles Released at 10,000 Years (Welded-tuff bulk permeability of 10^{-11} m^2 (DOE94))

fraction is likely to represent between 1.25 and 5.75 percent of the total inventory. The slow release of the larger, remaining fraction of C-14 from the fuel matrix to the container and subsequently into the repository environs is likely to further extend the time period during which C-14 can be expected to enter the accessible environment. With a physical half-life of 5,730 years, it is reasonable to conclude that the quantity of C-14 that will reach the accessible environment will be less than the 91,000 Ci inventory existing at the time of waste emplacement.

9.2.4 Dose Modeling and Exposure Estimates

For practical reasons, estimates of human exposure to C-14 assume that the specific activity of C-14 in the atmosphere in gaseous CO_2 form is equal to that of organically bound carbon contained in all plant and animal products that may be ingested as food. Thus, pathways for internal exposure may involve inhalation and ingestion.

For all practical purposes, under a steady-state distribution of C-14 in the environment, the inhalation of $^{14}CO_2$ contributes insignificantly when compared to the ingestion pathway and may, therefore, be eliminated from dose consideration.

Upon the ingestion of organically bound C-14, the uptake, retention, and excretion by the body involve numerous pathways that correspond to biologic half-times ranging from less than one hour to several years. Even for a specific category of organic molecules such as proteins, turnover times are highly variable. While structural proteins show relatively long turnover times, other proteins such as enzymes, plasma albumin, and hemoglobin have relatively short turnover times. When all protein compartments are considered, the half-time of carbon (and therefore C-14) is estimated to be 119 days (NCR93). For fats, which are largely stored in the body as adipose tissue, the biological half-time of carbon is estimated to be 99 days; for carbohydrates, the half-time is estimated to be one day. For a daily dietary intake of 300 grams of carbon, a weighted biologic half-time of about 39 days is obtained. For dosimetric purposes, the ICRP has suggested a biological half-time of 40 days for C-14 (ICR82).

For steady-state environmental conditions, estimates of individual organ and whole body doses from ingestion have been derived by Killough and Rohwer (KIL78). Their model assumes that the specific activity of C-14 (i.e., pCi/g carbon) in the human body will, in time, be the same as that observed in environmental media, inclusive of all plant and animal food products. Correspondingly, the model takes into account the carbon content of individual tissues and organs that will be subject to the beta-ray exposure of C-14. At the present specific activity of C-14 in the atmosphere of seven pCi/g carbon, C-14 is estimated to contribute an annual dose of about 1.5 mrem to humans throughout the world.

9.2.5 Dose Estimates from Repository Releases

Global Doses. Any gaseous release of C-14 from the proposed Yucca Mountain repository will disperse itself globally and, therefore, lead to relatively constant exposures among individuals within the world community. The global distribution model yields a population dose estimate of 399 person-rem per curie of C-14 for a world population of 12.2 billion over a 10,000-year period (EPA96). Using this dose-conversion factor and assuming that the entire repository inventory of 91,000 Ci of C-14 is released, an average individual dose of about 0.0003 mrem/yr is estimated. If this release is scaled down to the C-14 release from the 18 failed packages used in the TSPA-VA analyses (18 packages over 10,000 years), where each package has an inventory of 11.7 Ci, the global dose estimates become extremely small, particularly in comparison with the above estimate for doses from atmospheric C-14.

Local Doses. Estimating potential doses from gaseous releases from the repository is a very complicated assessment, particularily since any potential doses received would be strongly influenced by wind direction and population distributions. In addition, estimating the amount of C-14 that would be released at the ground surface in gaseous form rather than contained as biocarbonate ion dissolved in water is also difficult. Some insight relative to the potential magnitude of doses through the gaseous release pathway can be gleaned from looking at dose estimates from gaseous C-14 emissions from a nuclear power plant. In both the repository and nuclear power plant situations, gaseous C-14 is released into the atmosphere and dispersed downwind of the source.

Doses Within 50 Miles of a Nuclear Power Plant. In another study, air concentrations of $^{14}CO_2$ were modeled out to 50 miles for the Dresden Nuclear Power facility (NCR93). A standard diffusion model, as defined above, and local meteorological data were used to calculate concentrations for all sectors out to 50 miles from the plant. Figure 9-4 identifies isolines of the average annual $^{14}CO_2$ air concentrations.

The numbers not in parentheses in Figure 9-4, multiplied by the continuous source activity per second (e.g., Ci/s), yield the predicted ^{14}C concentrations in Ci/m^3. However, to estimate uptake by growing vegetation, the concentration of ^{14}C should be given as a ratio to stable carbon. To make the example more relevant, a continuous emission rate of 100 Ci/y of ^{14}C was used as the source strength. With the additional assumptions listed on the figure, the isolines are also labelled, in parentheses, in units of specific activity (pCi ^{14}C/g ^{12}C).

Parenthetical values may also be converted to dose based on the relationship that on average seven pCi ^{14}C per gram of carbon is estimated to result in an annual dose of about 1.5 mrem (see Section 9.2.5). Based on the model defined in Figure 9-4, annual doses from a continuous release of 100 Ci of ^{14}C can be estimated at various distances as defined in Table 9-1. The isolines can be scaled linearly to source strengths other than 100 Ci/yr.

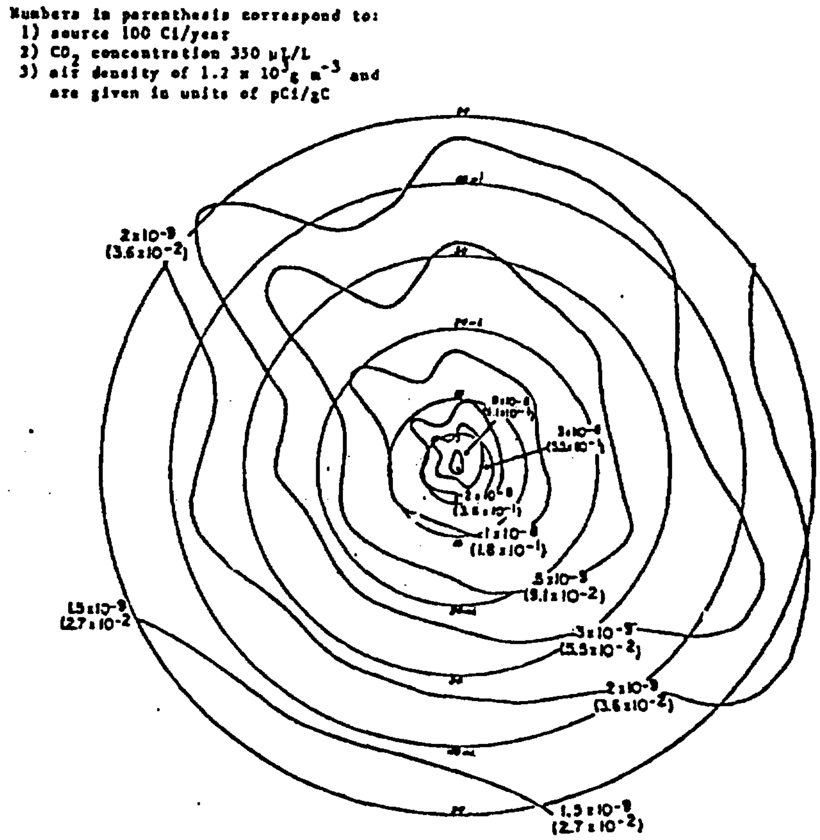

Figure 9-4. Annual Average Concentration for Uniform Continuous Source and Specific Activity (in parentheses) for 100 Ci/year (NCR93)

Table 9-1. Annual Average Doses Resulting from the Release of 100 Ci $^{14}CO_2$ for Distances Out to 50 Miles

Distance (miles)	Atmospheric ^{14}C Concentration ($pCi\ ^{14}C/g\ C$)*	Annual Dose - CEDE (mrem/yr)
10	1.8×10^{-1}	3.8×10^{-2}
20	9.1×10^{-2}	2.0×10^{-2}
30	5.5×10^{-2}	1.2×10^{-2}
40	3.6×10^{-2}	7.7×10^{-3}
50	2.7×10^{-2}	5.8×10^{-3}

* Numbers were based on atmospheric CO_2 concentration of 350 μL/L and air density of 1.2×10^{-3} g/cm^3.

For the Yucca Mountain situation, the assumed 100 Ci/yr source release assumed in the power plant assessment can be approximately scaled to estimate potential doses from failed waste packages. The quick release fraction of C-14 in the waste packages may vary from 1.25 to 5.75 percent of the inventory. Using the high end estimate and a C-14 inventory of 11.4 Ci/waste package (DOE98, Vol. 3 p. 3-96), 0.673 Ci/waste package would be released. Assuming that this instantaneous release is transported completely to the ground surface and released, scaling the doses calculated for the power plant (for a location of 20 km from the source) gives a dose estimate on the order of 1.3×10^{-4} mrem/yr for gaseous releases from a single waste package. This estimate represents a conservative upper bound estimate for gaseous phase released in that actual gaseous releases from the repository would be attenuated during upward transport through the unsaturated zone by dissolution in pore waters in the overlying rocks, and by partitioning between fractures and the matrix porosity voids in the overlying rocks. Gaseous C-14 releases after initial breaching of the waste package are likely to be less than the instantaneous release fraction since ground waters interacting with the wastes would dissolve the C-14, with its subsequent transport through the ground water pathway rather than gaseous release.

9.2.6 Potential Non-Radiological Impacts of C-14

A concern uniquely associated with some contaminant radionuclides involves the transmutation effect and its potential for inducing molecular disorientation. The potential impact of chemical transmutation is of particular concern for genetic macro-molecules of DNA and RNA. Chemical transmutation refers to the fact that when a radioactive isotope emits a beta particle, it also undergoes chemical transformation due to the change in atomic number. For example, when C-14 undergoes radioactive decay, it becomes nitrogen. When such atoms are incorporated in critical molecules such as DNA, the resulting change in atomic number, recoil, or excitation may give rise to biologic effects, including mutation, beyond those induced by the attendant ionizing radiation. At issue, therefore, is whether or not dose-response values, involving cytogenetic/genetic effects for absorbed radiation energy, might underestimate the hazards presented by these potential radionuclide contaminants. Potential impacts of transmutation have been reviewed by the National Academy of Sciences (NAS). In their first report, the NAS Committee on the Biological Effects of Ionizing Radiation (BEIR) concluded:

> *...that the genetic effects of decays of H-3, C-14, and P-32 can, in fact, be attributed almost entirely to their beta radiation and that the contribution from transmutation is so small in comparison that it is justified to consider the main effect to come from the radiation emitted when the isotope disintegrates (NAS72).*

However, in the Committee's subsequent report (BEIR III), evidence was acknowledged which indicated a modest transmutation effect when C-14 (and H-3) occupied highly specific locations within DNA (NAS80). The Committee concluded that it still seems unlikely that neither H-3 nor C-14 decay are significantly underestimated by considering only the ionizing radiation dose accumulated by germ-line cells .

9.3 DEVELOPMENT OF PERFORMANCE SCENARIOS AND COMPLIANCE ISSUES

9.3.1 Identification of Improbable Phenomena

For a regulatory time frame that can extend to thousands of years, it is reasonable to conceive of circumstances defined by various natural and human-induced events and processes that may result in some persons at some time being exposed to levels well in excess of anticipated levels considered acceptable for an undisturbed repository. In recognition of the need to address repository performance under disturbed conditions, the NAS Committee on Technical Bases for Yucca Mountain Standards stated the following:

> *...the probabilities and consequences of modifications by climate change, seismic activity, and volcanic eruptions at Yucca Mountain are sufficiently boundable that these factors can be included in performance assessments that extend over this time frame. ... The challenge [therefore] is to define a standard that specifies a high level of protection but that does not rule out an adequately sited and well-designed repository because of highly improbable events* (NAS95). (Emphasis added.)

Substantial difficulties are likely to be encountered in making these predictions. Both the NRC and EPA have explicitly recognized that no analyses of compliance will ever constitute an absolute proof; the objective instead is a reasonable level of confidence in analyses that indicates whether limits established by the standard will be exceeded. Thus, in 40 CFR Part 191 (Appendix B), the EPA stated the following for a disturbed disposal system:

> *In making these various predictions, it will be appropriate for the implementing agencies to make use of rather complex computational models, analytical theories, and prevalent expert judgement relevant to the numerical predictions. Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with <u>qualitative</u> judgement as well* (EPA85). (Emphasis added)

Similarly, in 10 CFR Part 60, the NRC acknowledged that for performance assessment "...it is not expected that complete assurance that they [performance objectives and criteria] will be met can be presented." (NRC81)

Events and processes that may require consideration are not limited to those identified by the NAS and shown in Figure 9-1. Over the years, numerous reports have identified generic events and processes that do not consider geographical or site-specific features (DOE74, DOE79, BUR80, IAE83, AND89, and DOE90a). Table 9-4 represents a consolidated listing that was used as a starting point in the development of disruptive scenarios for the Waste Isolation Pilot Plant (WIPP).

9.3.2 Screening of Events and Processes

Not all events and processes cited in Table 9-2 need necessarily be considered for Yucca Mountain. Phenomena such as erosion, sedimentation, etc. are certain to occur during extended time periods such as the NAS-suggested one million-year time frame. This suggests that these phenomena should be part of the base-case scenario. The effects of other events (e.g., sea-level variations, hurricanes, seiches, and tsunamis) are restricted to coastal areas.

To analyze the potential relevance of events and processes to a specific repository site, three criteria must be considered:

- Probability of occurrence
- Physical reasonableness
- Consequence

Table 9-2. Potentially Disruptive Events and Processes (DOE91)

Natural Events and Processes	Human-Induced Events and Processes
Celestial Bodies:	Inadvertent Intrusions
Meteorite Impact	Explosions
	Drilling
Surficial Events and Processes:	Mining
Erosion/Sedimentation	Injection Wells
Glaciation	Withdrawal Wells
Pluvial Periods	
Sea-Level Variations	Hydrologic Stresses:
Hurricanes	Irrigation
Seiches	Damming of Streams and Rivers
Tsunamis	
Regional Subsidence or Uplift	Repository- and Waste-Induced Events and Processes:
Mass Wasting	Caving and Subsidence
Flooding	Shaft and Borehole Seal Degradation
	Thermally-Induced Stress Fracturing in Host Rock
	Excavation-Induced Stress Fracturing in Host Rock
	Gas Generation
	Explosions
	Nuclear Criticality

To analyze the likelihood of a given event, it is most desirable to express its probability of occurrence in quantitative terms that draw on scientific data. Physical reasonableness as a screening criterion is a qualitative estimate of low probability that reflects subjective judgment. For subjective probability, the ICRP states:

> *...a number is assigned to the likelihood of an event occurring in a defined period of time, as a measure of the degree of belief that the event will actually occur during that time.... The assignment can be made on the sole basis of subjective judgement, no statistical experience being needed. The result is conceptually identical to a traditional probability and can be used in the same way* (ICR85a). (Emphasis added)

In instances where events are assigned subjective probabilities of occurrence, the ICRP offers an additional note of caution:

> *It is important to distinguish between the degree of belief and the idea of confidence limits applicable to an estimate of probability, which itself has some associated uncertainty.*

The third screening criterion is consequence. An assessment of consequence determines whether the event or process either alone or in combination with other phenomenon may adversely affect performance of the repository.

On the basis of these criteria, a proposed future standard may, for example, specify that events and processes with less than a specified chance of occurring within the regulatory period do not have to be considered in scenarios used to demonstrate compliance with the standard. Conversely, physically reasonable events and processes with significant impacts and probabilities greater than a threshold value would be considered for scenario development.

The likelihood of a disruptive event and its consequence must also be defined temporally. For some events (e.g., meteorite impact), the probability of occurrence over time is a constant. For these cases, the probability of events occurring within a year's time interval can be assessed from Poisson statistics. For other types of events, the probability of occurrence will vary with time after repository closure, or it may be co-dependent on the occurrence of other time-dependent events. This second and more complex event scenario is described in ICRP Publication 46 (ICR85b) and is illustrated in Figure 9-5. For this type of event-induced scenario, the probabilistic annual individual dose rate is a function of both the time of occurrence of the initiating event, t, and the time elapsed since its occurrence, (T-t).

9.3.3 Compliance With a Standard

It is the responsibility of the Nuclear Regulatory Commission (NRC) to assure compliance with EPA's environmental radiation protection standards for Yucca Mountain. Accordingly, the following discussion is for illustrative purposes only and not indicative of how the NRC will discharge this responsibility.

A total system performance assessment employs a quantitative approach that characterizes the releases and health impacts of the disposal system. Key questions that must be addressed in the performance assessment are: "How reliable are the models employed in the performance assessment?" and "What is the uncertainty in the results of the performance assessment?" Preceding portions of this document have acknowledged uncertainties associated with all major elements affecting repository performance. Important sources of uncertainties pertain to the appropriateness of selecting scenarios representing conditions far into the future; the variability and/or lack of knowledge regarding many parameter values employed by the models; the reliability of historical data in predicting the time-dependent probability of future events that may

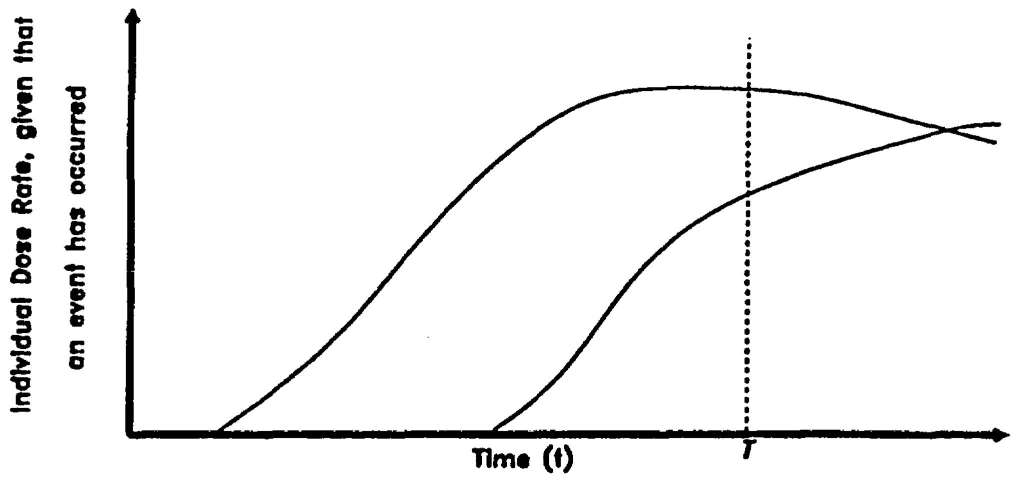

Figure 9-5. An Illustration of Hypothetical Individual Dose Rates Associated with a Disruptive Event Happening at Two Different Times after Disposal of Radioactive Waste

disrupt the repository; and the complex, but uncertain, interaction of independent variables on repository performance. While the uncertainty for some of the sources can be reasonably quantified (e.g., quantities of food and water ingested by humans), others are considerably more difficult (e.g., the probability of human intrusion). While there are no rigorous techniques for quantifying or eliminating uncertainties, several techniques for mitigating their impacts have been proposed by Bertram-Howery and Hunter (BER89), as summarized in Table 9-3.

The EPA has acknowledged that performance assessments will contain uncertainties and that many of these uncertainties cannot be eliminated. Accordingly, the EPA has previously stated that:

> *...standards must accommodate large uncertainties, including uncertainties in our current knowledge about disposal system behavior and the inherent uncertainties regarding the distant future.* (EPA85)

Uncertainty and sensitivity analyses are, therefore, important aspects of performance assessment. Uncertainty analysis involves determining the uncertainty in model projections that results from imprecisely known (or variable) model input parameters. Sensitivity analysis involves determining the contribution of individual input parameters to the uncertainty in model predictions.

Table 9-3. Techniques for Quantifying or Reducing Uncertainty in the Performance Assessment

Type of Uncertainty	Technique for Assessing or Reducing Uncertainty
Scenarios (Completeness, Logic, and Probabilities)	Expert Judgment and Peer Review Quality Assurance
Conceptual Models	Expert Judgement and Peer Review Sensitivity Analysis Uncertainty Analysis Quality Assurance
Computer Models	Expert Judgment and Peer Review Verification and Validation* Sensitivity Analysis Quality Assurance
Parameter Values and Variability	Expert Judgement and Peer Review Data-Collection Programs Sampling Techniques Sensitivity Analysis Uncertainty Analysis Quality Assurance

* To the extent possible. (BER89)

Because of the many uncertainties associated with the events and processes affecting repository performance, probability distributions of human exposure (and risk) are likely to vary over several orders of magnitude within the 5th and 95th percentile range. An important limitation of such a probability distribution is that no single value is correct in predicting future exposures. The probability distribution, however, does identify mean and median values, which represent expected values of dose (or risk) most likely to be received by individuals considered at maximum risk. To that extent, EPA (EPA85) has previously acknowledged that the most probable (or expected) value of a probabilistic distribution of estimated radiation exposure may be used to demonstrate compliance:

> *...the implementing agencies need not require that a very large percentage of the range of estimated radiation exposures...fall below limits [of the standard]. The Agency assumes that compliance can be determined based on best estimate predictions (e.g. the mean or the median of the appropriate distribution, whichever is higher).*

9.3.4 Development of Site Performance Issues

The subject of defining performance issues for a geologic repository has been addressed on a generic basis both in this country and abroad. Processes and events that could potentially affect repository integrity and performance have been identified so that they can be critically examined to develop site-specific performance scenarios for a particular candidate repository site. The challenge in developing site-specific scenarios for a candidate repository location is to credibly incorporate all the relevant processes and events that significantly affect repository performance.

To develop site-specific scenarios that will be addressed in licensing assessments, an iterative process of site characterization and evolving performance assessments has been used since the initiation of extensive site characterization work. Chapter 7 describes the sequence of total system performance assessments for the Yucca Mountain site that have been performed by DOE as site characterization has proceeded. These assessments have identified which processes and events have most relevance to sub-system and total system performance, and indicated the areas where more rigorous assessment capability was needed and areas where more extensive laboratory and field studies are necessary. As a result of this iterative site characterization - performance assessment process, a number of technical issues have been defined through interactions between the DOE and the NRC staff. Resolution of these issues is critical in developing a credible assessment of the site's performance that can be carried into the licensing process. These issues are discussed in more detail later in this section.

The progress of DOE's Yucca Mountain site characterization efforts is documented in semi-annual progress reports prepared as required by provisions of the Nuclear Waste Policy Act of 1982 (NWP83). Descriptions of the laboratory and field studies conducted by the DOE and other parties are reported in numerous reports published in the open technical literature. In Chapter 7, descriptions of the total system performance assessments carried out by the DOE, the NRC, and EPRI are given. These descriptions illustrate the iterative and evolving nature of the site characterization and performance assessment efforts carried out by these organizations. In developing the Yucca Mountain standard, the Agency has relied heavily on the information provided from these sources as well as the reviews of these efforts by experts outside the program.

The NRC staff have been in dialog with DOE concerning technical issues for the repository since inception of site characterization and repository design work. As a result of this dialog, the NRC staff has identified 10 Key Technical Issues (KTIs) to be resolved as part of demonstration of regulatory compliance, and has established Issue Resolution Status Reports (IRSRs) as the means by which the requirements for, and the status of, issue resolution are documented (see Chapter 4 of this BID).

The IRSRs are updated periodically as progress is made in issue resolution as a result of, for example, data additions or improvements in performance models. Resolution of the KTIs is sought before submission of the LA, but any issues resolved to the satisfaction of DOE and NRC staff during pre-licensing interactions are subject to being opened again during licensing reviews, e.g., by the licensing board.

9.3.4.1 Reviews of Recent Yucca Mountain Performance Assessments

DOE's Viability Assessment (DOE98) provided a recent basis for NRC expression of issues of current concern. The most recent DOE assessment, the TSPA for Site Recommendation (TSPA-SR) has not yet been formally reviewed by NRC, so the VA remains the most recent TSPA to undergo a thorough review by outside parties.

Although NRC had no statutory or other official role in review of the VA, staff performed a review of the total system performance assessment (TSPA) and licensing plan elements of the VA (i.e., cost estimates were not reviewed) as an aid to DOE's development of a complete and high-quality LA. The NRC comments were officially transmitted to DOE in a June 2, 1999 letter (NRC99). This transmittal of the results of the staff review had been preceded by informal expression of comments and an NRC/DOE Technical Exchange (NRC99a) in which NRC staff provided detailed feedback to DOE concerning issues associated with the TSPA-VA.

Comments on the VA were also documented by the NWTRB (TRB99) and DOE's independent Peer Review Panel (PRP99). In general, the NRC, NWTRB, and Peer Review Panel comments (summarized in Section 7.2.4 of this BID) were consistent with DOE's own assessment of issues associated with the VA's reference engineered design and the status of data and models used in the TSPA-VA (documented in Volume 4 of the VA, DOE98). Overall, there was consensus that the data base and performance models available for the VA were inadequate for the LA, and that there were technical issues stemming from the VA reference repository design that would be difficult to resolve in licensing reviews. These findings were consistent with DOE's assertion that the VA was a snapshot in time of evolution of repository design, performance modeling, and the technical data base.

9.3.4.2 Compliance Issues for Licensing Reviews

On the basis of their VA reviews, NRC staff identified, in NRC99, the following current issues, in order to help DOE "...to focus its program and develop a high-quality LA." Broad issues identified by the NRC staff are identified below along with associated issues more specific to the performance of the natural and engineered barriers.

While the growing emphasis on the engineered barriers is apparent in the evolution of DOE's efforts, there are some data gaps in the characterization of the natural barrier system that have important performance implications. Hydrologic characterization data are sparse for the down gradient portion of the ground water flow system at distances greater than 5 km from the repository. The absence of hydrologic data seriously limits the reliability of radionuclide transport calculations for projected repository releases. Some specific technical issues involved include:

- The range of infiltration estimates for water moving through the unsaturated zone and entering waste emplacement drifts in the repository
- The nature of the flow regime in the alluvial deposits lying beyond the Yucca Mountain location southward into the Amargosa Valley area, i.e., where and how flow from the tuff aquifer enters the alluvial sediments
- The extent of down gradient dispersion expected for the contamination plume from ant repository releases and the extent of mixing that can be assumed when releases from the repository enter the saturated zone beneath the repository
- The areal extent of the upward hydrologic gradient assumed to exist between the lower carbonate aquifer and the overlying tuff and alluvial flow system

These concerns, and planned efforts to address them and others, are discussed below.

Timely Selection of a Preferred Repository Design

NRC staff noted that the TSPA-VA identified, and provided preliminary evaluations of, design enhancements in comparison with the VA reference design that could provide defense-in-depth and improved performance for the engineered features of the repository system. The staff expressed concern that continued retention of flexibility and analysis of design options might not permit DOE to meet its schedule for preparation of a high-quality LA focused on a specific design.

DOE's selection of the EDA II design as the basis for future evolution of engineered barrier system design provides focus for future design development efforts. It will be necessary, however, that evolution of the data base and performance models needed to support use of the EDA II design (or its progeny) in the LA proceed at a rate, and with content, sufficient to produce a high-quality LA.

Waste Package Corrosion

Under present repository design concepts and waste isolation strategy, waste package corrosion resistance (i.e., lifetime before penetration which allows water to contact the waste form) is one of the most important factors in repository system performance. The waste package design for the VA used a so-called Corrosion Allowance Material (CAM), as the outer package wall, with a primary purposes of providing structural strength and radiation shielding. The CAM was A 516 steel. The VA waste package design also included a high-nickel alloy, Alloy 22, as the inner package wall material. This element of the waste package design served as the Corrosion Resistant Material (CRM) and was intended to be the principal basis for VA-design waste package lifetime.

The waste package design for the VA posed two major licensing issues. One was potential for rapid crevice corrosion of the Alloy 22 CRM, as a result of its being under the A 516 steel CAM. Rapid penetration of the CRM would negate its effectiveness as the means for achieving a long package lifetime. The other concern was the lack of a data base for corrosion of the Alloy 22 CRM under repository conditions. As noted in NRC99, the corrosion rate values used in the TSPA-VA, especially those for the CRM, were based primarily on results of expert elicitations rather than experiments under representative service conditions.

A key current licensing issue concerning waste package performance is therefore the sufficiency, and applicability to the repository environment, of data for waste package corrosion performance. NRC staff are concerned that, under current schedules, there is not enough time to gather quality data for the LA that are sufficient in quantity and duration of test conditions. NRC99 notes that it is appropriate for DOE and NRC to take into consideration more long-term data at later times (e.g., at the time disposal is approved), but sufficient data must be available to support the LA. In sum, corrosion parameter values used in the TSPA-VA that were based on results of expert elicitations must be adequately supplanted, for the LA, by data derived from measurements under environmental conditions expected for a repository at Yucca Mountain.

Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms

NRC99 states that DOE and NRC analyses both indicate that the fraction of waste packages contacted by water is the most important factor affecting dose for the ground water pathway. It also notes that the quantity and chemistry of water contacting the waste packages are the major factors determining waste package lifetime, and that these water characteristics also affect radionuclide release from the waste forms and waste packages.

NRC99 indicates that DOE recognizes the need for additional data concerning water quantities and chemistry in the repository, and also recognizes that performance models used in the TSPA-VA do not adequately capture the effects of coupled processes (thermal, chemical, hydrologic, and mechanical) on the quantity and chemistry of water that contacts the waste packages. NRC99 also states, however, that the range of licensing plan activities outlined by DOE in the VA are unlikely to provide, for the LA, an adequate basis for assessing the quantity and chemistry of water that contacts the waste packages and waste forms.

Two additions to DOE's suite of pre-LA activities, which could be completed before submission of the LA, are suggested in NRC99, based on a Drift Seepage Peer Review held in January 1999 (HUG99). One action would be to conduct systematic measurements of air permeability in horizontal boreholes in the repository host rock units. These measurements would provide data on the scales of variability in rock properties that are needed to adequately describe seepage. The other action would be to expand model development efforts to focus on explanation of patterns of seepage observed in the niche experiments.

The amount of additional data and analyses needed for an adequately supported LA will depend on how important the quantity and chemistry of water contacting the waste package is to the DOE's safety case.

Saturated Zone Flow and Transport

The saturated zone (SZ), which is the principal pathway for radionuclide transport from the repository to the dose receptor location, has been shown by DOE and NRC sensitivity studies to be an important factor in repository system performance. Potentially important SZ performance factors include low flow rates, dilution along the SZ pathway, and radionuclide holdup in alluvium between the repository and the dose receptor location. Dilution effects expected during pumping of contaminated water by the dose receptor may also help reduce the potential dose, but DOE did not take credit for this performance factor in the TSPA-VA.

A major issue for assessing the SZ contribution to performance in the TSPA-LA is the fact that the SZ is at present poorly characterized, and current DOE plans to improve characterization before submittal of the LA are limited. Flow and transport characterization data between about 5 and 20 km from the repository are at present highly limited; Gelhar (GEL98) described the situation as a "data hole". Nye County is implementing an "Early Warning Drilling Program" (NYE99) in which shallow and deep wells will be drilled and tested down gradient of the repository; these wells, which are basically arrayed along Highway 95 at a radius of about 20 km south of the proposed repository location, will provide data concerning SZ flow and transport properties, but the data field will be limited under current DOE and Nye County plans. Well log data to date (NYE99a) indicate that the geologic features of the alluvial deposits are highly heterogeneous.

NRC99 expresses concern about availability of sufficient SZ characterization data for the LA. It notes that DOE's planned activities are of low priority and will extend beyond current cutoff dates for refinement and update of SZ flow models, and that DOE might supplement the Nye County program with additional field work that could produce meaningful data for the LA, but has no present plans to do so. NRC99 also notes that DOE's licensing plan in the VA documentation characterized the SZ flow and transport uncertainties as "moderate", but that this designation appears to be inconsistent with the results of DOE and NRC/CNWRA sensitivity studies which show an important role for the SZ in overall repository system performance. Defensible demonstration in the LA of the SZ contributions to the natural system component of a defense-in-depth repository design will be essential.

Volcanic Disruption of the Waste Package

NRC99 asserts that the TSPA-VA analyses may underestimate the contribution to risk associated with future igneous activity. It states that NRC calculations show a small but finite risk from volcanic disruption of the proposed repository; DOE concluded in the TSPA-VA that risks from volcanism are negligible during a 10,000-year post-closure period. The NRC staff review of the TSPA-VA concluded that the DOE analyses are based on assumptions of physical conditions not representative of basaltic volcanism; that the data base was insufficient for evaluation of waste package performance under appropriate physical conditions; and that the modeling assumptions were incongruent with those used elsewhere in the TSPA-VA.

NRC99 asserts that models used by DOE in their volcanism evaluations are nonconservative, and that key assumptions are not supported by available data. It also notes that, although the VA licensing plan does not indicate planned activities to resolve these issues, supplemental work plans are being developed which could resolve them if implemented. NRC staff positions will be well documented in future versions of the Igneous Activity IRSR.

DOE responded to this criticism in its development of the TSPA for Site Recommendation (TRW00b). In the TSPA-SR, igneous activity was treated in a highly conservative manner, and proved to be the only mechanism for release of radionuclides in the first 10,000 years. However, despite the conservatism of the analysis, the mean dose rate remained below proposed regulatory criteria during 10,000 years.

Quality Assurance

NRC99 notes that DOE has consistently had problems in implementing its Quality Assurance (QA) program, which was reviewed and accepted by NRC. Audits have determined that some data in the technical data base are not traceable to their origins and could not be ensured to be applicable, correct, and technically adequate. The Technical Basis Document supporting the VA (DOE98a) indicated that a major portion of the data supporting the VA is not qualified in accord with QA program requirements.

NRC99 states that DOE must be able to demonstrate in its LA that the data, analyses, and designs of barriers and systems important to safety or waste isolation meet QA requirements of Appendix B to CFR Part 50.

DOE has recognized the need to meet QA requirements and has committed resources to development of an overall data qualification strategy and to resolution of QA issues. Plans for resolving QA issues address identification of unqualified data sets approved for qualification; methods for qualification and their rationale; technical disciplines required to achieve qualification; data evaluation criteria to be used; and criteria for changing data status from "unqualified" to "qualified". The NRC has formed a QA Task Force which will conduct an independent and objective review of the DOE program and its implementation.

9.3.4.3 New Repository Design Concepts

In the DOE TSPA-VA a number of alternative engineered barrier design elements were evaluated relative to their effects on the performance of the reference repository design in the VA. These alternatives included such design options as drip shields and backfilling the emplacement drifts. Reviews of the VA assessments pointed out a number of uncertainties in DOE's VA performance assessments concerning the performance of engineered and natural barriers as well as site characteristics. These uncertainties might be reduced in two ways: by more extensive site characterization work to more defensibly quantify the range of expected natural barrier performance conditions and by introducing additional engineering features that compensate for the uncertainties in site conditions and in performance of the engineered repository system components.

Subsequent to issuance of the VA report in December 1998, DOE assessed alternative engineered repository designs intended to reduce issues associated with uncertainties in performance of the VA reference design. As described in Section 7.2.2.5 of this BID, DOE characterized and evaluated six design options and selected, as basis for the Site Recommendation, the so-called EDA II design, whose key design features are compared with those of the VA reference design in Table 7-9 of this BID.

The EDA II design features are in part responsive to repository performance and regulatory compliance issues identified by NRC staff, the NWTRB, and the Peer Review Panel as a result of their review of the TSPA-VA. NRC staff also, however, identified and characterized issues that are important to DOE's effort for timely development of a high-quality LA, and for pre-licensing resolution of KTIs (NRC99) so that the basis for LA-review findings concerning reasonable assurance of compliance with regulatory standards is as clear and well-established as possible. These issues were identified and discussed in Section 9.3.3.

Key performance issues and uncertainties associated with the reference VA design that are intended to be mitigated by the EDA II design include:

- The reduced areal mass loading and increased drift spacing for the EDA II design are intended to reduce uncertainties associated with the effect of heat emissions on the movement and chemical characteristics of water in the geologic formations adjacent to the repository, and issues concerning coupling of thermal, hydrologic, chemical, and mechanical phenomena such as the areal extent of the "dry out" zone and its changes over time.

- Elimination of the concrete lining and invert is intended to eliminate uncertainties about the effect of concrete materials on the chemical characteristics of water that can contact and corrode the waste packages and dissolve the waste form.

- Revision of the waste package design to use Alloy 22 as the outside wall material is intended to eliminate the potential for crevice corrosion of this material when it is under carbon steel, as was the case for the waste package design for the VA. This change would significantly increase waste package lifetimes by significantly reducing or eliminating the potential for rapid corrosion of the Corrosion Resistant Material. The EDA II waste package design concept uses, in addition to Alloy 22 as the outer wall material, 316L stainless steel as the inner wall material. As described by DOE at the summer meeting of the NWTRB (DOE99), this design concept, in conjunction with the planned heat load and expected repository temperatures, is expected to keep corrosion conditions for the Alloy 22 outside the "window of vulnerability" to rapid crevice corrosion, which spans the range of 80-100 ^{0}C and 50-100 percent relative humidity. If sufficiently supported by data and analyses, this strategy could eliminate crevice corrosion as a potential cause of early waste package failure.

- Use of drip shields and backfill is intended to add defense-in-depth to the engineered design and to defer the time at which seepage water could contact the waste packages and initiate aqueous corrosion. Drip shields would significantly delay the start of waste package corrosion, and would also dramatically reduce the uncertainty in projecting the effects of premature failures due to manufacturing defects. The occurrence of premature failures is a difficult performance factor to characterize because there is no directly-transferrable empirical data base from industrial experience that matches expected repository conditions. DOE's's base case VA assessments show that the projected dose rates for 10,000 years are strongly influenced by radionuclides releases from the single package assumed to be prematurely failed at 1,000 years. If more than one package is assumed to fail, dose estimates would increase in proportion. Use of drip shields is an example of an additional engineered measure to compensate for uncertainties that can not be reduced in any other way. By shielding the waste packages with the drip shield, ground water infiltrating into the drift has to first cause corrosion of the shield rather than directly contacting a prematurely-failed waste package.

- Blending of spent fuel subassemblies to reduce variations in waste package heat emissions is intended to reduce temperature levels and gradients that could stimulate corrosion and other degradation processes, and to reduce uncertainties in modeling of EBS performance. By eliminating "hot spots" in the repository, the averaging approach needed to model at the repository scale becomes more defensible.

TSPA results for this design in the TSPA-SR have demonstrated that the design, accompanied by improved modeling and scenario analysis, have accomplished the goal of improved repository performance. Unlike the VA design, the TSPA-SR showed that there are no releases from the repository under nominal conditions during 10,000 years.

REFERENCES

AND89 Andersson, J., T. Carlsson, T. Eng, F. Kautsky, E. Söderman, and S. Wingefors, *The Joint SKI/SKB Scenario Development Project*, TR89-35, Stockholm, Sweden, 1989.

BAR92 Barnard, R.W., M.L. Wilson, H.A. Dockery, J.H. Gauthier, P.G. Kaplan, R.R. Eaton, R.W. Bingham, and T.H. Robey, *TSPA 1991: An Initial Total-System Performance Assessment for Yucca Mountain,* SAND91-2795, Sandia National Laboratories, Albuquerque, NM, 1992.

BER89 Bertram-Howery, S.G. and R.L. Hunter, Editors, *Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant,* SAND89-0178, Sandia National Laboratories, Albuquerque, NM, 1989.

BUR80 Burkholder, H.C., *Waste Isolation Performance Assessment: A Status Report*, Scientific Basis for Nuclear Waste Management, Volume 2, Plenum Press, pp. 689-702, 1980.

DAV79 Davis, W., "Carbon-14 Production in Nuclear Reactors", page 151 in *Management of Low-Level Radioactive Waste*, Carter, M.W., Moghissi, A.A., and Kahn, B., editors, Vol. I, Pergamon Press, New York, NY 1979.

DOE74 U.S. Department of Energy, *Potential Containment Failure Mechanisms and Their Consequences at a Radioactive Waste Repository in Bedded Salt in New Mexico*, ORNL-TM-4639, 1974.

DOE79 U.S. Department of Energy, *Scenarios for Long-Term Release of Radionuclide From a Nuclear-Waste Repository in the Los Medanos Region of New Mexico,* SAND78-1730, 1979.

DOE90a U.S. Department of Energy, *Risk Methodology for Geologic Disposal of Radioactive Waste: Scenario Selection Procedure,* NUREG/CR-1667, SAND80-1429, 1990.

DOE91 U.S. Department of Energy, *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991, Volume 1: Methodology and Results*, prepared by Sandia National Laboratories, Albuquerque, NM, under Contract DE-AC04-76DP00789, 1991.

DOE94 U.S. Department of Energy, *Total-System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993)*, SAND93-2675, April 1994.

DOE98 U.S. Department of Energy, *Viability Assessment of A Repository at Yucca Mountain*, DOE/RW-0508, December 1998.

DOE98a CRWMS Contractor, *Total System Performance Assessment - Viability Assessment (TSPA-VA) Analyses Technical Basis Document*, B00000000- 01717-4301-00001 Rev 01, November 13, 1998.

DOE99 U.S. Department of Energy, *Presentations at the Summer Meeting of the Nuclear Waste Technical Review Board*, Beatty, Nevada, June 29 and 30 1999.

EPA85 Environmental Protection Agency, *Final Rule, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, 40 CFR Part 191, Federal Register, 50 FR 38066-38089, September 19, 1985.

EPA96 Environmental Protection Agency, *Summary of EPA Office of Radiation Programs Carbon-14 Dosimetry as used in the Analysis for High-Level and Transuranic Wastes (Draft)*, prepared for the HLW/Carbon-14 Release Subcommittee of the EPA Science Advisory Board's Radiation Advisory Committee, 1996.

GEL98 Gelhar, Lynn W., *Report on U.S. Technical Review Board Winter Meeting*, January 20-21, 1998, Amargosa Valley, Nevada.

HUG99 Hughson, D., *Drift Seepage Peer Review*, Trip Report, Las Vegas, Nevada, January 11-13, 1999, Center for Nuclear Waste Regulatory Analyses, San Antonio, Texas.

IAE83 International Atomic Energy Agency, *Concepts and Examples of Safety Analyses for Radioactive Waste Repositories in Continental Geological Formations*, Safety Series No. 50, Paris, 1983.

ICR82 International Commission on Radiological Protection, *Limits for Intakes of Radionuclides by Workers, Part 3,* ICRP Publication 30, Pergamon Press, New York, NY, 1982.

ICR85a International Commission on Radiological Protection, *Principles of Monitoring for the Radiation Protection of the Population*, Publication 43, Annals of the ICRP, 15(1), Pergamon Press, 1985.

ICR85b International Commission on Radiological Protection, *Radiation Protection Principles for the Disposal of Solid Radioactive Waste,* ICRP Publication 46, Pergamon Press, 1985.

KIL78 Killough, G.G. and P.S. Rohwer, *A New Look at the Dosimetry of ^{14}C Released to the Atmosphere as Carbon Dioxide,* Health Physics 34:141, 1978.

NAS72 National Academy of Sciences - National Research Council, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiations (BEIR I),* Report of the Biological Effects of Ionizing Radiation, Washington, D.C., 1972.

NAS80 National Academy of Sciences - National Research Council, *The Effects of Populations of Exposure to Low Levels of Ionizing Radiation (BEIR III),* Report of the Biological Effects of Ionizing Radiation, Washington, D.C., 1980.

NAS95 National Academy of Science - National Research Council, Committee on Technical Bases for Yucca Mountain Standards, *Technical Bases for Yucca Mountain Standards*, National Academy Press, Washington, DC, 1995.

NRC81 U.S. Nuclear Regulatory Commission, *Disposal of High-Level Radioactive Wastes in Geologic Repositories*, 10 CFR Part 60, Federal Register, 46 FR 13980, 1981.

NCR93 National Council on Radiation Protection and Measurements, *Carbon-14 in the Environment,* NCRP Report No. 81, 1993.

NRC99 U.S. Nuclear Regulatory Commisssion, *Letter to DOE-Viability Assessment,* June 2, 1999.

NRC99a U.S. Nuclear Regulatory Commission, *NRC/DOE Technical Exchange on Total System Performance Assessment (TSPA) for Yucca Mountain,* May 25-27, 1999.

NWP83 *Nuclear Waste Policy Act of 1982*, Public Law 97-425, January 7, 1983.

NYE99 Nye County, Nevada, *Presentation by T. Buqo to the Nuclear Waste Technical Review Board Summer Meeting,* Beatty, Nevada, June 29 and 30, 1999.

NYE99a Nye County, Nevada, *Well Logs for the Early Warning Drilling Program,* available on the Nye County website, www.nyecounty.com.

PRP99 TSPA-VA Peer Review Panel, *Peer Review of the Total System Performance Assesment - Viability Assessment,* Final Report, February 1999.

ROS93 Ross, B., Y. Zhang, and N. Lu, "Implications of Stability Analysis for Heat Transfer at Yucca Mountain," in *High Level Radioactive Waste Management, Proceedings of the Fourth Annual International Conference, Las Vegas, Nevada, April 26-30, 1993,* American Nuclear Society, La Grange Park, IL, 1993.

TRB99 U.S. Nuclear Waste Technical Review Board, *Moving Beyond the Yucca Mountain Viability Assessment - A Report to the U.S. Congress and the Secretary of Energy*, April, 1999.

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CHAPTER 10

RADIOLOGICAL RISKS FOR DEEP GEOLOGICAL DISPOSAL AND SURFACE STORAGE OF SPENT NUCLEAR FUEL

10.1 BACKGROUND INFORMATION

In September 1996, the United States Senate (Senate Report 104-320, p.98, September 12, 1996) requested an evaluation by EPA of alternatives to the disposal of radioactive materials in a deep geologic repository at Yucca Mountain, as well as an evaluation of public health risks of these alternatives against standards proposed for deep geologic disposal. Alternatives to be considered included: (1) storage of nuclear wastes at each site where it is currently stored and (2) one or more centralized above-ground storage sites.

Spent nuclear fuel (SNF) from the operation of commercial nuclear power reactors is currently stored at more than 70 nuclear generating sites around the country. It is expected that existing nuclear power plants will produce approximately 87,000 metric tonnes of spent fuel during their operational lifetimes. Approximately 40,000 metric tonnes of spent nuclear fuel were stored at commercial nuclear power reactors as of 1999. By the year 2003, this amount is expected to increase to 48,000 metric tonnes (NPJ97).

To date, most SNF is stored in water-filled pools at the reactor sites where it was generated. However, space is not available in existing pools to store all of the spent fuel expected to accumulate over the lifetime of the reactors. When the pool capacities were established, it was expected that the SNF would be removed from the reactor site for reprocessing about five years after discharge from the reactor. After national plans for reprocessing were terminated, removal of SNF from the reactor sites for central interim storage or disposal was expected to begin in January 1998, but these programs have been delayed. Consequently, additional SNF storage capacity is therefore needed.

Facilities for interim storage of SNF prior to disposal have been under consideration since 1972. In February 1972, the Atomic Energy Commission (AEC) began consideration of surface storage facilities at the Hanford site in the State of Washington. The facility would be used "...for high-level commercial wastes and low-level wastes from both commercial and AEC activities (HEW87)." In June 1972, the AEC revealed plans to develop a Retrievable Surface Storage Facility (RSSF), which would be an array of mausolea or vaults where waste or spent fuel canisters would be stored (CAR87).

The decision to choose the surface storage option "...was a response to the dilemma of irretrievability" and seemed a "practical answer to a difficult political and technical problem (HEW87)". The AEC concluded that such storage would be satisfactory for decades or centuries (USC72, USC75). The Congress' Joint Committee on Atomic Energy reported in 1972 that the radioactive waste management program "...now includes the conceptual design of manmade surface facilities of an expected lifetime of several centuries (USC72)."

Three technical concepts for the RSSF were considered by the AEC: (1) stainless steel canisters in water basins for heat removal and shielding; (2) canisters in concrete basins, cooled by circulating air; and (3) a canister within a two-inch thick container with doubly-contained waste in a three-foot thick concrete cask cooled by circulating air.

Recently, members of Congress, other public officials, environmental groups, and private citizens have expressed concern that a surface storage facility might be regarded as a *de facto* repository, thereby reducing the impetus for building a geologic repository as expeditiously as possible. To allay these concerns, proposed Monitored Retrievable Storage (MRS) facilities have consistently limited the total storage capacity to well below total SNF quantities projected for permanent deep geologic disposal. MRS designs have been proposed from a few thousand up to 15,000 metric tonnes uranium (MTU). This chapter compares the potential impacts of continued storage to those associated with disposal at a geologic repository at Yucca Mountain. The comparison is presented in terms of applicable regulatory limits (Section 10.2) and anticipated (estimated) risks (Sections 10.3 and 10.4).

10.2 REGULATORY LIMITS

The Energy Policy Act of 1992 (EnPA) directs the Administrator to establish, after consultation with the National Academy of Sciences (NAS), a maximum individual dose standard for the proposed repository at Yucca Mountain. The NAS found that such an approach would provide protection for all exposed individuals and suggested that levels of a few millirems/year to a few tens of millirems per year (mrem/yr) would provide a reasonable point of departure for rulemaking. Therefore, for the purposes of comparison, it is assumed that the Yucca Mountain standard will establish a maximum individual dose standard. Further, absent the Administrator's final decision on the level of the standard, this comparison uses the upper end of the NAS'suggested range (i.e., a few tens of millirems per year) to characterize the allowable exposure limits for the proposed repository. This limit, which encompasses all exposure pathways, will apply to releases from the repository over an extended period of time. The NAS has recommended that it apply during the period of geologic stability for the site, a time frame that could extend to one million years.

The regulatory limits that would apply to continued surface storage depend upon the specific site at which the wastes are stored. For continued storage at the sites at which the spent fuel and high level wastes were generated or are currently stored, different limits apply to the following types of facilities:

- Power reactors
- Research reactors
- Independent spent fuel storage installation (ISFSI)
- DOE facilities

If the government opts to store wastes at a centralized facility such as an an ISFSI or an MRS facility, the applicable limits would likely be those for an ISFSI. However, if the ISFSI or MRS were constructed on a site owned by DOE prior to 1983, the limits applicable to DOE facilities would likely apply.

10.2.1 Power Reactors

For waste stored at power reactors, the applicable regulatory limits would be those established by EPA for the nuclear fuel cycle (40 CFR Part 190), and the NRC (10 CFR Parts 20, 50, and 100). 40 CFR Part 190 establishes exposure limits from normal facility operations of 25 mrem/yr to the whole body or any organ (except the thyroid, which is allowed 75 mrem/yr). These limits, established under the old "whole body/critical organ" protection concept, are roughly equivalent to a 15 mrem/yr limit under the current "effective dose equivalent (EDE)" protection concept. The 40 CFR Part 190 limits consider all exposure pathways and require the site to consider potential exposures from all facilities that are part of the nuclear fuel cycle. Under 10 CFR Part 20, power reactors are required to maintain exposures as low as is reasonably achievable (ALARA), consistent with maximum individual exposures of 100 mrem/yr "total effective dose equivalent" (TEDE) at an exposure rate not to exceed 2 mrem/hr. The limits for normal operations at power reactors can be characterized as ALARA, with maximum individual exposures limited to less than two millirem per hour (mrem/hr) TEDE and not to exceed 75 mrem/yr to the thyroid or 25 mrem/yr to the whole body or any other organ. The EPA's recent evaluation of the airborne emissions from power reactors during its reconsideration of the National Emission Standards for Hazardous Air Pollutants (NESHAPS) (40 CFR 61 Subpart I) found that the ALARA design objectives and limiting conditions of operations set forth in Appendix I to 10 CFR Part 50 are being met by power reactor licensees and that actual exposures from the air pathway are a fraction of the regulatory limits.

In addition to the operating limits on power reactor licensees, 10 CFR Part 100 establishes siting criteria that assure that no member of the public will receive an exposure greater than 25 rem to the whole body or 300 rem to the thyroid over a two-hour period of exposure to a fission product release associated with a hypothetical major accident at the facility.

10.2.2 Research Reactors

The regulatory limits for research (non-power) reactors are established by 10 CFR Part 20. Exposures via all pathways to any member of the public from normal operations are also required to be as low as reasonably achievable, consistent with a maximum individual exposure limit of 100 mrem/yr TEDE at an exposure rate not to exceed 2 mrem/hr. Additionally, under the recently adopted "constraint rule," corrective actions must be initiated should exposures via the air pathway exceed 10 mrem/yr TEDE. Given this and a 50/50 split of the 100 mrem/yr limit between the air and liquid pathways outlined in 10 CFR Part 20, the effective maximum individual dose limit for research reactors from normal operations is 60 mrem/yr TEDE. No quantitative limits are imposed on research reactors for demonstrating ALARA for non-airborne exposure pathways, nor are quantitative criteria given for exposures from accidental releases. However, site suitability is considered during licensing.

10.2.3 Independent Spent Fuel Storage Installations (ISFSIs)

The regulatory requirements for ISFSIs are those established by the NRC in 10 CFR Parts 20 and 72. The limits established in Part 20 require exposure to be maintained as low as reasonably achievable, consistent with a maximum individual exposure limit of 100 mrem/yr TEDE at an exposure rate not to exceed two mrem/hr. Additionally, Part 72 imposes the nuclear fuel cycle exposure limits of 40 CFR 190. Therefore, like power reactors, the limits for normal operations of an ISFSI can be characterized as ALARA with maximum individual exposures limited to less than two mrem/hr TEDE and not to exceed 75 mrem/yr to the thyroid or 25 mrem/yr to the whole body or any other organ.

10 CFR Part 72 also establishes an exposure limit of five rem to the whole body or any organ in the case of an accident. This limit is applied at the boundary of the controlled area and cannot be exceeded by any design basis accident.

It should be noted that the limits for an ISFSI currently apply to dry storage of spent fuel at operating nuclear power plants, but not the original wet fuel pools. However, as reactors reach the end of their operating lives and are decommissioned, it is likely that long-term storage of all spent fuel would be conducted under a license issued pursuant to 10 CFR Part 72.

10.2.4 DOE Facilities

Relevant exposure limits for DOE facilities are those established by EPA for airborne releases of radionuclides (40 CFR 61, Subpart H) and by DOE Order 5280. 40 CFR 61, Subpart H, limits airborne releases of radioactive materials (excluding radon and its decay products) to quantities that do not cause any member of the public to receive an exposure greater than 10 mrem/yr EDE. The limits established by DOE Order 5280 mirror 10 CFR Part 20; i.e.,, exposures are to be as low as reasonably achievable, consistent with a maximum individual exposure limit of 100 mrem/yr TEDE from all pathways at an exposure rate not to exceed two mrem/hr. Given the constraint rule for the airborne pathway and a 50/50 split of the 100 mrem/yr limit between the air and liquid pathways, the limits for DOE facilities can be characterized as ALARA with maximum individual exposures not to exceed 60 mrem/yr TEDE at a dose rate of less than two mrem/hr (10 CFR Part 20).

No quantitative exposure criteria for accidental releases from DOE facilities are established by DOE Order 5280 or 40 CFR Part 61.

10.2.5 Summary of Regulatory Limits

As the above subsections have detailed, different regulatory limits would apply at existing or future storage sites, depending upon the specific use of the site. However, given the ALARA requirement imposed on all sites and the various limits on maximum annual exposures, it is not unreasonable to expect that exposures from undisturbed storage would be on the order of a few tens of millirems per year at any of these facilities. This level of exposure is consistent with the limits that will likely be promulgated for Yucca Mountain.

Such comparability cannot be assumed in the event of accidents. The Yucca Mountain standards explicitly require that natural phenomena be evaluated and factored into the design of the facility. Thus, a maximum individual exposure limit of a few tens of millirems per year would apply to exposures caused by both accidents and natural phenomena. By contrast, no explicit criteria exist for accidents at research reactors or DOE facilities. Consequently, the limits for storage at power reactors and ISFSIs could potentially allow individual exposures of up to five rem EDE in the case of an accident.

10.3 REPORT BY THE MONITORED RETRIEVABLE STORAGE REVIEW COMMISSION

Information presented in this and the following section addresses the risks associated with storage of SNF at reactor sites and at a central interim storage facility, characterized as a Monitored Retrievable Storage Facility. These risks are compared to those associated with disposal at the proposed Yucca Mountain repository site in Nevada. A review of literature on the risks of SNF storage and disposal revealed a large body of information. However, no studies to date have specifically addressed the scope of the directives of the Senate Report. Past studies have focused on dry storage at reactors and on an MRS facility as part of a dynamic total waste management system configuration. Despite its limitations, this information was used as the basis for the data presented in this section of the BID.

In 1987, the Nuclear Waste Policy Amendments Act established the Monitored Retrievable Storage Review Commission. The Commission's charter was to compare storage of spent fuel at a Federal MRS facility to storage of spent fuel at the reactors at which it was generated. Through public hearings, the Commission solicited the views of private citizens, technical experts, and utility and government representatives. In addition, several contractors performed specific tasks to augment the Commission's technical work. The Commission's final report, issued in November 1989, examined each alternative's merits, including an assessment of radiological doses and risks to members of the general public. The report's principal findings are summarized below (MRS89).

10.3.1 At-Reactor Storage Options

Water-filled pools have been used for SNF storage since the earliest days of nuclear reactor operation and are universally used for storage of commercial Light Water Reactor (LWR) fuels today. Spent fuel pools employ a large amount of water for heat removal and radiation shielding. Pools remain a proven method for cooling LWR fuels for periods lasting from five to ten years. Thereafter, the fuel can be removed from the pool to make room for new inventories of hot fuel.

As stated above, existing pool capacities were not designed to accommodate SNF quantities generated from the 40-year operating life of a reactor. Expansion of storage capacity at the reactor sites includes options that are broadly categorized as wet storage and dry storage. (Rod consolidation for expanding on-site storage capacity is currently not considered a viable option and was therefore not considered.)

Two wet storage options commonly considered are spent fuel reracking and new pool construction:

- Spent Fuel Reracking. This option entails a reconfiguration for high density storage. Typically, this is done by manufacturing fuel racks that bring fuel elements closer together in order to create additional storage space. Most utilities have reracked their pools at least once. From the original typical design of 1-1/3 reactor core storage capacity, utilities have frequently increased storage to four to six reactor cores. However, even with these measures, pool-storage capabilities at most reactors will not be considered adequate.

- New Pool Construction. This option entails the construction of a pool for long-term storage of SNF. Due to high costs and operational/maintenance factors, new pool construction is not considered competitive to dry storage.

Since the early 1980s, demonstration projects at several utilities and research by the Electric Power Research Institute have demonstrated the viability of dry storage methods for SNF. Many different dry storage methods have been proposed and/or tested, including metal or concrete storage casks, air-cooled vaults, and universal multipurpose casks. (Note: In 1990, the NRC amended its regulations to authorize licensees to store spent fuel at reactor sites in storage casks approved by the NRC. To date, seven cask designs have received certificates of compliance (NPJ97).) A generic description of dry storage methods includes:

- Modular Concrete Vaults (MCV). MCVs consist of sealed metal tubes inside an above surface concrete structure. Inside the sealed metal tubes, the spent fuel is kept under an inert cover gas or air. The tubes are typically made of carbon steel and each tube contains a single fuel assembly or a single element. The MCV has received site-specific NRC licensing.

- Horizontal Concrete Vaults (Modules). Horizontal concrete modules keep the fuel inside a sealed stainless steel canister back-filled with an inert gas. The canister is protected and shielded by an above-surface concrete module. The heat generated by the spent fuel is removed by thermal radiation, conduction, and natural convection through air channels in the concrete module. The canister contains a basket for holding the fuel in place. The horizontal concrete vault has received site-specific NRC licensing.

- Metal Dry Casks (MDC). Metal dry casks are the most mature of the methods available for dry interim storage. Their use was successfully tested and demonstrated in 1984. The casks are large heavy vessels (100 to 125 tonnes loaded). They are equipped with an internal basket for holding the spent fuel assemblies or elements. The body is made from forged steel, modular cast iron, or lead and stainless steel with a double seal lid. The MDC has received site-specific NRC licensing.

- Concrete Dry Storage Casks. Concrete dry storage casks are similar to metal dry casks except that the body of the cask is made of steel-reinforced concrete with an inner metal liner for containment. Concrete dry storage casks have received site-specific NRC licensing.

- Dual Purpose Casks (DPC). The DPC was derived from the metal dry cask concept. The design and manufacture are very similar to that of the metal dry cask, but it would also be used to transport the fuel to a Federal spent fuel management facility. The fuel would be removed upon arrival at the spent fuel management facility, but would not be disposed of in a DPC. The DPC remains in development.

- Multi-Purpose Casks (MPC). This dry cask combines storage, transportation and disposal in one container. The MPC would potentially allow spent fuel to be stored, transported and disposed of in the same container in which it was originally placed. The use of the MPC would not require the fuel to be extracted from it prior to being placed in a repository.

10.3.2 Radiation Exposure Modeling Assumptions for At-Reactor Storage of SNF

To model public radiation exposures associated with at-reactor storage of SNF, the MRS Commission Report assumed that there were to be no new orders for nuclear power plants beyond those operating or being constructed as of December 1987. For post-1988 SNF, burnup rates of 36,600 megawatt-days per metric ton uranium (MWd/MTU) and 42,000 MWd/MTU were assumed for BWRs and PWRs, respectively.

It was also assumed that all fuel would be stored at the reactor sites until DOE was ready to accept the waste and ship it to the repository for disposal. The analysis assumed utilities would select from a number of currently available options to provide at-reactor storage that includes fuel-pool reracking supplemented by dry-storage. Since most utilities have already reracked their pools at least once, the Commission concluded that future reracking will be limited. Adding a second tier of racks was not considered a practical way to expand the current pool storage capacity. It was further assumed that there would be no transhipment of spent fuel from one reactor site to another to alleviate storage problems. Every utility would maintain enough pool storage capacity so that the full core of the reactor could be unloaded into the spent fuel pool, if necessary.

For the balance of life-of-plant SNF, dry storage, either at the reactor sites or on utility-owned land contiguous to the reactor, was assumed to involve metal or concrete casks. The typical metal dry storage cask is made of stainless steel or nodular cast iron that may hold from a few to 25 PWR fuel assemblies per module. For concrete casks with an inner metal liner, the unventilated type will hold nine PWR or 25 BWR fuel elements, while a ventilated type may hold 17 PWR or 50 BWR elements.

Although a few reactors have already been permanently shut down, the majority of currently licensed and operating facilities will reach their end-of-operating life between the years 2009 and

2030. Table 10-1 shows the amounts of five-year-old SNF that are expected to be stored in fuel pools and in dry storage.

Table 10-1. Spent Fuel Accumulation at Shutdown Commercial Light Water Power Reactors (Source: MRS89)

Year	MTU of Five-Year-Old Fuel		
	Dry Storage	Pool Storage	Total
2000	0	500	500
2005	0	500	500
2010	0	1,500	1,500
2015	500	4,000	4,500
2020	7,500	21,000	28,500
2025	12,000	29,000	41,000
2030	19,500	40,000	59,500
2035	27,000	54,000	81,000
2040	29,000	55,500	84,500
2045	30,000	57,000	87,000

10.3.3 Model Assumptions for MRS Storage of SNF

For the MRS alternative analyzed by the Commission, spent fuel is assumed to be stored at the reactors until an MRS facility becomes available. At this time, spent fuel from some reactors would be transported to and stored at an MRS until a repository is available for permanent disposal. The MRS would continue to operate until all the spent fuel has been emplaced in the repository.

The MRS facility as defined in the Nuclear Waste Policy Amendments Act of 1987 was analyzed. Given the MRS capacity limitation of 15,000 MTU, most spent fuel would be stored at the reactor site. The MRS would, therefore, only supplement at-reactor storage and reduce the need for dry storage at reactor facilities, as defined in Table 10-2. Dry modular storage, using technologies similar to those described in Section 10.3.1, was assumed for the MRS facility.

Table 10-2. Reduction in Dry Storage Needs At Reactor Facilities with Linked MRS (Source: MRS89)

Cases	Maximum MT in Dry Storage	Difference From No-MRS Case
No-MRS	7,693	---
Linked MRS*	3,562	4,131

*MRS schedule linked to repository schedule.

10.3.4 Transportation Models for SNF With and Without MRS

The MRS Review Commission's dose assessment for members of the public also included radiation exposure that would result from transportation of wastes if an MRS facility were part of the spent fuel management system and if it were not. In the absence of an MRS facility, transit doses could result to members of the public along the paths of travel between individual reactor sites and a repository assumed to be at the Yucca Mountain Site. With an MRS facility, transit exposures could occur between: (1) reactor sites and the MRS facility, (2) reactor sites and the repository, and (3) the MRS facility and the repository. For SNF shipments originating from reactors, 54 percent would be shipped by rail and 46 percent by truck; 100 percent of the shipments between the MRS facility and the repository were assumed to be made by rail. These assumptions will hold despite the location of the MRS, since all waste that could be moved by rail (rail head at reactor site) were assumed to be moved by rail. The assumed MRS location was actually in the Eastern United States.

Table 10-3 identifies primary parameters that define transportation risk for each of the base cases. In effect, these parameters serve as surrogate measures to approximate risk. For example, to compare the relative radiological risk of the three base cases, the total number of shipment miles or cask miles was added. The underlying assumption was that public exposure was proportional to the number of casks and distances traveled.

Table 10-3. Life-Cycle Transportation Risk Measures*
(Source: MRS89)

Cases	Shipment-miles (in millions)	Cask-miles (in millions)
No-MRS	64.7	74.1
Linked MRS**	26.9	40.3

* Repository in 2013 (54% rail/46% truck from reactor; 100% rail from MRS facility)

** MRS facility to begin operations in 2010

10.3.5 Public Exposure From SNF Storage

Radiation doses to members of the public were assessed for spent fuel management operations at reactor sites, the MRS facility, and the repository. The computer model used to evaluate radiation doses for different system configurations was MARC: MRS Review Commission's Analysis of System Risk and Cost. MARC is a network model that incorporates DOE's computer code TRICAM. TRICAM describes how spent fuel moves through the system and is used for modeling transportation. The code also uses facility-specific data such as reactor spent fuel discharges, population data, reactor rail accessibility, repository capacity and demographics, and acceptance schedules.

Table 10-4 summarizes population doses predicted by MARC for members of the public. Population dose estimates were 130 person-rem for individuals living within a 50-mile radius of the 70 reactor sites; 4 person-rem for individuals living within a 50-mile radius of an MRS facility located in the eastern United States; and 0.125 person-rem for individuals living within a 50-mile radius of a deep geologic repository assumed to be located at Yucca Mountain.

The Commission report found that public exposures from spent fuel were small at all locations associated with SNF management. By far, the largest source of public exposures was estimated to result from the transportation of SNF between reactor sites and the MRS facility and the repository and between the MRS facility and the repository. Table 10-4 shows that public transportation exposure is reduced by more than a factor of two (i.e., from 7,900 to 3,400 person-rem) when an MRS facility is included in the management of SNF. This is almost exclusively due to reduced shipping miles and its attendant shift from truck to rail services when an MRS facility is employed.

Table 10-4. Total Life-Cycle Doses in Person-Rem from Spent Nuclear Fuel Management With and Without MRS
(Source: MRS89)

Activity Center	At-Reactor Storage Only (person-rem)	At-Reactor Storage Plus MRS (person-rem)
All Reactors	130	13
MRS Facility	Not applicable	4
Repository	0.1	0.1
Transportation	7,900	3,400
TOTAL	~ 8,000	~3,500

Results reported by the MRS Review Commission (as summarized in Table 10-4 above) cannot be used directly to compare potential public risks from SNF stored at the proposed Yucca Mountain Site (YMS) with the alternatives of At-Reactor Storage and MRS storage. The dose estimates given in Table 10-4 correspond to <u>different</u> and <u>changing</u> SNF inventories at these facilities over different time periods. The variations in SNF quantities and locations with time associated with the MRS Review Commission evaluations are shown in Table 10-5.

By interpolation, average SNF quantities can be defined for each time period that, when added, yield time-weighted quantities of stored SNF at the reactor facilities, MRS, and repository in terms of metric tonnes of uranium-years (MTU-years):

- <u>For At-Reactor Storage,</u> which spans the 50-year period between 1995 and 2045, fuel pool and dry storage correspond to 1,672,067 MTU-years

- <u>MRS Storage</u> that is assumed to begin in 2010 and ends in 2045 represents a time-weighted SNF storage value of 106,400 MTU-years

- <u>Repository Storage and Disposal</u> that is assumed to begin in 2013 yields a cumulative value of 1,302,431 MTU-years

Table 10-5. Location of Spent Fuel With MRS in 2010 and Repository in 2013 (MTUs)
(Source: MRS89)

Year	Pool Storage At-Reactor	Dry Storage At-Reactor	MRS Storage	Repository
1995	28,680	1,286	---	0
2000	36,807	3,711	---	0
2005	42,026	8,019	---	0
2010	46,362	11,532	2,400	0
2015	49,914	7,907	12,100	1,149
2020	43,857	5,819	15,000	12,798
2025	36,799	4,208	15,000	27,715
2030	28,037	459	15,000	45,644
2035	18,949	0	9,800	57,596
2040	9,831	0	3,000	72,436
2045	0	0	1,000	86,756

From the MRS Review Commission's previous estimates of public exposures, normalized public dose estimates can be derived that provide a fair comparison for these three modes of SNF storage (Table 10-6). Based on normalized values, public exposures that would result from SNF stored at reactor sites and a designated MRS are nearly the same. For storage at a repository, however, public exposure is projected to be lower by two to three orders of magnitude.

The projected similarity of public doses for at-reactor and MRS storage is to be expected if it is assumed that: (1) release fractions of stored SNF for these two alternatives are either identical or very similar and (2) the population density and distribution for the hypothetical MRS facility are similar to the 0-50 mile populations that characterize each of the 70 reactor facilities expected to store SNF onsite.

The much lower collective population exposure estimated for repository storage is also to be expected. For deep geologic disposal, the release fraction from the waste package to the biosphere is likely to be reduced by at least two to three orders of magnitude, as suggested by the reduced normalized population dose estimates in Table 10-6. It can also be assumed that cited population dose estimates will decline to even lower levels when the repository progresses from its operational phase to post-closure that includes backfilling of all access shafts and repository penetrations (MRS89).

Table 10-6. Comparison of Public Exposures Resulting from Three SNF Storage Alternatives

SNF Storage Alternative (Collective Dose)*	Time-Weighted SNF Quantities (MTU-Yrs x 1,000)	Normalized Public Exposure	
		Person-rem per 1,000 MTU-Yrs	Person-rem per Year for 70,000 MTU
At-Reactor Storage (130 person-rem)*	1,672	7.8E-02	5.5E+00
MRS (4 person-rem)*	106	3.8E-02	2.7E+00
Repository (0.125 person-rem)*	1,302	< 9.6E-05	6.7E-03

*MRS Review Commission's public dose estimates (see Table 10-4).

10.4 OTHER INFORMATION SOURCES

A comprehensive literature review was performed to identify other potential sources of information concerning radiation exposures associated with SNF management and disposal. Additional data were needed to: (1) confirm and/or compare dose estimates cited by the Commission, and (2) supplement Commission's data that were limited to collective population doses from routine facility operation. Lacking in the Commission Report were dose data for the reasonably maximally exposed individual (RMEI) and doses linked to accidental releases.

Estimates of offsite doses that result from accidental releases of radioactivity to the environment are complex and require predictive risk analyses that include: (1) a facility-specific characterization, (2) identification of potential accident scenarios, (3) estimation of accident probability, and (4) pathway modeling that incorporates site-specific data on weather, population distribution, land use, hydrology, etc.

It was found that, for the studies reviewed, a simple comparison of reported dose estimates is made difficult by variations in the studies' scope and objectives, selection of accident scenarios, and model-parameter values. To provide a common basis for comparison, secondary information, when provided within each study, was used to convert reported data to a common normalized value that would permit comparison. Summarized below are the most relevant studies and their estimates for doses to members of the public.

10.4.1 "An Assessment of LWRS Spent Fuel Disposal Options" (BEC79)

This study was conducted by the Bechtel Corporation for the DOE National Waste Terminal Storage Program and provided background documentation that dealt with three treatments of SNF prior to disposal at a repository:

Case 1: Simple encapsulation and disposal of spent fuel at the repository following storage at an ISFSI for nine years

Case 2: Encapsulation of fuel, end fittings, and secondary wastes after chopping the fuel bundle and removal of volatile materials

Case 3: Encapsulation of fuel, end fittings, and secondary wastes after chopping, removal of volatile materials, calcination, and vitrification

These base case scenarios assumed a spent fuel throughput of 5,000 MTU per year at a processing and encapsulation facility before the SNF was shipped to a repository for final disposal.

Risk analysis at the repository was further limited to the preclosure period, which defines the period of emplacement of the processed/encapsulated SNF. Estimates of public exposures were defined for normal operations and "shaft drop" accident conditions as summarized in Table 10-7.

Table 10-7. Public Doses for Normal Repository Operation and From Shaft-Drop Accident (Based on data from BEC79)

SNF Packaging	0-50 Mile Population Dose (person-rem/1,000 MTU-yr)
Case 1	
Normal Operation	1.0E-06
Accident	1.1E-02
Case 2	
Normal Operation	1.5E-06
Accident	1.1E-02
Case 3	
Normal Operation	2.0E-06
Accident	1.1E-02

10.4.2 "Generic Environmental Impact Statement, Management of Commercially Generated Radioactive Waste" (DOE80).

This study, known as the GEIS, was issued as a basis for reexamining the strategy for disposing HLW in a mined geologic repository with several alternative configurations. Reference repositories located in salt, granite, shale, and basalt were analyzed at a "reference" location in a midwestern state. Preclosure facility risk categories analyzed included routine exposures to the regional population and maximum individual exposure from potential worst-case accidents. Routine doses to the regional population from chronic radiological releases to the atmosphere were derived from the standard Gaussian dispersion model. Of a total of 207 potential accident scenarios considered, 116 had the potential for offsite exposure. Dropping a spent fuel canister was considered the most serious radiological event, with an estimated frequency of occurrence of 1.0E-05 per year.

Exposure to the 50-mile population from routine repository preclosure operation was considered "negligible," with no quantitative estimate given.

For all accidents considered, public exposure was estimated at 5.0E-05 person-rem per year; and for any single worst-case accident, a maximum individual exposure of 1.1E-04 rem was estimated.

10.4.3 "Review of Dry Storage Concepts Using Probabilistic Risk Assessment" (ORV84)

This study provided a comparative risk analysis for dry storage of SNF at reactor sites. Assessed storage designs included drywall, storage cask, and vault. The reference reactor facility was a 1,000-MWe PWR that was assumed to discharge 60 spent fuel assemblies (~19 MTU) to the fuel pool. After five years of cooling, SNF was transferred to dry storage with a capacity of 2,400 fuel assemblies (~62 MTU).

To model accidental release fractions, a starting assumption was that one percent of the fuel was failed prior to any of the accident scenarios. Principal elements modelled included long-lived radionuclides of Kr, I, Cs, Sr, Cs, and actinides.

Conservative model parameters were used to estimate population doses out to a distance of 200 miles from the reference reactor site. For example, primary model parameters used included the relatively high population density distribution for the Zion nuclear power plant, one meter per second wind velocity, and stability class D. Table 10-8 defines population dose risks for 12

Table 10-8. At-Reactor Storage Accidents: Summary of Results (ORV84)

Accident Scenario	Frequency (events/yr)	Number of Assemblies	Dose Consequence (Person-rem/event)	Dose Risk (Person-rem/yr)
Fuel Assembly Drop During Loading	1E-01	1	4E-01	4E-02
Drop of Transport Cask During Loading				
Cask	4E-03	10	4E+00	2E-02
Drywall	7E-02	10	4E+00	3E-01
Venting of Cask During Transport				
Cask	2E-03	24	1E+03	2E+00
Drywall	3E-02	1	4E+01	1E+00
Collision During Transport				
Cask	2E-04	24	1E+03	2E-01
Drywall	2E-05	1	4E+01	8E-04
Collision with Fire During Transport				
Cask	2E-06	24	5E+03	1E-02
Drywall	2E-07	1	2E+02	4E-05
Canister Drop During Emplacement				
Drywall	1E-06	1	4E+01	4E-05
Canister Shear During Emplacement				
Drywall	2E-06	1	4E+01	8E-05
Cask Drop During Emplacement				
Cask	1E-05	24	1E+03	1E-05
Tornado Missile Penetration				
Cask	6E-06	10	4E+02	2E-04
Drywall	1E-04	10	4E+02	4E-02
Plane Crash Topples Cask with Fire				
Cask	6E-09	24	5E+03	3E-05
Plane Crash Plus Fire				
Cask	9E-09	24	5E+03	4E-05
Drywall	2E-07	1	2E+02	4E-05
	2E-08	10	2E+03	4E-05
Earthquake				
Cask	4E-06	24	1E+03	4E-03
	4E-08	2,400	1E+05	4E-03
Drywall	8E-06	1	4E+01	3E-04
	8E-07	10	4E+02	3E-04
	2E-08	2,400	2.4E+04	5E-04
Total Risk: Cask				2.3E+00
Drywall				1.4E+00

accident scenarios. For cask and drywall storage, the annual population doses of 23 and 14 person-rem, respectively, were estimated.

10.4.4 "Requirement for the Independent Storage of Spent Fuel and High-Level Radioactive Waste" (NRC84).

This environmental assessment study performed by the Nuclear Regulatory Commission analyzed a fuel storage installation (i.e., MRS) that was intended to accommodate 70,000 MTU for a period of 70 years using dry store technology. It was further assumed that the facility would receive 3,500 MTU per year for a period of 20 years, with an additional 50-year storage period at maximum capacity.

The NRC assumed MRS construction designs that effectively reduce potential air emissions to near zero levels. Public doses resulting from routine operation/storage were, therefore, assumed to be "insignificant."

For accidental fuel canister failure containing 1.7 MTU, the Commission estimated a maximum individual dose of about 1×10^{-6} rem per year per event.

10.4.5 "Environmental Assessment Related to the Construction and Operation of the Surry Dry Cask Independent Spent Fuel Storage Installation" (NRC85)

Virginia Electric and Power Company conducted a study as part of an application for a license to construct and operate an onsite Dry Cask ISFSI. The function of the Dry Cast ISFSI was to provide on-site interim storage for about 420 MTU of spent fuel from its reactors, Surry 1 and 2.

Based on cask design and specifications, no liquid and gaseous releases were assumed and only direct irradiation was considered for an exposure pathway under normal facility operations. The estimated maximum annual dose to the nearest actual offsite person located at 2.5 km from a direct radiation source was estimated to be 6E-05 mrem/yr.

For a hypothetical worst case accident, an upper-bound individual dose of 1.35 mrem/yr was estimated at the site boundary.

10.4.6 "Environmental Assessment Deaf Smith County Site, Texas" (DOE86a)

This DOE study evaluated the suitability of an HLW repository site in salt as specified in the NWPA of 1982. The reference repository was assumed to have a capacity of 36,000 MTU SNF and 3,510 metric tonnes of DOE-HLW. SNF was assumed to be 6.5 years old with an average annual receipt rate of 634,000 rods per year.

Estimated offsite radiological effects for routine and accidental releases are cited in Table 10-9.

Table 10-9. Preclosure Exposure Associated with a Reference Salt Repository
(Based on data from DOE86a)

Scenario	Dose
Normal Operation	
50-Mile Population	390 person-rem/yr
RMEI	5.6E-03 rem/yr
Worst-Case Accident	
50-Mile Population	3,000 person-rem/event
RMEI	4.7E-02 rem/event

10.4.7 "Preliminary Assessment of Radiological Doses in Alternative Waste Management Systems Without an MRS Facility" (SCH86)

This study analyzed the effects of nine waste management system alternatives, excluding an MRS facility, specifically dealt with at-reactor facilities and the surface facilities of a deep geologic repository site. The nine alternatives largely involved transportation modes and options between reactors and the repository and resulted in nominal differences in public exposures.

Public doses from routine waste management activities at reactor facilities were estimated to be at less than one person-rem per year per 1,000 MTU. The potential drop of a fuel assembly was cited as the typical accident scenario, with an occurrence frequency estimated at 0.006 per year and an estimated population exposure of 0.1 person-rem per event.

Public doses under normal operating conditions at the surface facility of a repository would likely be due to effluents associated with cask venting and fuel consolidation. On a 1,000 MTU basis, public exposure was estimated to be 6 person-rem. Public doses from accidental fuel-assembly and shipping cask drop were estimated to vary between 0.03 and 0.006 person-rem per year. Table 10-10 summarizes the public-dose estimates cited in this study.

Table 10-10. Public-Dose Estimates for Reference Reactor and Repository Surface Facility (Based on data from SCH86)

Routine Activity	Public Dose (person-rem/1,000 MTU)
• SNF Handling At-Reactor	1
• SNF Handling/Consolidationat Repository Surface Facility	6
• Transportation Between Reactor and Repository	164
Accidental Conditions	**Public Dose (person-rem/yr)**
• At-Reactor	0.0006
• At Repository Surface Facility	0.03 - 0.006

10.4.8 "Monitored Retrievable Storage Submission to Congress" (DOE86b)

This comprehensive environmental assessment study was prepared by DOE and submitted to Congress under Section 141 of the Nuclear Waste Policy Act. The study assessed impacts to humans and the environment from construction, operation, and decommissioning of an MRS facility at three potential sites (Clinch River, Oak Ridge, and Hartville, Tennessee) and two possible designs for a storage system: storage casks and field dry wells. Radiological doses from routine emissions from the MRS facility were estimated, along with doses resulting from specific accident scenarios. The facility was assumed to have a 26-year operating life with a total throughput of 62,000 MTU.

For routine operations that assume a "store-only MRS" and a repository that containerizes intact fuel, the estimated population doses are given in Tables 10-11a and 10-11b.

Tables 10-11a and 10-11b indicate that: (1) exposures to members of the public are significantly greater for routine operations than for accidental releases, (2) exposures are consistent with values cited by the MRS Review Commission, and (3) exposures for the RMEI are well below all regulatory limits.

Table 10-11a. Public Doses From Routine Operations at MRS and Repository (DOE86a)

Routine Activity	Annual Offsite Population Dose (person-rem/1,000 MTU)	RMEI (rem/yr)
• MRS-Routine Release	0.1*	< 0.001
• Repository-Routine Release	< 0.1*	< 0.001
• Transportation-Normal		<0.005
- Reactors to MRS	64	
- MRS to Repository	16	

*Population dose assumes storage only without fuel consolidation.

Table 10-11b. Public Doses from Accidental Releases at MRS and Repository (DOE86a)

Accident Events	Annual Offsite Population Dose (person-rem/yr)	RMEI (rem/yr)
• MRS Facility		
- Fuel Assembly Drop	0.03	0.004
- Shipping Cask Drop	0.006	0.0009
- Storage Cask Drop	0.006	0.0009
• Repository	N/A	N/A

10.4.9 "The Safety Evaluation of Tunnel Rack and Dry Well Monitored Retrievable Storage Concepts" (LIG83)

This study evaluated the safety of dry rack storage of SNF at an MRS facility. Only the radiological risks to members of the public due to select accidents during MRS operations were addressed. The MRS facility was assumed: (1) to have a throughput of 900 MTU per year; (2) to receive SNF for 36 years; and (3) to store the fuel for 100 years before it was shipped to a repository for permanent disposal.

In total, the study analyzed 15 different accident scenarios that included transportation collision during emplacement/retrieval of SNF, canister drops during emplacement/retrieval, an airplane crash with and without fire, and pin failure resulting from seismic events. Accident frequencies for these scenarios ranged from a low of 4E-10 per year (plane crash) to 1.4E-01 per year (canister drop during retrieval).

For all 15 accident scenarios combined, the annual population dose risk was estimated to be 17 person-rem for the 0-50 mile population.

10.4.10 Summary Assessment of Available Data

This chapter of the BID has presented information from a variety of studies that provided quantitative estimates of population doses from future fuel management activities that may be conducted at individual reactor sites, at a centralized monitored retrievable storage facility, and at a deep geologic repository.

Because the MRS Review Commission Study provided data for all three facility types, it was regarded as the reference study. Table 10-12 presents population doses for a 50-mile area around a given facility based on normalized Commission data.

Table 10-12. Normalized Population Doses (Based on data from MRS89)

Facility	Person-rem/1,000 MTU-yr
At-Reactor Storage	7.8E-02
MRS (Eastern U.S. location)	3.8E-02
Repository (at Yucca Mountain)	< 9.6E-05

While acknowledging the much lower population dose associated with deep geologic disposal, the Commission concluded that short-term spent fuel storage at reactor facilities or at an MRS facility, albeit higher, yielded population doses that were safe. In association with this conclusion, the Commission offered the following summary statements:

- *... spent fuel management operations have been safely carried out at reactors for many years under NRC regulatory control and by trained personnel.... Although the inventory of spent fuel at reactors is increasing there is no reason to believe that safe management of fuel cannot continue or that the fuel will interfere significantly with safe reactor operations.*

- *It appears that most, if not all, reactor sites can safely store all of the spent fuel that would be generated during the reactor's 40-year operation life. ... This storage can be expanded as necessary to meet life-of-plant storage requirements.... At most sites, life-of-plant* *storage can be accomplished by reracking spent fuel pool and using dry storage.*

- *From a technical perspective, both the No-MRS and MRS options are safe...Although neither option is completely without risk, ...the risks are expected to be small and within regulatory limits, and the degree of difference in risks is so small that the magnitude of difference should not affect the decision as to whether there should be an MRS.*

The views of the MRS Review Commission are generally supported by other data. Radiological dose values from various other studies were reviewed and are summarized in Table 10-13.

As indicated by the brief overviews presented, the studies varied widely in scope, facility designs, primary assumptions regarding SNF processing, waste packaging, accident scenarios, modeling approaches, and other factors.

Table 10-13 illustrates the risk categories that have been addressed and the forms or units in which the data were reported. Although an attempt was made to present results in common units for unbiased comparison, necessary data were frequently lacking. For example, some studies presented accident risk in terms of resultant dose without specifying the probability of occurrence for a given accident scenario. In other instances, 50-mile population doses were cited for the entire preclosure period of a facility with full awareness that SNF inventories were variable/accumulating throughout that period. In the absence of detailed inventory data, a representative annual population dose could not be determined.

Table 10-13. Summary Data of Public Doses Associated with SNF Storage At-Reactor, MRS, and Repository

Study	At-Reactor				MRS				Repository			
	Population Dose		RMEI		Population Dose		RMEI		Population Dose		RMEI	
	Routine	Accident	Routine	Accident	Routine	Accident	Routine	Accident	Routine	Accident	Routine	Accident
Bechtel (1979)									1.5E-06[a]	1.1E-02[a]		
DOE (1980)									negligible		negligible	1.1E-04[f]
Orvis (1984)		2.3E+00[c]										
NRC (1984)	negligible[a]			1.0E-06[e]								
DOE (1985)	negligible[a]		6.0E-08[e]									
DOE (1986a)									3.9E+02[b]	3.0E+03[f]	5.6E-03[e]	4.7E-02[f]
Schneider (1986)	1.0E+00[a]	6.0E-04[c]							6.0E+00[a]			
DOE (1986b)					1.0E-01[a]	3.0E-02[c]	1.0E-03[c]	4.0E-03[e]	1.0E-01[a]		1.0E-03[c]	
Ligon (1983)						1.7E+01[c]						
MRS Review Commission (1989)	7.8E-02[a]				3.8E-02[a]				9.6E-05[a]			

Population Doses:
a = person-rem/1,000 MTU-yr
b = person-rem/SNF inventory-yr (see text)
c = person-rem/yr

RMEI Doses:
d = Rem/1,000 MTU-yr
e = Rem/yr
f = Rem/event

REFERENCES

BEC79 Bechtel National, Inc., *An Assessment of LWR Spent Fuel Disposal Options*, ONWI-39, prepared for the Office of Nuclear Waste Isolation, Columbus, OH, 1979.

CAR87 Carter, Luther, *Nuclear Imperatives and Public Trust*, Washington, D.C.: Resources for the Future, 1987, p. 46.

DOE80 U.S. Department of Energy, *Generic Environmental Impact Statement, Management of Commercially Generated Radioactive Waste*, DOE/EIS-0046F, Vol. 1 of 3, Office of Nuclear Waste Management, Washington, D.C., 1980.

DOE86a U.S. Department of Energy, *Environmental Assessment Deaf Smith County Site, Texas*, DOE/RW-0069, Office of Civilian Radioactive Waste Management, Washington, D.C., 1986.

DOE86b U.S. Department of Energy, *Monitored Retrievable Storage Submission to Congress*, DOE/RW-0035, Office of Civilian Radioactive Waste Management, Washington, D.C., 1986.

EnPA92 Energy Policy Act of 1992, Public Law 102-486, October 24, 1992.

HEW87 Hewlett, Richard G., *Federal Policy for the Disposal of Highly Radioactive Wastes from Commercial Nuclear Power Plants*, Department of Energy, Washington, D.C., March 9, 1987, p. 21.

LIG83 Ligon, D.A., et al., *The Safety Evaluation of Tunnel Rack and Dry Well Monitored Retrievable Storage Concepts*, GA-A16955, GA Technologies, Inc., San Diego, CA, 1983.

MRS89 Monitored Retrievable Storage Revew Committee, *Nuclear Waste: Is There a Need for Federal Interim Storage?*, November 1, 1989.

NPJ97 Nuclear Plant Journal, *U.S. Rad Waste Disposal Update*, Vol. 15, No. 1, Jan.-Feb. 1997.

NRC84 U.S. Nuclear Regulatory Commission, *Licensing Requirements for the Independent Storage of Spent Fuel and High-Level Radioactive Waste*, NUREG-1092, Washington, D.C., 1984.

NRC85 U.S. Nuclear Regulatory Commission, *Environmental Assessment Related to the Construction and Operations of the Surry Dry Cask Independent Spent Fuel Storage Installation*, Virginia Electric and Power Company, Docket No. 72-2, Washington, D.C.,1985.

ORV84 Orvis, D.D., *Review of Proposed Dry Storage Concepts Using Probabilistic Risk Assessment*, EPRI/NP-3365, NUS Corporation, San Diego, CA, 1984.

SCH86 Schneider, K.J., et al., *Preliminary Assessment of Radiological Doses in Alternative Waste Management Systems Without an MRS Facility*, PNL-5872, Pacific Northwest Laboratory, Richland, WA, 1986.

USC72 U.S. Congress, *Joint Committee on Atomic Energy, Report on Authorizing Legislation for the Atomic Energy Commission for Fiscal Year 1973*, JCAE Report 92-1066, 92nd Congress, 2d. Session, May 16, 1972, p. 11.

USC75 U.S. Congress, *Hearings on ERDA Authorizing Legislation for Fiscal Year 1976 Before Subcommittee on Legislation, Joint Commission on Atomic Energy*, Part 2, 94th Congress, 1st Session, February 27, 1975, pp. 1260-1261, 1297.

USC96 Senate Report 104-320, p. 98, September 12, 1996.

APPENDIX I

DEMOGRAPHY AND ECOSYSTEMS

APPENDIX 1

DEMOGRAPHY AND ECOSYSTEMS

The following sections present information about the demography and ecosystems of the Yucca Mountain area.

Land Use

The environment in and around Yucca Mountain is characterized by desert valley and Great Basin mountain terrain and topography. Its climate, flora, and fauna are typical of the southern Great Basin deserts. Access is restricted to the Yucca Mountain area due to its remoteness and its proximity to the Nevada Test Site (NTS) and adjacent U.S. Air Force lands. The predominant non-government land use surrounding Yucca Mountain is open range for livestock grazing, with scattered mining, farming, and recreational areas.

Figure I-1 delineates the variety of land uses within 180 miles (300 km) of the NTS and Yucca Mountain areas. The area southeast of Yucca Mountain (shown on the southwest border of the NTS) is relatively uniform, since the Mojave Desert ecosystem comprises most of this part of Nevada and California. The area directly south is the Amargosa Valley, which has limited, but locally intensive, farming and ranching activity. In the relatively barren area north of Yucca Mountain, the major agricultural activity is the grazing of cattle and sheep.

Population

Yucca Mountain is located in Nye County, NV. As shown in Figure I-2, eight counties in Nevada and one county in California border Nye County. The county population levels shown in this figure are from the 1990 census. Population estimates for Nye County and its communities were updated in 1994; these updated estimates will be used in the remainder of this section. Excluding Clark County, which is the major population center in Nevada (about one million persons), the population density of counties adjacent to Yucca Mountain is about 0.7 people per square mile (0.4 per square km)(NYE93d).

For comparison, the population density of the 48 contiguous states is 70.3 persons per square mile (27 per square km). The average population density of Nevada is 10.9 persons per square mile, or 3.1 per square km. The only region in Nye County with a density greater than three people per mile is in the extreme southern portion, in and around the community of Pahrump, which is 60 miles west of Las Vegas (NYE93d).

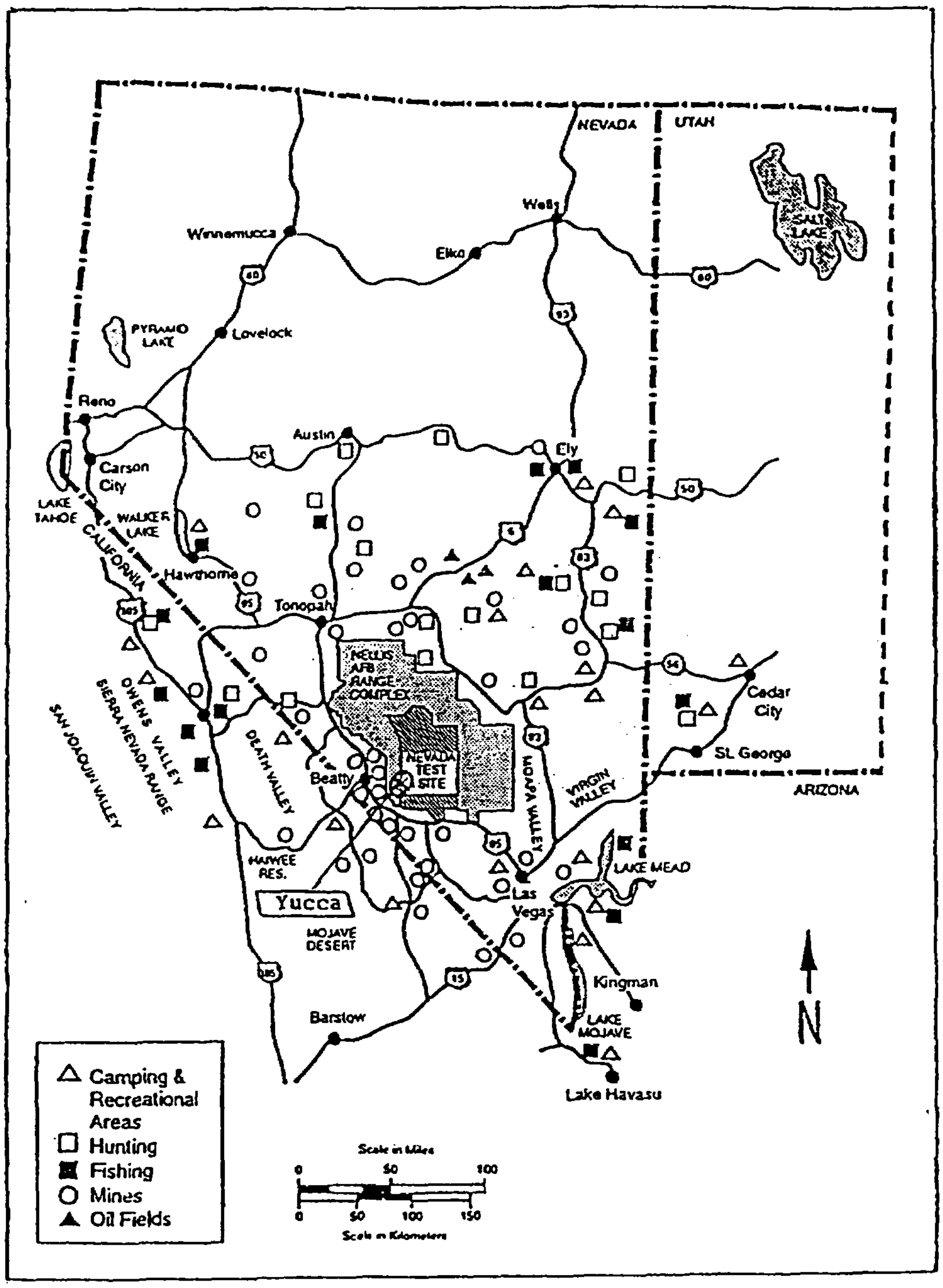

Figure I-1. General Land Use Within 180 Miles (300 km) of the Nevada Test Site (NYE93a)

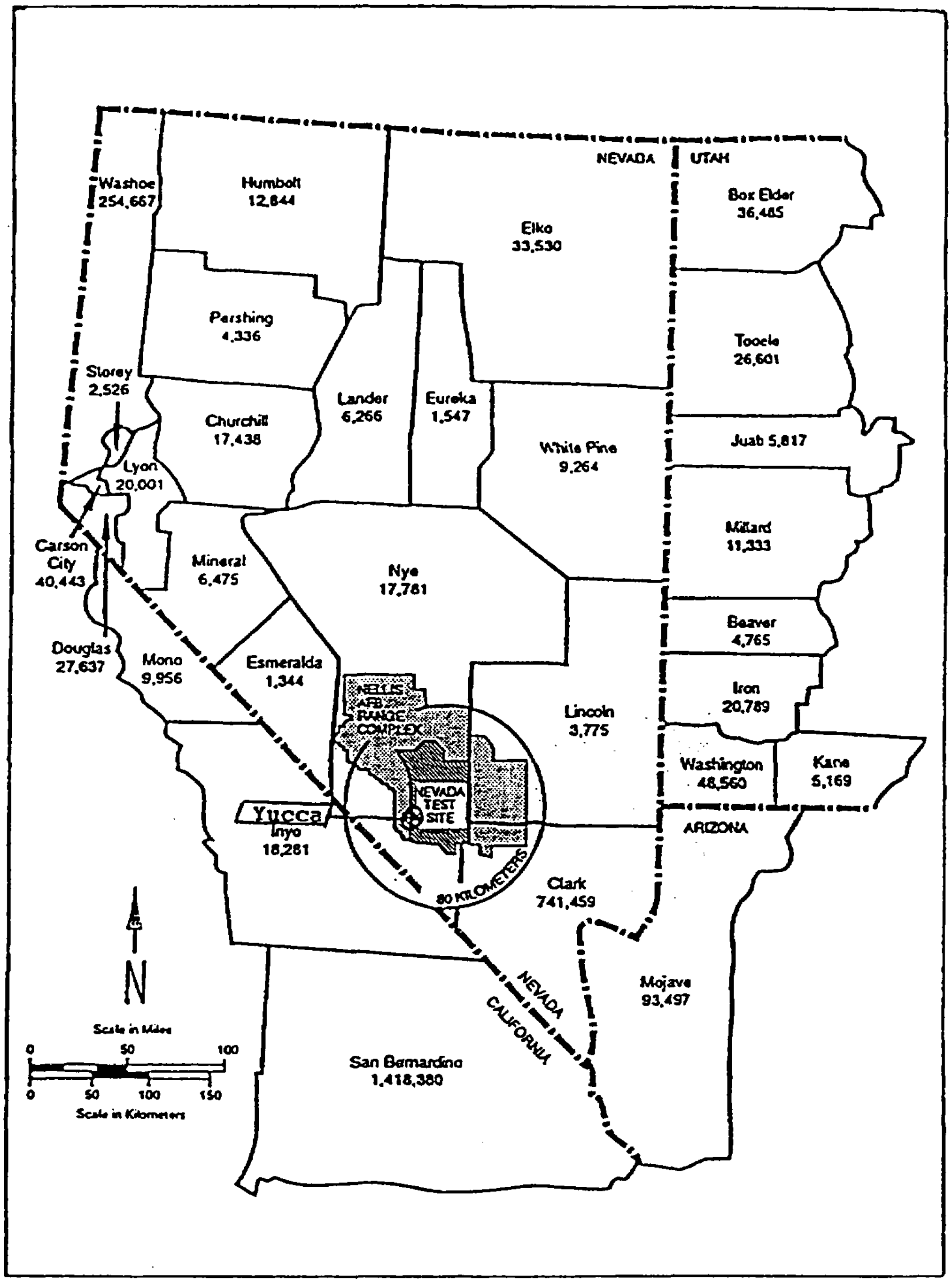

Figure I-2. Population of Arizona, California, Nevada, and Utah Counties Near the Nevada Test Site (NYE93a)

The primary area of interest (based on DOE95a) is within an 80-km radius of Yucca Mountain, shown approximately in Figure I-2. This region also includes several small communities that are not shown here, but are generally located southeast to west of the site. The largest of these communities, Pahrump, is a growing rural community with a 1994 estimated population of 10,892. Pahrump is located about 80 km southeast of Yucca Mountain. Other communities in the immediate area include: Beatty (25 km west) and Amargosa Valley (20 km south) in Nye County, Nevada; Indian Springs (70 km east) in Clark County, Nevada; and Death Valley Junction in Inyo County, California (55 km south). Also contained in this area are portions of Death Valley National Park (DVNP). The socioeconomic characteristics of the Nevada communities are summarized in Table I-1 and in NYE94.

The Mojave Desert of California, which includes DVNP, lies along the southwest border of Nevada. Population within the park ranges from a minimum of 200 residents in the summer to 5,000 tourists per day in winter (excluding major holidays, when as many as 30,000 can be present). The largest populated area in the region is Ridgecrest, California (160 km southwest), with a population of 28,000. The Owens Valley, beginning 50 km west of Death Valley, contains many small towns, the largest of which is Bishop, California, with a 1990 population of 3,475. As shown in Figure I-2, the area of southwestern Utah, due east from Yucca Mountain, is more developed than the adjacent parts of Nevada, based on population levels. St. George (200 km east) is the largest community, with a 1990 population of 28,500. The extreme northwestern part of Arizona (Mojave County) is mostly range land except for the portion containing Lake Meade and other small communities along the Colorado River.

Employment

The NTS, which is adjacent to Yucca Mountain, accounts for a high concentration of employment in southern Nye County, although approximately 80 percent of the employees reside in Clark County (M&O94). During the week, an average of approximately 140 persons reside in NTS group quarters at Mercury. In December 1994, NTS employment was reported to be 3,000, down significantly from more than 5,000 workers in the mid-1980s. At the same time, the employment at Yucca Mountain increased substantially from 281 workers (65.8 FTEs) in January 1988 (M&O90) to 540 (371.9 FTEs) in December 1994 (M&O95). Table I-1 shows establishments in the Nye County communities by Standard Industrial Classification (SIC) Groups and demonstrates potential employment concentrations in the region.

Table I-1. Summary of Socioeconomic Characteristics Compiled by Community for the First Quarter of 1994 (DOE95a)

Socioeconomic Characteristics	Pahrump	Beatty	Amargosa Valley	Indian Springs
Square Miles	298	692.5	499	18
Acreage (1)	190,720	443,200	319,360	11,520
Total Occupied Housing Units:	4,879	788	352	492
Single Family (2)	4,692	719	344	492
Multi Family	187	69	8	
Group Quarters (3)	2	4		
Total Estimated Population:	10,892	1,947	909	1,200
Single Family (2)	10,463	1,747	888	1,200
Multi Family	417	168	21	
Group Quarters (3)	12	32		
Establishments by Standard Industrial Classification Group:	660	134	60	37
Ag/For/Fishing (4)	20	6	7	
Mining/Construction	98	15	6	
Manufacturing	21	2	1	
TCEGSS (5)	42	8	7	2
Wholesale & Retail Trade	178	29	15	5
FIRE (6)	67	17		7
Services	209	47	20	13
Government	25	10	4	10

* Tax boundaries specified by the Nye County Board of Commissioners are used to delineate the boundaries for Pahrump, Beatty, and Amargosa Valley. For Indian Springs, the legal description specified by the Clark County Commissioners for the unincorporated town is used.

Please note: Community boundaries encompass many whole, as well as some partial, cells. Therefore, information within this table is not directly comparable to the information presented in this Appendix. For Pahrump, the information included in this table is for the entire community both inside and outside of the RadMP grid.

(1) Acreages for the communities in Nye County were supplied by the Nye County Assessor's Office, and are the best estimate of the actual acreages encompassed within the taxation boundaries (Nye County Assessor's Office, 1988).

(2) This category was refined to include all single-family dwellings and mobile homes, due to the new method of data collection. Units housing persons visiting or residing in the area on a "short-term" temporary basis, such as in RV parks, are not included.

(3) This category includes the group quarters in Pahrump and the employee housing in Beatty, reported as the number of facilities in the housing section (not included in total) and number of residents in the population section (included in total and not used to calculate the PPH).

(4) Agriculture/Forestry/Fishing.

(5) TCEGSS refers to Transportation, Communications, Electric, Gas, and Sanitary Services.

(6) FIRE refers to Finance, Insurance, Real Estate.

Agriculture

Within the 80 km radius around Yucca Mountain, agricultural activity appears to be holding steady, with increases in alfalfa being offset by decreases in acreage planted in barley and oats. Farmers in the Amargosa Valley primarily grow sod/turf, alfalfa, barley, oats, and relatively small amounts of fruits. The area west of Pahrump grows primarily alfalfa. The majority of livestock in the region consists of bee colonies in Pahrump (honey production); catfish farming in Amargosa Valley; dairy cows in Pahrump and Amargosa that produce milk shipped to southern California; pigs raised for commercial consumption locally; and range cattle. Recent openings of new dairies in Amargosa have generated additional demand for locally produced feed for dairy cows.

Mining and Construction

Within the 80-km radius, the areas west and south of Yucca Mountain near the communities of Beatty, Amargosa Valley, and Pahrump contain 12 mining and open pit operations and 71 construction and drilling operations. The activities associated with these businesses include mining, sand and gravel operations, construction, drilling, and landfills. Other active mines and oil and gas wells are widely dispersed throughout the state.

Ecosystems

As described in previous sections, the diverse topography, geology, and climates of the southern Nevada desert create a complex variety of plant life. Vegetation ranges from sparse desert scrub in the lowest valleys to well-developed woodland on highlands above 2,000 meters (m). Only sheer cliffs and playa floors are devoid of plants. Even the apparently barren hills of the Amargosa Desert support widely spaced shrubs and succulents.

Table I-2 shows plant types and associations found in the regions in and around Yucca Mountain. As described in the table, plant associations classified as Great Basin conifer woodlands are distinguished by dominance of single-needle pinyon pine and Utah juniper. In south-central Nevada, these pygmy conifer communities are restricted to elevations above 1,800 meters. Dominant plant taxa in Great Basin desert scrub communities are flowering plants such as shadscale. These desert scrub associations usually occur below the tree line, but above Mojave Desert vegetation. The plant species typical of lower elevation Mojave desert scrub vegetation, like creosote bush and white bursage, have their center of distribution south of Yucca Mountain. Exceptions include plants dominated by species endemic to the northern Mojave, such as box thorn and greasewood. The vegetation classifications at Yucca Mountain are dominated by representatives of Mojave desert scrub. However, many Mojave desert scrub species are at the northern limits of their distribution in southwest Nevada, and most are restricted to elevations below 1,800 m.

Table I-2. Principal Plant-Community Types and Examples of Representative Plant Associations on Rock Slopes (SPA85)

Representative Plant Association	Distribution and Common Associates
Great Basin Conifer Woodland	
Pinus monophylla-Quercus gambelii-Juniperus osteosperma	Volcanic highlands in the northern test site, generally at elevations above 1,950 meters (such as the eastern Pahute Mesa and Timber Mountain). Associates include Artemisia tridentata Symphoricarpos longiflorus, Purshia tridentata, and Lupinus argenteus.
Pinus monophylla-Artemisia tridenta-Juniperus osteosperma	Highlands at elevations above 1,770 meters; restricted to xeric habitats at elevations above 2,100 meters. Common associates include Artemisia nova, Cowania mexicana, Haplopappus nanus, and Brickellia microphylla.
Great Basin Desertscrub	
Atriplex canescens-mixed scrub	The flanks of hills and rocky mesas, usually of volcanic substrate. Elevations from about 1,500 to 2,000 m.
Atriplex confertifolia-mixed scrub	Limestone and dolomite slopes at elevations from about 850 to 1,700 m. Common associates are usually: Mojave Desert shrubs such as Amphipappus fremintii; Ephedra torreyana; Larrea divaricata; and Gutierrezia microcephala.
Mojave Desertscrub	
Lepidium fremontii-mixed scrub	On the talus slopes and ridges of calcareous mountains at elevations from about 1,050 to 1,700 meters. Associates include a diverse complement to upper elevation Mojave desertscrub species, such as Coleogyne ramosissma, Ephedra torreyana, Buddleja utahensis, and Lycium andersonii.
Gutierrezia microcephala-mixed scrub	Talus slopes, cliff bases, and ridges generally at elevations below 1,400 meters on calcareous substrates. Common associates include Larrea divaricata, Ambrosia dumosa, Ephedra spp., Amphipappus fremontii, and Lycium pallidum.
Ambrosia dumosa-Larrea divaricata	On talus slopes, ridges, and mesas generally at elevations below 1,200 m. Normally occurring with lower-elevation Mojave Desert species, such as Peucephyllum schottii, Eucnide urens, Gutierrezia microcephala, and Echinocactus polycephalus. Atriplex confertifolia is common at some sites.

According to the U.S. Fish and Wildlife Service (USF99, 64 FR 46542), Southern Nye County (south of Tonopah), like most of the state, hosts a number of threatened and endangered species, as shown in Table I-3. According to the Nye/Esmeralda Economic Development Authority, however, only two of these have affected growth and development (NYE93b).

Table I-3. Threatened and Endangered Species in Southern Nye County (NYE93b)

Common Name	Scientific Name
ENDANGERED	
Southwestern Willow Flycatcher	Empidonax traillii extimus
Devil's Hole pupfish	Cyprinodon diabolis
Ash Meadows Amargosa pupfish	Cyprinodon nevadensis mionectes
Warm Springs pupfish	Cyprinodon nevadensis pectoralis
Ash Meadows speckled dace	Rhinichthys osculus nevadensis
Ash Meadows speckled pupfish	Cyprinodon nevadensis mionectes
Amargosa niterwort	Nitrophila mohavensis
THREATENED	
Bald Eagle	Haliaeetus leucocephalus
Desert tortoise	Gopherus agassizii
Ash Meadows naucorid	Ambrysus amargosus
Ash Meadows milkvetch	Astragalus phoenix
Spring-loving centaury	Centaurium namophilum
Ash Meadows sunray	Enceliopsis nudicaulis var. corrugata
Ash Meadows gumplant	Grindelia fraxino-pratensis
Ash Meadows ivesia	Ivesia eremica
Ash Meadows blazing star	Mentzelia leucophylla

The Devil's Hole Pupfish has limited development in the Ash Meadows area of Amargosa Valley. Protection of the Pupfish and several other threatened and endangered species resulted in the creation of the Ash Meadows National Wildlife Refuge. Thus, casual use of this region is restricted to existing roads, trails, and washes. The ground water level is protected in spring flows in Ash Meadows, which is managed by the Fish and Wildlife Habitat Management Program of the Bureau of Land Management.

Also, like much of southern Nevada, certain areas in Pahrump and Amargosa Valley have been classified as desert tortoise habitat. Land within this classification requires a biological assessment before it can be developed. If necessary, the U.S. Fish and Wildlife Service may require a second environmental assessment and a site-specific habitat conservation plan.

Sources of Human Radiation Exposure

All members of the public are exposed to ionizing radiation from a variety of sources. Exposure to some sources is not only inevitable, but life-long; exposure to other sources may be episodic and influenced by numerous factors. For convenience, sources of public exposures are commonly categorized as: (1) natural origin and unperturbed by human activities; (2) natural origin but affected by human activities (termed enhanced natural sources); and (3) man-made sources. Natural radiation and naturally-occurring radioactivity in the environment are by far the major sources of human radiation exposure. Consequently, these sources have been extensively studied and are commonly compared with various man-made sources of ionizing radiation.

Natural sources include cosmic radiation from outer space; terrestrial radiation from radionuclides in soil, rocks, and other materials; and radionuclides within our bodies. Each of these natural sources has specific characteristics that cause variations in individual exposures, which are influenced by geographic location, dietary habits, lifestyles, and other factors.

Enhanced natural sources include those for which human exposures have increased due to deliberate or inadvertent behavior. For example, extensive air travel may significantly increase exposure to cosmic radiation. Similarly, tailings from phosphate mining, when used for construction fill, can increase terrestrial exposure. Another example involves the combustion of fossil fuels (coal, oil, natural gas) by industry and electric utilities, which results in the localized release of naturally-occurring radionuclides in stack gases released into the air. Even indoor exposure to radon might be considered "enhanced," because air concentrations of radon and radon daughters are significantly affected by the design, construction, and use of a home or building.

In addition to natural sources, most individuals are also exposed to radiation from numerous man-made sources, materials, and devices. The largest category among man-made sources is classified as medical and refers to a variety of diagnostic and therapeutic procedures (e.g., x-rays, fluoroscopic examinations, CAT-scans, radioactive pharmaceuticals and implants, and exposure to teletherapy units). The public is also exposed to a variety of consumer products, such as televisions and smoke detectors, nuclear weapons production and testing, and nuclear power and the associated fuel cycle.

The scientific literature abounds with information on public exposure to natural and man-made radiation sources. Among the most comprehensive reports are those issued by EPA (EPA72a, EPA77) and several prominent scientific committees, including the United Nations Scientific Committee on the Effects of Atomic Radiation (UNS88, UNS93, UNS94), the Committee on the Biological Effects of Ionizing Radiation of the National Academy of Sciences (NAS80, NAS88, NAS90), and the National Council on Radiation Protection and Measurements (NCR87a, NCR87b, NCR89).

This section summarizes average exposures received by the general public in the United States, as well as estimates of exposures to individuals currently residing in the vicinity of Yucca Mountain.

Natural Radiation Sources and Exposures

<u>Cosmic Radiation</u>

Cosmic radiation refers to primary energetic particles originating from the sun and from outside the solar system, as well as to secondary radiation generated by their interaction with the earth's atmosphere. In the absence of the earth's atmosphere, the biosphere's dose of cosmic radiation would be about 1,000 times greater than current levels. The intensity of cosmic radiation is also affected by the earth's geomagnetic field, which varies with latitude, and by the sun's activity, which follows a cycle of about 11 years. However, at ground level, variations in cosmic radiation intensity within the continental United States, due to the geomagnetic field effect, are less than two percent (CAR69); the 11-year variations due to solar activity are less than 10 percent of the mean level (ERD77).

At sea level, the average cosmic-ray annual dose equivalent is about 26 mrem. This annual dose rate essentially doubles with each 2,000 meter increase in altitude in the lower atmosphere. Accordingly, inhabitants of Denver at 1,600 meters and Leadville, Colorado, at 3,200 meters have estimated annual external exposures from cosmic radiation of 50 mrem and 125 mrem, respectively (NCR87b). Considering the distribution of altitudes for the U.S. population, an average annual cosmic-ray dose of 27 mrem is generally assumed. However, the dose to a specific individual is affected by the amount of time spent outdoors and the shielding provided by indoor environments.

The cosmic-ray exposure rates in aircraft are considerably higher. At normal commercial jet aircraft altitudes of about 11-12 kilometers (km), average dose rates of 0.5 mrem/hour have been estimated (NAS86). A single transcontinental flight from New York to Los Angeles would be expected to result in an average dose of 2 to 3 mrem, so crew members working ordinary schedules on high-altitude, long-distance routes would likely receive average doses in excess of 500 mrem per year (BAR95). Solar flares, although infrequent, can yield dose rates in excess of 1,000 mrem/hour at these altitudes (UNS82).

Naturally-Occurring Radionuclides

Several dozen naturally-occurring radionuclides exist with half-lives on the same order of magnitude as the estimated age of the earth (about 4.5 billion years). These include potassium-40, rubidium-87, and radionuclides belonging to the decay chain series of uranium-238, uranium-235, and thorium-232 (such as radium). These naturally-occurring radionuclides contribute to exposure that is both external and internal to the body.

External Terrestrial Radiation

Potassium-40 and several decay-chain members in each of the uranium and thorium series emit penetrating gamma radiation. These radionuclides exist in low, but varying, concentrations in virtually all types of rocks and soil. Since many building products, such as cut stone, brick, cement, and gypsum are derived from natural stone, they also contribute to external radiation. For most individuals, external exposure received indoors to radionuclides derived from the terrestrial environment is nearly equivalent to that received outdoors (Table I-4).

Table I-4. Comparison of External Indoor to Outdoor Radiation Dose

Building Materials (exterior walls)	Percent of Outdoor Terrestrial Radiation
1. Mostly Woodframe (single homes)	70 - 82
2. Brick (apartment building)	96
3. Stone (apartments & houses)	80 - 100
4. Steel and Concrete (office building)	87 - 106

Source: EPA72b

Two distinct major regions of the United States differ in average terrestrial dose rates by a factor of about two (EPA72b). A lower dose rate of 16 mrem/year corresponds to the Atlantic and Gulf Coastal Plain; the remaining major portion of the country (referred to as Non-Coastal Plain) yields average dose rates of about 30 mrem/year (Figure I-3). The Denver area showed average terrestrial dose rates of 63 mrem/year. (It is assumed that other areas on the eastern slopes of the Rocky Mountains would show similar levels.) It should be further noted that for each average value cited above, the range in values between the 10th and 90th percentile differed by at least a factor of two.

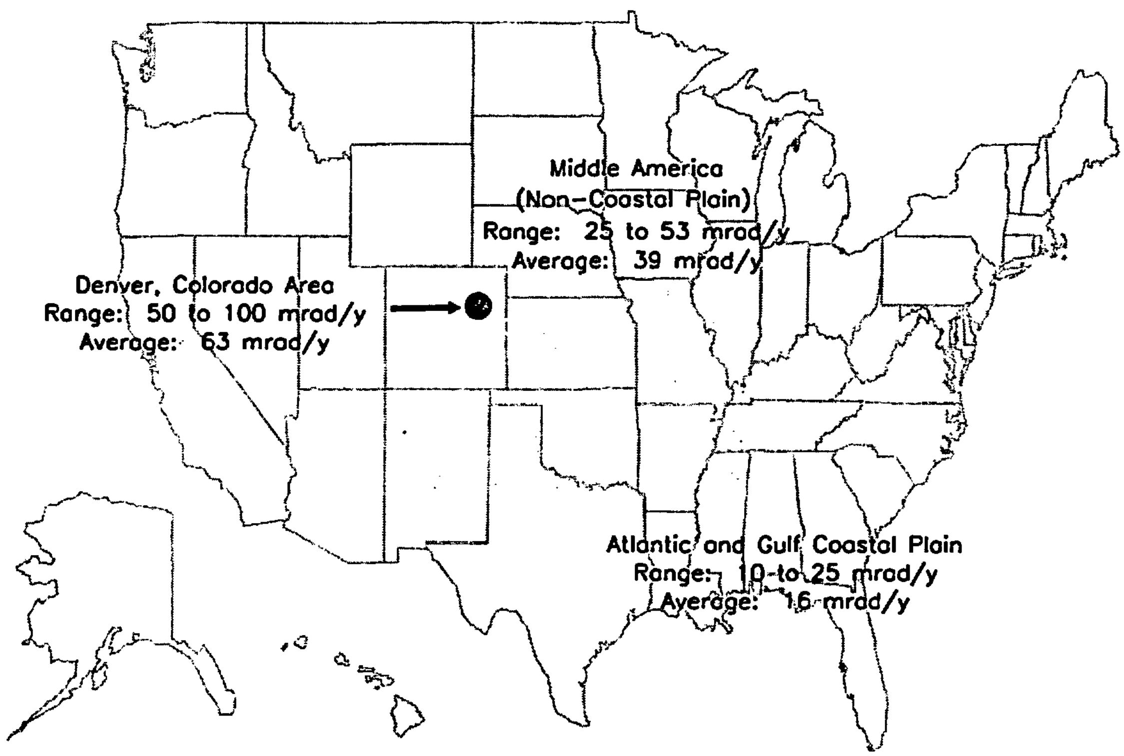

Figure I-3. Terrestrial Dose Rates in the United States

Radionuclides in the Body

Naturally occurring radionuclides in rocks and soil also give rise to internal radiation exposure because they are present in drinking water and foods that are consumed by humans. Upon ingestion, their distribution in the body is complex and is governed by their chemical properties and the physiological regulatory mechanisms of the body. For example, radioactive potassium-40 exists in a fixed ratio to its non-radioactive form of potassium. Potassium is an essential dietary element to most living systems, and it is distributed nearly uniformly in lean soft tissue. The concentrations of other radionuclides associated with the decay chains of uranium and thorium are potentially highly variable. For humans, internal exposure to these naturally-occurring radionuclides is not only determined by dietary composition, but also by the total quantities of foods consumed and the geographic location/origin of the food products. Maximum body burdens would, therefore, be expected for individuals who consume foods (and water): (1) that are derived from areas of high terrestrial background radioactivity; (2) that are higher in radionuclide content than foods of normal diets; and (3) in large quantities.

Internal Doses. Reports of unusual exposure in the United States are contained in the literature. High exposures have been documented for Eskimo and select Indian tribes whose diet includes reindeer caribou, moose, elk, and deer that subsist largely on lichen during winter months. Here the lichen-animal-human food chain leads to high concentrations of natural Pb-210 and Po-210 (as well as Cs-137 from fallout) in the diet (HOL66, ECK86, MAT75).

In general, however, there are insufficient data at this time to define the extent of variability of internal exposures among individuals. Factors cited above that would potentially yield significant differences in exposure are largely eliminated by a food distribution system that is nationwide and offers a wide range of foods.

Dose estimates from internally-deposited naturally-occurring radionuclides are principally based on limited post-mortem measurements of the nuclide content of various organs. Estimates of average doses to specific tissues of the body are given in Table I-5. By multiplying annual tissue doses by their corresponding weighting factors, it is estimated that the average individual in the United States receives an internal dose of 39 mrem per year from naturally occurring radionuclides.

Table I-5. Average Annual Dose from Internal Exposure to Naturally Occurring Radionuclides

Tissue	Tissue Dose (mrem)	Tissue Weighting Factor	Effective Dose Equivalents (mrem)
Lung	33	0.12	4
Gonads	36	0.25	9
Bone Surfaces	100	0.03	3
Bone Marrow	50	0.12	6
Other Tissues	35	0.48	17
Total Body		1.00	39

Inhaled Radionuclides

Except for radon and its short-lived decay products, the inhalation pathway yields doses that are small relative to the ingestion pathway. For this reason, reference to inhaled radionuclides is limited to gaseous radon and its solid radioactive daughter products. This group of radionuclides belongs to the uranium-238 and thorium-232 decay chain series and is, therefore, present in all soils and rocks, as previously discussed.

As a gas, radon is able to diffuse through soil pore spaces and escape into surrounding media. In outdoor air, radon quickly diffuses and results in relatively small exposures. Significant exposures, however, result when radon gas enters homes and other buildings where it is contained for periods of time that allow the buildup of its solid (i.e., non-gaseous) radioactive daughters. When inhaled, particulate radon daughters deposit onto the mucous layer of the airways and emit energetic alpha particles, imparting substantial doses to cells that line the upper respiratory tract and lungs.

Estimates of Radon Doses. The magnitude of human exposure to radon and radon daughters is not only influenced by the amount of radon formed in the soil, but also by numerous other factors affecting its migration and movement through soil, rate of entry into a home or building, and containment and daughter buildup in indoor air. For example, factors affecting exposure include soil porosity and moisture content, the design of the structure, and building operating variables related to heating, air conditioning, and ventilation.

A large number of localized survey data exist for indoor radon or decay-product concentrations. However, most of these measurements have been made in single-family houses, and little data

exist for high rise apartments, commercial and industrial buildings, and other structures in which various population subgroups spend significant amounts of time.
Further complicating estimates of average exposure and the distribution of individual exposures is the fact that existing data exhibit very large variations. For example, clusters of unusually high indoor radon concentrations have been found in parts of northeastern Pennsylvania, New Jersey, and southeastern New York. This area, known as the Reading Prong, is characterized by soil concentrations of uranium series radionuclides that are about 100 times greater than the national average.

Best estimates suggest an average indoor radon concentration of about 1.25 pCi/L, which yields an average individual dose (i.e., effective dose equivalent) of about 200 mrem per year (NCR87a, NCR87b).

Summary of Natural Background Exposures

Table I-6 summarizes the average individual exposures in the United States to natural background radiation. On average, cosmic radiation, external terrestrial gamma radiation, and radionuclides within the body contribute nearly equally, yielding a total dose of about 100 mrem per year. However, this is only about one-half of the annual inhalation exposure resulting from indoor radon and its decay products, estimated to be 200 mrem. It is important to note, however, that the dose resulting from exposure to indoor radon has a very large amount of variability, with a significant number of people experiencing doses that are several times that of the average value.

Table I-6. Estimated Average Annual Dose* To Members of the Public in the United States from Natural Background Radiation

Source	Dose* (mrem/yr)
Cosmic	28
Terrestrial	28
In the Body	39
Inhaled (Radon)	200
Rounded Total	300

* All doses are expressed as effective dose equivalents.

Public Exposures to Artificial and Other Sources of Radiation

Members of the public are also exposed to a variety of radiation sources categorized as "artificial," i.e., those that involve human technological activities. Among artificial sources, the largest exposures involve medical x-rays and radioactive pharmaceuticals used for diagnostic purposes or the treatment of various diseases. There are also a number of consumer products that contain radioactivity or emit radiation.

It is estimated that on average, artificial sources contribute an annual dose of 60 mrem. An important aspect of human exposure to most of these sources is that the exposure is: (1) episodic; (2) voluntary; or (3) has an associated benefit to the individual or society at large.

<u>Medical Sources</u>

Radiation has broad application in the diagnosis and treatment of various diseases that affect humans and is widely employed by physicians, dentists, podiatrists, chiropractors, and other health-care professionals. Diagnostic radiation principally involves x-rays, fluoroscopic examinations, and specialized medical imaging procedures such as computerized tomography and scans involving radiopharmaceuticals. Therapeutic uses of radiation, such as cancer therapy, involve similar sources of radiation but deliver larger individual doses.

Table I-7 provides summary data on medical radiation exposures in the United States (NCR89). It is estimated that on average, medical radiation contributes an annual dose of about 54 mrem to individuals living in the United States. While such an average value is an important and useful statistic, it must be pointed out that the distribution of medical exposures among individuals is highly variable.

<u>Consumer Products</u>

Many commercial and consumer products either emit radiation or contain radioactive materials. In 1977, the NCRP issued a comprehensive report, NCRP Report No. 56 (NCR77), that estimated population exposures from consumer products. Because of revised Federal regulations and newly introduced technologies, the NCRP updated its earlier estimates in a revised report issued in 1987 (NCR87c). Scaling the population estimates contained in the 1987 report to the current U.S. population of 260 million, it is estimated that the average annual exposure in the United States to consumer products is in the range of six to 13 mrem.

Table I-7. Estimated Total Number and Frequencies of Diagnostic Procedures in the United States and Associated Radiation Doses

Group	Total No. of Exams	No. of Exams per 1,000 Population	Range of Doses per Exam (mrem)[1]	Avg. Dose Per Exam (mrem)[1]	Avg. Annual Dose to a Member of the Public (mrem/yr)[1]
Diagnostic X-Rays[2]	181,000,000	1,230	6 > 400	50	40
• Physicians/Osteopaths	164,000,000	724	---	---	---
• Chiropractors	9,800,000	43	---	---	---
• Podiatrists	5,900,000	23	---	---	---
• Dentists	101,000,000	440	---	---	---
Radiopharmaceuticals[3]	7,400,000	32	150-1,200	430	14
Total					54

[1] Doses are expressed in effective dose equivalents.
[2] Data reflect procedures performed in 1980.
[3] Data reflect procedures performed in 1982.

This estimate does not include the contribution of tobacco, which contains Po-210. The deposition of Po-210 on the bronchial epithelium of smokers is estimated to result in a localized tissue dose of 16 rem/year, which corresponds to an effective dose equivalent of 1,300 mrem/year. Current data compiled by the American Cancer Society identified 26 percent of persons aged 18 and over as smokers (ACS95). Therefore, the average annual dose to adults from tobacco is estimated to be 340 mrem.

Thus, radiation exposure from the use of tobacco not only represents the greatest contributor to the effective dose equivalent of all consumer products, but also exceeds the average combined contributions from indoor radon and all other natural sources of radiation.

Miscellaneous Sources of Public Exposures

Nominal exposure to members of the public may also result from past and ongoing activities related to nuclear power generation and associated fuel cycle facilities, other NRC-licensed facilities (e.g., radiopharmaceutical manufacturers, hospitals, research facilities), DOE facilities associated with nuclear weapons, and the transportation of radioactive materials. For all but transportation, exposure results primarily from airborne releases.
Public dose estimates for these source categories rely on computer models. The discrete nature of these facilities/sources suggests that public exposures are highly variable and primarily affect

near-field residents. Doses as high as 50 mrem/year, for example, have been assigned to near-field residents of the Oak Ridge Reservation (NCR87c). The total estimated population dose of 16,000 person-rem from all such sources yields an average annual dose of about 0.6 mrem to individuals in the near-field. Since the exposed near-field population represents only about 10 percent of the total U.S. population, these miscellaneous sources are thought to contribute about 0.06 mrem/year on average to members of the total population.

Between 1945 and 1962, atmospheric tests conducted by the United States involved nuclear weapons with an explosive yield of about 140 megatons of TNT equivalence, which represents about 27 percent of the world's total, estimated to be 510 megatons (UNS82). The radiation dose commitment from fallout has changed significantly over the years due to natural decay and depletion/removal mechanisms from environmental media which limit further biological uptake. The current dose rate to members of the general public is estimated to be one mrem per year (NCR87b), derived largely from residual radionuclides contained in our bodies.

REFERENCES FOR APPENDIX I

ACS95 American Cancer Society, *Cancer Facts & Figures - 1995*, Atlanta, Georgia, 1995

BAR95 Barish, R.J., *Health Physics and Aviation: 1990-1994*, Health Physics, 69:538, 1995.

CAR69 Carmichael, H. and Bercovitch, M., *Analysis of IQSY Cosmic Ray Survey Measurements*, Canadian Journal of Physics, 47:2073, 1969.

DOE95a U.S. Department of Energy, *Yucca Mountain Site Characterization Project: Summary of Socioeconomic Data Analyses Conducted in Support of the Radiological Monitoring Program During Calendar Year 1994*, TRW Environmental Safety Systems, Inc., Contract DE-AC01-91RW00134, Las Vegas, 1995.

ECK86 Eckl, P., et al., *Uptake of Natural and Man-made Radionuclides by Lichens and Mushrooms*, Radiation Environmental Biophysics, 25:43, 1986.

EPA72a U.S. Environmental Protection Agency, *Estimates of Ionizing Radiation Doses in the United States 1960-2000*, Office of Radiation Programs, Report ORP-CSD 72-1, Washington, D.C., 1972.

EPA72b U.S. Environmental Protection Agency, *Natural Radiation Exposure in the United States*, Office of Radiation Programs, Report ORP/SID-72-1, Washington, D.C., 1972.

EPA77 U.S. Environmental Protection Agency, *The Radiological Quality of the Environment in the United States 1977*, EPA 420/1-77-0009, Washington, D.C., 1977.

ERD77 U.S. Energy Research and Development Agency, *Measurement of Cosmic-ray Charged Particle Ionization and Flux Densities in the Atmosphere*, USERDA Report HASL-324, 1977.

HOL66 Holtzman, R.B., *Natural Levels of Lead-210, Polonium-210, and Radium-226 in Humans and Biota of the Arctic*, Nature, 210:1094, 1966.

M&O90 CRWMS M&O Contractor, *Yucca Mountain Project Socioeconomic Monitoring Program Data Report - June 1986 Through September 1989*, Tables 3-1 and 3-2, Las Vegas, Nevada, ACC:NNA.900327.0189.

M&O95 CRWMS M&O Contractor, *Yucca Mountain Site Characterization Project: Socioeconomic Monitoring Program Quarterly Employment Data Report - October 1994 Through December 1994*, Tables 3-1 and 3-3, Las Vegas, Nevada, ACC:MOL.19950626.0522.

MAT75 Mattson, S.L.J., *Cs-137 in the Reindeer Lichen Cladonia Alpestris: Deposition, Retention and Internal Distribution, 1961-1970*, Health Physics 28:233, 1975.

NAS80 National Academy of Sciences - National Research Council, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation (BEIR III)*, Report of the Biological Effects of Ionizing Radiation, Washington, D.C., 1980

NAS86 National Academy of Sciences - National Research Council, *The Airliner Cabin Environment: Air Quality and Safety*, National Academy Press, Washington, D.C., 1986.

NAS88 National Academy of Sciences - National Research Council, *Health Risks of Radon and Other Internally Deposited Alpha-Emitters (BEIR IV)*, Report on the Biological Effects of Ionizing Radiation, Washington, D.C., 1988.

NAS90 National Academy of Sciences - National Research Council, *Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR V)*, Report on the Biological Effects of Ionizing Radiation, Washington, D.C., 1990

NCR77 National Council on Radiation Protection and Measurements, *Radiation Exposure from Consumer Products and Miscellaneous Sources*, NCRP Report No. 56, Bethesda, MD, 1977.

NCR87a National Council on Radiation Protection and Measurements, *Ionizing Radiation Exposure of the Population of the United States*, NCRP Report No. 93, 1987.

NCR87b National Council on Radiation Protection and Measurements, *Exposure of the Population in the United States and Canada from Natural Background Radiation*, NCRP Report No. 94, 1987.

NCR87c National Council on Radiation Protection and Measurements, *Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources*, NCRP Report No. 95, 1987.

NCR89 National Council on Radiation Protection and Measurements, *Exposure of the U.S. Population from Diagnostic Medical Radiation*, NCRP Report No. 100, 1989.

NYE93a Nye/Esmeralda Economic Development Authority, *Nye County Overall Economic Development Plan* (Draft), 1993.

NYE93b Nye/Esmeralda Economic Development Authority, *Nye County Overall Economic Development Plan; Appendix C 'Threatened and Endangered Species Considered in the Analysis of the Effects of Defense-Related Activities on Wildlife in Nevada,'* July 23, 1993.

NYE93d Nye County Board of Commissioners, *Baseline Economic and Demographic Projections: 1990-2010 Nye County and Nye Country Communities*, Planning Information Corporation, May 25, 1993.

NYE94 Nye County Board of Commissioners, *Nye County, Nevada Socioeconomic Conditions and Trends 1993*, Planning Information Corporation, 1994.

SPA85 Spaulding, W.J., *Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South Central Nevada*, 1985.

UNS82 United Nations Scientific Committee on the Effects of Atomic Radiation, *Ionizing Radiation: Sources and Biological Effects*, New York, 1982.

UNS88 United Nations Scientific Committee on the Effects of Atomic Radiation, *Sources, Effects and Risks of Ionizing Radiation*, New York, 1988.

UNS93 United Nations Scientific Committee on the Effects of Atomic Radiation, *Sources and Effects of Ionizing Radiation*, New York, 1993.

UNS94 United Nations Scientific Committee on the Effects of Atomic Radiation, *Sources and Effects of Ionizing Radiation*, New York, 1994.

USF99 U.S. Fish and Wildlife Service, Letter from R.D. Williams Nevada Fish and Wildlife Office, to W.R. Dixon, Manager, Environmental Affairs, U.S. Department of Energy, January 21, 1999.

APPENDIX II

RADIONUCLIDE EXPOSURES TO PERSONS IN THE VICINITY OF THE NEVADA TEST SITE/YUCCA MOUNTAIN SITE

APPENDIX II

RADIONUCLIDE EXPOSURES TO PERSONS IN THE VICINITY OF THE NEVADA TEST SITE/YUCCA MOUNTAIN SITE

For populations living near the Nevada Test Site (NTS), exposure to normal background radiation levels may be modified by NTS activities. Past NTS activities have introduced radioactivity into air, soil, and ground water. Atmospherically-released radioactivity has contributed to local and global exposure in the past and will continue to do so in the future. Radioactivity introduced on-site into soil and proximally to ground water has the potential to expose future persons living in the vicinity of the NTS. For purposes of this discussion, past NTS activities relevant to human exposure may be grouped into several discrete categories that are discussed below. In addition, risks and consequences from these activities are summarized.

Atmospheric Weapons Testing

Over 100 events on the Nevada Test Site have resulted in the release and deposition of radionuclides on the soil surface outside the test-site boundary (HIC90). Atmospheric weapons testing at NTS began in 1951 and continued into 1962. Atmospheric testing included weapons that were dropped by airplanes, those detonated from towers at heights ranging from 30 to 213 meters (m), tests conducted on land surfaces, and tests in which helium balloons lofted weapons 137 to 457 m above ground.

It is estimated that for near-surface detonations, about 12 percent of the fission products were distributed locally, with the remaining 10, 76, and 2 percent introduced into the troposphere, stratosphere, and very high altitudes, respectively (UNS82). In addition, the large number of neutrons released at the time of the detonation results in significant quantities of activation products in the bomb's structural components, as well as ambient surface materials.

The primary radionuclides deposited locally were americium, plutonium, cobalt, cesium, strontium, and europium. Based on the most recent estimates, about 20 Curies (Ci) remain in surface soils at or near the original testing area(s) (MCA91).

Safety Tests

Between 1954 and 1963, more than 30 tests were conducted to investigate safety issues regarding nuclear weapons in accident scenarios. The safety tests used mixtures of plutonium and uranium that were detonated using conventional explosives. These tests also assessed the disposal and transport of these isotopes in the environment, including plant and animal uptake. In the 3,500 acres originally contaminated, the inventory of radionuclides is estimated to be between 34 and 39 Ci.

The primary isotopes at test locations are plutonium, uranium, and americium, with lesser amounts of cesium, strontium, and europium. Currently, these long-lived radionuclides are contained in surficial soils and are relatively immobile. They are, however, potentially available to be transported off-site by wind erosion.

Nuclear Rocket and Related Tests

Between 1959 and 1973, the Nuclear Rocket Development Station area was used for a series of open air nuclear reactor, nuclear engine, and nuclear furnace tests, and for the High Energy Neutron Reactions Experiment. The total estimated inventory of soil contaminants that include strontium, cesium, cobalt, and europium has been estimated to be one Ci (MCA91).

Waste Disposal Activities

Since the early to mid-1960s, NTS Areas 3 and 5 were established for disposal of low-level waste from on-site and off-site DOE waste generators and include landfill cells (pits and trenches) and greater confinement disposal (GCD) boreholes. Approximately one-half of the buried waste represents atmospheric testing debris generated during cleanup activities of above-ground nuclear test areas, with the remaining half from other defense-related facilities.

Currently, NTS operates Areas 3 and 5 as a LLW repository and receives waste from on-site activities and off-site defense generators. Approximately 500,000 Ci of low-level waste are disposed in shallow pits and trenches. Approximately 9.3 million Ci of high-specific-activity waste containing primarily tritium have been disposed in GCDs. In addition, both areas also contain smaller inventories of mixed waste.

Underground Testing

In August of 1963, the United States and the former Soviet Union signed the Limited Test Ban Treaty (LTBT), which effectively banned weapons testing in the atmosphere. Approximately 800 underground nuclear tests have been conducted that include shallow borehole tests (< 60 m) and deep underground tests (about 600 m). Of the total inventory (estimated to be 300 million Ci), about 112 million Ci are considered a potential hydrological source term. About 90 percent (or 100 million Ci) of this radioactivity is represented by tritium.

Table II-1 provides a summary of residual radionuclide source terms at NTS for the aforementioned activities.

Potential Impacts on Surrounding Populations

Population impacts from NTS activities are most effectively discussed in terms of activities that have resulted in the introduction of radioactivity: (1) into the atmosphere; (2) into surficial soils; and (3) at subsurface depths, where radioactivity could in the future become available to the ground water regime.

While maximum human exposure from atmospheric releases essentially coincided with peak periods of past nuclear detonation, human exposure to radioactivity introduced below ground is primarily a concern of the future.

Past Impacts Associated with Atmospheric Releases

In 1979, the Department of Energy (DOE) launched a major effort, called the Off-site Radiation Exposure Review Project (ORERP). The principal objective of the ORERP was to collect, organize, and analyze all relevant documents and data pertaining to fallout and resultant exposure to off-site population groups in the vicinity of the NTS. Since that time, more than 200,000 documents have been amassed and exposure estimates for discrete fallout events have been derived from empirical measurements and computer-projection models (ANS90).

Table II-1. Summary of Remaining Radioactivity on the NTS

Source	Area Affected	Media	Major Known Isotopes	Depth Range	Remaining Inventory (Ci)
Atmospheric & Tower Tests	Aboveground Nuclear Weapon Proving Area	Surficial Soils & Test Structures	Americium Cesium Cobalt Europium Strontium	Above land surface	~ 20
Safety Tests	Aboveground Experimental Areas	Surficial Soils	Americium Cesium Cobalt Plutonium Strontium	At land surface	~ 35
Nuclear Rocket Development Station	Nuclear Rocket Motor, Reactor, and Furnace Testing Area	Surficial Soils	Cesium Strontium	Less than 10 ft	~1
Shallow Land Disposal	Waste Disposal Landfills	Soils & Alluvium	Dry-packaged low-level & mixed wastes	Less than 200 ft	~ 500,000[a]
Greater Confinement Disposal	Monitored Underground Waste Disposal Borehole	Soils & Alluvium	Tritium Americium	60 meters	~ 9.3 million[a] (~ 10,000 ft^2)
Shallow Borehole Tests	Underground Nuclear Testing Areas	Soils & Alluvium	Americium Cesium Cobalt Europium Plutonium Strontium	Less than 200 ft	~ 2,000 at land surface, unknown at depth
Deep Underground Tests	Underground Nuclear Testing Areas	Soils, Alluvium, & Consolidated Rock	Tritium, fission, and activation products	~ 600 meters	112 million[b]

[a] Inventory at time of disposal (not corrected for decay).

[b] The 112 million Ci represents that fraction of the total underground source term (estimated to be 300 million Ci) which is within 100 m of the water table. It is this fraction that is available to the ground water regime and is, therefore, referred to as the hydrological source term.

External exposure estimates were originally published in 1986 (ANS86) and updated in 1990 (ANS90). The total collective external exposure from 1951 through 1975 for all communities was estimated to be 86,000 person-R, with the greatest exposures occurring in Saint George, Utah; Ely, Nevada; and Las Vegas, Nevada. Summaries of the distribution of individual cumulative external exposures are provided in Tables II-2 and II-3, which identify three discrete time periods. By far, the largest collective and individual exposures occurred between 1951 and 1958. During the period from 1961 to the time of the Limited Test Ban Treaty, no individuals are known to have received cumulative external exposures greater than 0.5 R. The 480 individuals who received exposures between 0.1 and 0.5 R lived in small ranch communities just north and northeast of the NTS. From 1963 to 1975, cumulative external exposures were small, with only six individuals (at the Diablo Maintenance Station) receiving more than 0.1 R.

The contribution of dose resulting from inhalation and ingestion of radionuclides was not considered in earlier exposure estimates. Investigators from the Desert Research Institute (DRI), Colorado State University (CSU), and the Lawrence Livermore National Laboratory (LLNL) are now systematically reconstructing the internal dose to individuals for all locations and test events at the NTS. The computer code PATHWAY was developed to predict radionuclide ingestion by residents in the arid regions around the NTS following radioactive fallout deposition (WHC90). PATHWAY simulates the transport of approximately 21 fallout radionuclides through agricultural ecosystems to humans and accounts for agricultural conditions of the southwestern United States during the 1950s. Outputs can be generated that are specific to age, sex, and radionuclides. For the inhalation pathway, estimates will be based on empirical air sampling measurements, fallout data, and meteorologic records.

NTS Health Studies

Numerous population groups exposed to fallout from NTS weapon tests have been studied for health effects. Those studied include civilian populations in the Utah - Nevada area and military participants in weapons testing. Most of these studies assessed the incidence of leukemia and thyroid disorders among the exposed populations.

Table II-2. Exposure Summary by Major Time Period of the Locations with Recorded External Gamma Exposures, the Mean Location Exposure, and the Population Weighted Exposure[1]

	Time period		
	1951 to 1958	1961 to LTBT[2]	LTBT[2] to 1975
Collective exposure (Person-R)	84,400	610	320
Number of locations with recorded exposure	260	74	72
Mean location exposure (R)	1.3	0.048	0.017
Population weighted exposure (R)	0.47	0.031	0.002

[1] Source: ANS90
[2] Limited Test Ban Treaty signed August 5, 1963

Table II-3. Distribution of Individual Cumulative External Gamma Exposure by Exposure Range During the Three Major Time Periods

Exposure Range (R)	Persons within Exposure Range		
	1951 to 1958	1961 to LTBT	LTBT to 1975
<0.01 to 0.1	61,000	180,000	180,000
0.01 to 0.5	80,000	480	6
0.5 to 1.0	19,000	0	0
1.0 to 5.0	20,000	0	0
5.0 to 10.0	520	0	0
10.0 to 15.0	45	0	0
Total	180,000	180,000	180,000

Source: ANS90

The results of key leukemia and thyroid studies involving NTS population groups are summarized below.

- A 1979 study reported an apparent tripling in the rate of leukemia mortality among Utah residents born between 1951 and 1958 in "high exposure counties" (LYO79). Some scientists view this finding with skepticism because of a possible misinterpretation of the dose distribution and the paradox that the rates of cancer at other anatomical sites were lower in "high exposure" areas than those in "low exposure" areas.

- Machado et al. (MAC87) reported similar findings of an excess of childhood leukemia deaths in three "high exposure" southwestern Utah counties among individuals younger than 15 years of age who were born before the tests ended. These authors suggested the possibility that the transient increase of radiation-induced childhood leukemias followed the peak fallout deposition between 1953 and 1957.

- Johnson (JOH87) identified radiation-induced cancers among Mormon families in southwestern Utah exposed to fallout between 1951 and 1962 and venting of underground nuclear detonations between 1962 and 1979. This study was found to suffer from methodological deficiencies related to the selection of study subjects, the methods of obtaining medical information and cancer diagnosis, and the interpretation of data (ICR91).

- Caldwell et al. (CAL83) reported an excess incidence of leukemia, but no overall excess of other cancers, among the 3,224 military personnel who participated in the 1952 Smokey nuclear test. Through 1977, nine cases of leukemia had occurred, compared with 3.5 cases expected. The recorded average external dose was 520 mrem. A similar study of 5,000 other individuals who had participated in 24 detonations found no leukemia excess (ROB83).

- Another population group studied since 1965 for thyroid disorders includes a cohort of about 2,600 public school students who as infants lived in proximity to the Nevada Test Site in Utah and Nevada. The prevalence of thyroid abnormalities in these children has been compared to that in a control group of 2,219 children selected from a county in Arizona that was presumed to have received little or no fallout from the Nevada Test Site. Thyroid doses occurred primarily as the result of ingesting milk contaminated with radioiodine. Cumulative thyroid doses among study subjects were estimated to range from 30 to 700 rad (MAY66). Incidence of thyroid neoplasms was first reported in 1974 and 1975 (RAL74, RAL75). Although the rate of thyroid neoplasms among the Utah/Nevada subjects of 5.6 per 1,000 was higher than that of Arizona control subjects (3.3 per 1,000), the difference was statistically insignificant. In a follow-up study conducted in 1985-1986, in which 3,122 of the original 4,819 subjects were reevaluated, the rate of thyroid neoplasms in the Utah/Nevada subjects of 24.6 per 1,000 was again slightly but insignificantly higher than the Arizona subjects (20.2 per 1,000) (RAL90). The authors previously concluded that living near the Nevada Test Site in the 1950s had not resulted in a statistically significant increase in thyroid neoplasms among exposed subjects when compared to control subjects of the same age and gender.

It is now generally accepted that a fundamental limitation in all previous NTS studies was that individual radiation exposures were uncertain or lacking because individual residence histories for study subjects were unknown. In addition, reliable exposure rates for many locations were not available at the time of the study.

In response to DOE's previously cited Off-site Radiation Exposure Review Project that amassed exposure data on a county-by-county basis for all or part of seven western states, the National Cancer Institute (NCI) sponsored two major studies to determine whether there were any effects of fallout on the public near the NTS (WAC90).

The first NCI-sponsored study was intended to examine whether leukemia in the state of Utah was related to radiation fallout. Dose estimates for the Utah leukemia case-control study were recently reported by Simon et al. (SIM95). The primary objective of the dosimetry task was to estimate the total observed dose from all pathways to the active marrow by summing exposure from each event at each location where the individual resided. External exposure from radionuclides deposited on the ground presented by far the most significant dose contribution to the active marrow.

The second NCI-sponsored study was a reevaluation of the earlier thyroid study. This study reassessed exposures to the same cohort of subjects identified in the 1965-1970 study and reexamined subjects for thyroid neoplasia. Results of this study were reported by Kerber et al. (KER93) and more recently by Till et al. (TIL95). Their reassessment of the study cohort demonstrated a statistically significant dose-response relationship between exposure to radioiodines from open-air weapon tests at the NTS and the occurrence of thyroid neoplasms (carcinomas and benign neoplasms). It should be noted, however, that the association was not statistically significant for thyroid carcinomas alone.

In summary, the studies and information collected strongly indicate that most of the airborne radioactivity released during the detonation to which nearfield residents were exposed has been widely dispersed in the atmosphere, greatly diluted in the terrestrial biosphere, or decayed in the more than 30 years since the last atmospheric test. Therefore, future human exposures from past atmospheric tests can be assumed negligible.

Potential Future Exposures Associated with Current Soil Contaminants

The potential for significant future exposures to area residents of the NTS is limited to those soil contaminants that in time may migrate down through the unsaturated zone and encounter ground water that may subsequently be withdrawn for human use and consumption. Radionuclide inventories residing in surficial or shallow strata are unlikely to reach an aquifer. DOE considers only radionuclides from deep underground tests that were deposited beneath the water table or within 100 m of the top of the water table as a potential hydrological source term (DOE96).

As previously noted, the hydrological source term available to the ground water regime is estimated to be 112 million Ci, of which about 100 million Ci is represented by tritium. There is considerable uncertainty about the actual quantity of tritium that can enter the ground water regime. Uncertainties involve the extent to which radioactivity is securely trapped in the melt glass matrix formed in the detonation cavity and the nearfield impact of the detonation on ground permeability.

The shock wave and compressive forces from the tests can, on one hand, enhance permeability by creating fractures nearby; on the other hand, these forces may decrease permeability by closing pre-existing fractures.

Tritium, as water, is considered by far the most mobile radionuclide present in the subsurface environment surrounding the underground test cavity. With its half-life of about 12 years, the estimated 100 million Ci hydrologic source term of tritium represents the major radionuclide of concern for the next 200 years.

Risks Associated with Tritium Migration

Proposed changes in NTS operations, as well as DOE's policy of reviewing sitewide impacts under the National Environmental Policy Act (NEPA), have prompted the need for a new Environmental Impact Statement (EIS) for the NTS (DOE93a). The draft EIS (DOE96), issued in January 1996, assessed doses and risks from past activities and future operations under each of the following four alternatives:

- Alternative 1: No Action. The DOE would continue to support ongoing program operations, but no new initiatives would be pursued.
- Alternative 2: Discontinue Operations. Under this option, only services required to continue the protection of human health and safety would be performed, inclusive of environmental monitoring.
- Alternative 3: Expanded Use. Implementation of this alternative would involve expansion of many current activities and programs, including current remediation and waste management activities.
- Alternative 4: Alternate Use of Withdrawn Land. While defense programs would be discontinued, there would be increased activities for waste management, remediation, and nondefense research activities (e.g., solar energy).

The proposed NTS EIS alternatives, however, are not expected to change the current inventory or configuration of subsurface contamination. Thus, an assessment of future radiological impacts to off-site residents is considered identical for each of the proposed alternatives. The migration of tritium from discrete underground NTS test areas to locations outside the current site boundary and accessible to members of the public are of primary concern and have been evaluated in the draft EIS.

Table II-4 provides summary data regarding doses and risks to hypothetical individuals. Individuals are assumed to ingest contaminated well water for a period of 70 years from the nearest accessible location. The 70-year lifetime exposure scenario coincides with the time of peak concentrations of tritium in ground water for each of the three underground test sites:

- Yucca Flat. Tritium concentrations migrating from Yucca Flat to Mercury, Nevada are not expected to reach the minimum detectable level of one pCi/L. Lifetime doses and risks are, therefore, negligible.

- Project Shoal Area. At the closest accessible location (the eastern boundary of the Project Shoal Area), tritium is expected to reach a maximum concentration of about 280 pCi/L in about 206 years, yielding a lifetime dose of 1.6 mrem. At the nearest existing public well, maximum concentrations are not expected to occur for 278 years, resulting in doses and risks that are nearly four orders of magnitude lower.

- Central Nevada Test Area. At the nearest existing public well, the time of maximum tritium concentration is not expected for more than 400 years at concentrations that are small fractions of one pCi/L. Associated doses and risks at this location are essentially non-existent. Near the southern boundary, tritium concentrations as high as 1.2×10^8 pCi/L had been predicted for 1983 (or 15 years after testing), yielding a lifetime dose of about 8,000 mrem, or an average annual dose of 114 mrem. In 1996, these concentrations would be reduced by more than a factor of two due to natural decay. However, there has been no confirmation of these concentrations by ground water sampling and assessment at this location.

Radiological Surveillance Around the Nevada Test Site

Since 1970, the EPA's Characterization Research Division (formerly named the Environmental Monitoring Systems Laboratory - Las Vegas or EMSL-LV) has assumed responsibility for the Off-site Radiological Safety Program (ORSP) at NTS and other U.S. nuclear test sites. Among ORSP's primary objectives are to systematically measure and document levels and trends of environmental radiation and radioactive contaminants in the vicinity of the test sites.

Off-site levels of radiation and radioactivity are assessed by gamma-ray measurements using highly-sensitive pressurized ion chambers (PICs) and thermoluminescent dosimeters (TLDs); by sampling air, water, soil, milk, meats, food crops, and indigenous flora and fauna; and by in-vivo/-vitro bioassays of off-site population groups. Results of these measurements are collated and made available to the public in an annual report (DOE93b). Provided below is a brief description of the major elements of the ORSP and summary data for 1993, the most recent year of published data.

Table II-4. Doses and Health Risks to Exposed Individuals[a] from Subsurface Radioactivity

Test Location	Receptor Location	Arrival Time[b] of Peak Conc. (yr)	Peak Tritium Concentration (pCi/L)	Lifetime Dose (mrem)	Risk of Fatal Cancer
Yucca Flat	Mercury, NV	100	< 1	3.0×10^{-5}	1.5×10^{-11}
Project Shoal Area[c]	Eastern boundary[d]	206	280	$1.6 \times 10^{+0}$	8.0×10^{-7}
Project Shoal Area[c]	Nearest public well	278	<1	2.0×10^{-4}	1.0×10^{-10}
Central Nevada Test Area[e]	Central Nevada Test Area boundary[d]	15	1.8×10^{8}	$8.0 \times 10^{+3}$	4.0×10^{-3}
Central Nevada Test Area[e]	Nearest public well	410	<< 1	1.8×10^{-17}	9.0×10^{-24}

[a] The maximally exposed individual is a hypothetical person who is assumed to obtain drinking water from a well at the receptor location for a lifetime of 70 years, centered around the time of peak tritium concentration in the well water.

[b] Time period from the underground test date to the arrival of the peak tritium concentration in well water at the receptor's location.

[c] Results based on analysis performed by Chapman et al. 1995 (CHA95).

[d] No public well currently exists at these locations.

[e] Results based on analysis performed by Pohlmann et al. 1995 (POH95).

External Ambient Gamma Monitoring at the NTS

External ambient radiation levels are measured independently by a network of 27 pressurized ion chambers and 127 thermoluminescent dosimeters located in various communities surrounding the NTS (Figure II-1). Ambient dose and dose rates measured by these devices represent the combined sources of cosmic and terrestrial radiation. Ambient air dose levels ranged from 66 mR/yr at Pahrump, Nevada, to 166 mR/yr at Austin, Nevada, with an average absorbed tissue dose value of 97 mrem/yr. Observed variations in ambient dose rates reflect differences in altitude, soil composition, and meteorological factors. This average of 97 mrem/yr is considerably higher than the combined national average value of cosmic and terrestrial radiation level of 56 mrem.

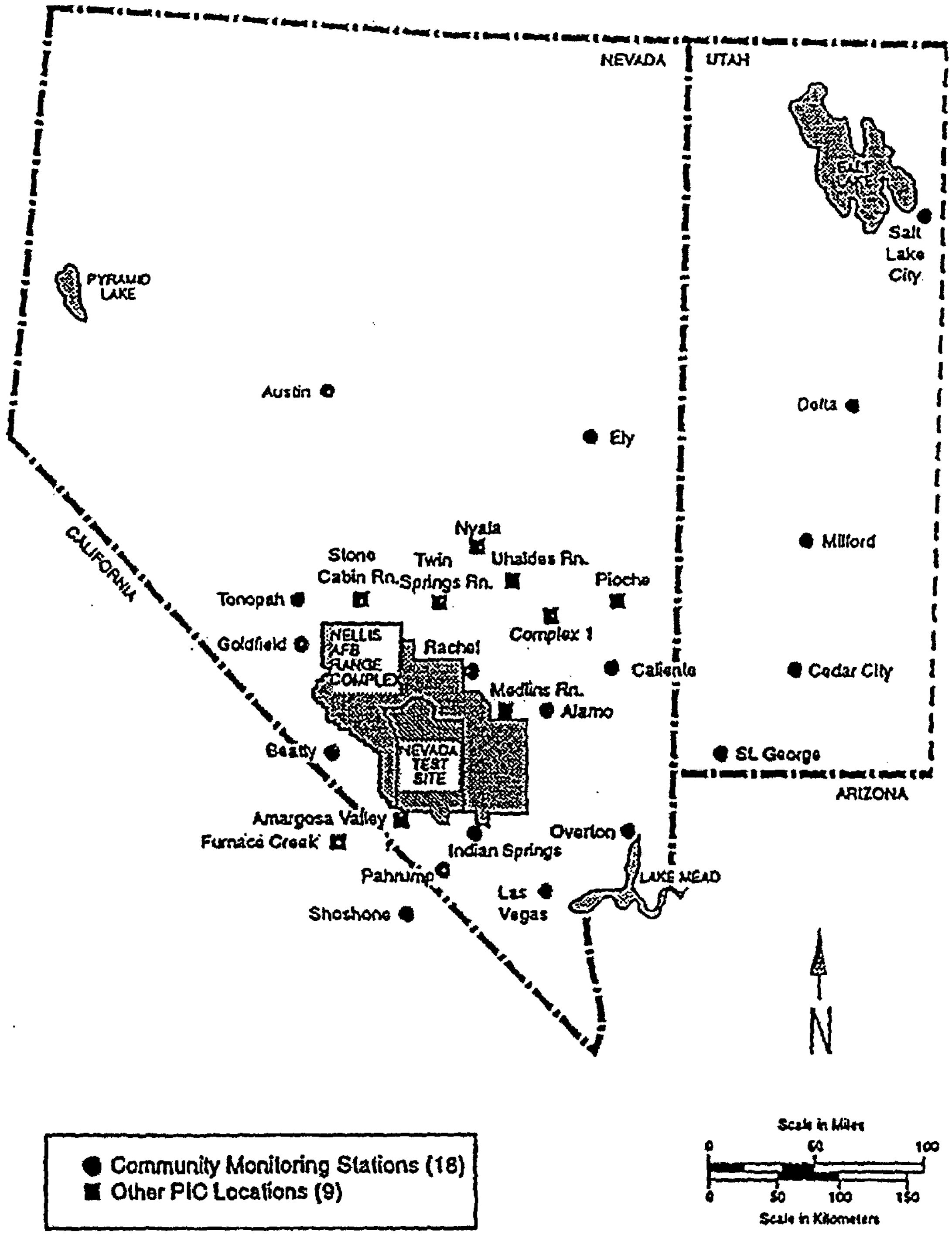

Figure II-1. Pressurized Ion Chamber Network Station Locations - 1993

Atmospheric Monitoring

A network of 30 continuously-operating stations monitor airborne particulate radionuclides and radioiodines. An additional 14 sampling stations sample for atmospheric tritium and noble gases. Data indicate that airborne radioactivity from diffusion, evaporation of effluents, or resuspension of radionuclides from past releases are currently below detection limits at off-site locations.

Using the CAP88-PC model and NTS radionuclide emission data, an effective dose equivalent of 0.004 mrem/yr was calculated for the off-site maximally exposed individual.

Monitoring of Local Food Products

A large variety of local foods that included milk, meat, vegetables, fruits, and wild game were obtained from specified locations to distances of up to 200 miles. Food products were analyzed for various radionuclides including H-3, Sr-89/90, and Pu-238/-239/-240. The Sr-90 levels in samples of animal bone remained very low, as did Pu-239/-240 in both bone and liver samples of domestic and game animals. Although a few milk samples contained measurable levels of Sr-90 and several fruit and produce samples contained measurable levels of Pu-239/-240 and Sr-90, their potential contribution to human internal exposures was considered insignificant.

Population Monitoring by Bioassay

Since 1970, the ORSP has been assessing representative members of the off-site populations for potential internal exposure from fallout. The off-site internal dosimetry program is designed to measure radionuclide body burdens among persons who were subjected to fallout during the early years of weapons testing, as well as to provide a monitoring system for present-day NTS activities and environmental conditions.

In 1993, this program included 158 individuals representing 54 families. Evaluation of participants includes a biannual whole-body count, lung count, and urinalysis. At 18-month intervals, participants also receive a comprehensive medical examination.

No transuranics were detected in any lung counts. In general, body burdens of participants were representative of any normal population when matched for age and sex distribution.

Ground Water and Long-Term Hydrological Monitoring

Since 1972, a Long-Term Hydrological Monitoring Program (LTHMP) has been implemented at the NTS. Routine monitoring is conducted at specified on-site wells and at wells, springs, and surface waters in the off-site area around the NTS.

Because tritium is a product of nuclear testing that was found in significant quantities in underground test cavities and is highly mobile, it is expected to be the first radionuclide to migrate. Therefore, tritium serves as a warning indicator of other potential radionuclide migration and was the primary radionuclide analyzed in the LTHMP. Off-site sampling locations include 23 wells, seven springs, and two surface water sites, which are sampled on a monthly basis.

In 1993 and over the past decade, detectable levels of tritium have been found in a limited number of samples obtained from surface water. In all cases, the tritium activities fall within the range of environmental levels and are thought to be the result of rainfall containing scavenged atmospheric tritium.

Summary of ORSP Results and Off-site Dose Estimates Pertaining to NTS Activities

For 1993, EPA's comprehensive off-site environmental surveillance program around NTS measured no levels of radiation that would contribute significant exposure to any member of the public.

Potential exposure from all pathways to members of the public due to NTS activities are estimated annually by two separate methods. The first calculates annual dose by means of computer effluent modeling (CAP88-PC), meteorologic, and demographic data. The second approach uses measurement data from the ORSP with conservative assumptions and standard dose conversion factors.

Based on computer modeling, the committed effective dose equivalent to the maximally exposed off-site resident for 1993 was estimated to be 0.004 mrem. Environmental sampling data estimate a comparable dose of 0.05 mrem/yr from NTS and non-NTS fallout. For the 80-km (50-mile) radius population of 21,750 individuals, a collective population dose of

1.2×10^{-2} person-rem was estimated for 1993. These doses are considered negligible when compared to the average ambient external gamma dose rate of 97 mrem/yr contributed by natural cosmic and terrestrial radiation alone.

REFERENCES FOR APPENDIX II

ANS86 Anspaugh, L.R., and B.W. Church, *Historical Estimates of External Exposure and Collective External Exposure from Testing at the Nevada Test Site. Vol. I. Test Series through Hardtack II, 1958*, Health Physics, 51:35, 1986

ANS90 Anspaugh, L.R., et al., *Historical Estimates of γ Exposure and Collective External γ Exposure From Testing at the Nevada Test Site. Vol. II. Test Series after Hardtack II, 1958, and Summary*, Health Physics, 59:525, 1990.

CAL83 Caldwell, G.G., et al., *Mortality and Cancer Frequency among Military Nuclear Test (Smokey) Participants, 1957 through 1979*, Journal of the American Medical Association, 250:620, 1983.

DOE93a U.S. Department of Energy, *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements*, Office of NEPA Oversight, 1993.

DOE93b U.S. Department of Energy, *Nevada Operations Office Annual Site Environmental Report*, Report No. DOE/NV/10630-66, 1993.

DOE96 U.S. Department of Energy, *The Environmental Impact Statement for the Nevada Test Site and Off-site Locations in the State of Nevada (Draft)*, Volume 1, DOE/EIS 0243, Las Vegas, Nevada, 1996.

HIC90 Hicks, H.G., *Additional Calculations of Radionuclide Production Following Nuclear Explosions and Pu Isotopic Ratios for Nevada Test Site Events*, Health Physics, 59(5):515, 1990.

ICR91 International Commission on Radiological Protection, *Risks Associated with Ionizing Radiations*, Volume 22, No. 1, Pergamon Press, 1991.

JOH87 Johnson, C.J., *A Cohort Study of Cancer Incidence in Mormon Families Exposed to Nuclear Fallout Versus an Area-Based Study of Cancer Deaths in Whites in Southwestern Utah*, American Journal of Epidemiology, 125:166, 1987.

KER93 Kerber, R.A.,et al., *A Cohort Study of Thyroid Disease in Relation to Fallout from Nuclear Weapons Testing*, Journal of the American Medical Association, 270:2076, 1993.

LYO79 Lyon, J.L., et al., *Childhood Leukemias Associated with Fallout from Nuclear Testing*, New England Journal of Medicine, 300:397, 1979.

MAC87 Machado, S.G., C.E. Land, and F.W. Mckay, *Cancer Mortality and Radioactive Fallout in Southwestern Utah*, American Journal of Epidemiololgy, 125:44, 1987.

MAY66 Mays, C.W., *Thyroid Irradiation in Utah Infants Exposed to Iodine-131*, Scientist Citizen, 8:3, 1966.

MCA91 McArthur, R.D., *Radionuclides in Surface Soil at the Nevada Test Site*, DOE/NV/10845-02, U.S. Department of Energy, Las Vegas, NV, 1991.

POH95 Pohlmann, K., J.B. Chapman, and R. Andricevic, *Exposure Assessment of Groundwater Transport of Tritium from the Central Nevada Test Area*, Publication #45233, Desert Research Institute, Las Vegas, NV, 1995.

RAL74 Rallison, M.L., *Thyroid Disease in Children. A Survey of Subjects Potentially Exposed to Fallout Radiation*, American Journal of Medicine, 56:457, 1974.

RAL75 Rallison, M.L., et al., *Thyroid Nodularity in Children*, Journal of the American Medical Association, 233:1069, 1975.

RAL90 Rallison, M.L., et al., *Cohort Study of Thyroid Disease near the Nevada Test Site: A Preliminary Report*, Health Physics, 59:739, 1990.

ROB83 Robinette, C.D., and S. Jablon, *Studies of Participants at Testing of Nuclear Weapons: I. The Plumbob series*, in Somatic and Genetic Effects, Proceedings of the Seventh International Congress of Radiation Research, Martinus Nijhoff Publishers C8-13, Amsterdam, 1983.

SIM95 Simon, S.L., et al., *The Utah Leukemia Case-Control Study: Dosimetry Methodology and Results*, Health Physics, 68:460, 1995.

TIL95 Till, J.E., et al., *The Utah Thyroid Cohort Study: Analysis of the Dosimetry Results*, Health Physics, 68:472, 1995.

UNS82 United Nations Scientific Committee on the Effects of Atomic Radiation, *Ionizing Radiation: Sources and Biological Effects*, New York, 1982.

WAC90 Wachholz, B.W., *Overview of the National Cancer Institute's Activities Related to Exposure of the Public to Fallout from the Nevada Test Site*, Health Physics, 59:511, 1990.

WHC90 Whicker, F.W., et al., *Estimation of Radionuclide Ingestion: The "PATHWAY" Food-chain Model*, Health Physics, 59:645, 1990.

APPENDIX VI
CURRENT INFORMATION REGARDING GROUND WATER FLOW AND RADIONUCLIDE TRANSPORT IN THE UNSATURATED AND SATURATED ZONES

APPENDIX VI

CURRENT INFORMATION REGARDING GROUND WATER FLOW AND RADIONUCLIDE TRANSPORT IN THE UNSATURATED AND SATURATED ZONES

VI.1 UNSATURATED ZONE

VI.1.1 Unsaturated Zone Hydrology Model

The unsaturated-zone (UZ) flow analysis of Yucca Mountain comprises four components (climate, infiltration, mountain-scale UZ flow, and seepage into drifts) that are believed to play an important role in the performance of the potential repository. Climate and infiltration influence the amount of water percolating toward the repository. Subsequently, water seeping into the drifts and onto the waste packages can accelerate waste-package degradation, and rapid pathways from the repository to the water table via fractures can decrease the transit time of radionuclides to the accessible environment. Prediction of these events relies on process models of UZ flow that have been tested or calibrated against available data at Yucca Mountain. This section describes the development of these models and the important processes and relevant parameters used in the TSPA-VA.

The TSPA-VA is the most recent TSPA analysis conducted by DOE that has undergone thorough external review by outside parties (NRC, TRB, etc.). The more recent TSPA for Site Recommendation (TSPA-SR) has been release very recently. Changes in the treatment of flow phenomena in the TSPA-SR are changed minimally from those in the TSPA-VA, so the current discussion will focus on the more heavily reviewed of the two.

VI.1.1.1 Synopsis of TSPA-VA Treatment and Changes from Prior Efforts

A primary difference in the treatment of UZ flow between TSPA-VA and previous TSPAs is the use of a fully three-dimensional UZ flow model developed at LBNL by Bodvarsson et al. (BOD97). Their goal was to synthesize all of the available data into a coherent, predictive model of water and air flow in the UZ using the dual-permeability continuum formulation or fracture and matrix flow and interaction. The numerical formulation of the model is implemented with the TOUGH2 computer code (PRU91). Model calibration is performed using an inverse method implemented in ITOUGH2 (FIN93) to optimize the model parameters against available data. A new feature of the current LBNL model (BOD97) is that a fracture-matrix coupling parameter, related to the wetted contact area between fractures and matrix, can be used as an inversion parameter in each hydrogeologic unit. The use of the three-dimensional UZ flow model precludes the need for simplified or abstracted flow fields, as has been required in previous TSPAs. However, because of the size and computational requirements of the three-dimensional UZ flow model, the emphasis in TSPA-VA has been on using selected conceptual models and parameter sets that span the range of uncertainty in UZ flow modeling, rather than randomly sampling large combinations of parameters.

VI.1.1.2 Infiltration

The ultimate source of water in the unsaturated zone at Yucca Mountain is precipitation on the mountain. The spatial and temporal relationships between infiltration and recharge are complex, because of the hydrogeologic variability of Yucca Mountain. Some water that infiltrates returns to the surface by interflow; another part is returned to the atmosphere by evapotranspiration. A small quantity that is not evaporated, or discharged as interflow, percolates deep into the unsaturated zone and becomes net infiltration or percolation. The terms "infiltration" and "percolation" are used frequently, sometimes interchangeably, in literature about the Yucca Mountain unsaturated zone. For the purposes of this report, "infiltration" is used to describe the amount of water which enters Yucca Mountain at the ground surface, while "percolation" is used to describe the amount of water which actually penetrates deep enough into the mountain to reach the repository horizon and below. The difference between the two terms lies mainly in the partitioning of part of the infiltration flux into the vapor phase, which may then be recirculated to the atmosphere.

At Yucca Mountain, the infiltration rate is both spatially and temporally variable. Because the quantity of net infiltration that percolates through different paths is quite variable, estimated average recharge rates do not represent percolation rates through specific flow paths. Spatial variations of infiltration depend mostly on variations in the properties of surficial units, topography, the intersection of faults with the surface, and the presence of local fracturing. Temporal variations in infiltration rate are related to the seasonality and relatively infrequent precipitation events in the arid climate of Yucca Mountain. Temporal variations in the infiltration rate have also occurred over a much larger time span, reflecting long-term climate changes.

Knowing the temporal and spatial variability of the percolation rates is crucial to modeling efforts because of the importance of the relationship of infiltration rate to horizontal and vertical permeabilities of the various units and the effect this has on whether or not significant lateral flow occurs in the unsaturated zone. The higher the actual infiltration rate, the lesser the likelihood of significant lateral flow. Such lateral flow could result from a combination of two factors. The first factor is that infiltrating water may encounter zones of lower relative permeability as it moves downward. The second factor is that in many of the units, the relative permeability is far greater in the direction parallel to bedding than the direction perpendicular to it. The anisotropic permeability may cause lateral flow of mounded water away from the area in which it accumulates. Lateral flow is important because it could transmit water to structural features which would then move the water downward, possibly acting as a conduit to divert large amounts of water flowing downward through a small area. Such flow paths could direct water into and through the repository or away from it.

The actual quantity of net infiltration or percolation beneath the surface of Yucca Mountain has not been accurately determined. The percolation flux is a difficult parameter to determine for low flux regions such as Yucca Mountain. There are currently no reliable direct measurements that can be made to determine this important parameter (LBL96). Existing estimates have been obtained from a mixture of indirect methods involving field testing and modeling of various processes at different scales. Data exist to suggest that the flux reaching the repository horizon through the matrix is relatively small. Relatively low matrix saturations measured in the upper portion of the TSw suggest that much of the moisture which infiltrates into the TCw does not reach the TSw (LBL96). Data from the ESF show that no weeping fractures were found, even in the region where perched water exists in boreholes. It should be noted, however, that because of ventilation equipment inside the ESF, much of any such moisture might be removed from the ESF as water vapor. Furthermore, no moisture was observed infiltrating into the radial boreholes of Alcove 1 of the ESF after storm events, even though the boreholes are located close to the land surface in the highly fractured and broken TCw formation (LBL96). However, other data suggest that the percolation flux may reach the repository level mainly through episodic fracture flow. These data include observation and testing of extensive bodies of perched water located below the repository horizon, as well as measurements of bomb-pulse isotope levels from atmospheric nuclear testing which show that some water in the unsaturated zone is relatively young (LBL96).

Estimates of net infiltration vary from slightly negative (net loss of moisture from the mountain) to about 10 mm/yr (LBL96). It is reported in USG84 that net infiltration flux probably ranges from 0.5 to 4.5 mm/year, based on estimates of earlier workers for various localities in the Yucca

Mountain area. Flint and Flint (FLI94) provide preliminary estimates of spatial infiltration rates that range from 0.02 mm/yr, where the welded Tiva Canyon unit outcrops, to 13.4 mm/yr in areas where the Paintbrush nonwelded unit outcrops. The bulk of the area above the repository block is underlain principally by the Tiva Canyon member. The DOE's 1995 Total System Performance Assessment concludes that, if the predominant flow direction is vertical, then the average infiltration through the repository block, using the average infiltration rates of Flint and Flint (FLI94), would be 0.02 mm/yr. If, on the other hand, the predominant flow direction has a significant lateral component due to material property heterogeneity and/or anisotropy and the sloping nature of the hydrostratigraphic unit contacts, then the average net infiltration rate over the repository block could be as high as some weighted average of the infiltration rates inferred from FLI94. The 1995 TSPA (DOE95) also reports that the average, spatially-integrated infiltration rate is about 1.2 mm/yr; most of this infiltration occurs along the Paintbrush outcrop in the washes north of the repository block.

Recently, several lines of evidence have converged to alter the prevailing view regarding the magnitude of infiltration/percolation rates beneath Yucca Mountain, with the most recent estimates being revised upward from previous work. The newer estimates of percolation are around five mm/yr, with a range of one to 10 mm/yr (LBL96). Recent isotopic analyses of rock samples from the ESF are consistent with a percolation rate of five mm/yr (LAN96, LBL96). Profiles of temperature versus depth of water in boreholes are consistent with a range of infiltration rates from one to 10 mm/yr (LBL96). Three-dimensional modeling results of the percolation flux at the repository horizon using the latest available spatially varying infiltration map indicate percolation fluxes on the order of five to 10 mm/yr. The UZ expert elicitation panel estimates for mean infiltration rates range from 3.9 to 12.7 mm/y (GEO97). The effect of uncertainty in infiltration and percolation flux rates is presented in the TSPA-VA.

The conceptual model used in infiltration studies defines the physical processes determining net infiltration, and is based on evidence provided from field studies at Yucca Mountain combined with established concepts in soil physics and hydrology (FRE79, HOR33, HIL80, FLI96). The overall framework of the conceptual model is provided by the hydrologic cycle, which includes all the processes on the surface and in the shallow subsurface (0 to 6 m beneath the ground surface) that affect net infiltration. These processes include precipitation, infiltration, run-off and run-on, evapotranspiration, and the redistribution of moisture in the shallow subsurface. Precipitation is the dominant hydrologic process at the site because it is the source of all moisture for the surface and shallow subsurface (there are no permanent streams or bodies of surface water affecting the site), excluding water introduced to the site by human activity (dust-control, drilling, waste water). Precipitation is dependent mostly on meteorological factors, but geographic location, elevation, and physiography are also important. Evapotranspiration is the second most dominant hydrologic process (in terms of the total volume of water involved) at Yucca Mountain and is dependent on vegetation, the distribution of available moisture stored in the shallow subsurface, and potential evapotranspiration, which is determined by an energy balance. Redistribution of moisture in the shallow subsurface occurs in response to gravity and matric potentials and is strongly dependent on soil and bedrock properties. The removal of water through evapotranspiration is dynamically integrated with the redistribution of moisture in the shallow subsurface. The generation of run-off is dependent on a combination of soil depth, soil porosity, soil permeability, bedrock permeability, and ground surface slope. Run-on and the routing of surface flow are dependent mostly on surficial material properties, topography, and channel geometry.

The conceptual model of net infiltration has been developed from analysis of an 11-year record of neutron logs from 99 boreholes on Yucca Mountain (FLI95). Relative changes in water content profiles were compared against precipitation records and estimates of evapotranspiration (HEV94). The measured changes in water content were also compared to physiographic setting, bedrock geology, and soil cover. In general, field studies indicated that saturated soils are established primarily during the winter in response to a series of medium to large storm events which tend to occur more frequently during periods associated with an active El Nino Southern Oscillation. The timing, intensity, and duration of precipitation, the storage capacity of the soil, and evapotranspiration determine the availability of water for net infiltration. In the upland areas of Yucca Mountain where the soil cover is shallow, the lower the effective conductivity of the underlying bedrock, the longer moisture from precipitation is held in the soil profile where it is potentially available for evapotranspiration. During winter, when potential evapotranspiration is at a minimum, smaller amounts of precipitation are needed for developing and maintaining saturated conditions at the soil-bedrock contact. When the storage capacity of the soil and the effective conductivity of the underlying bedrock are exceeded, or when precipitation intensity exceeds the infiltration capacity of the soil, runoff is generated and water is available for routing down slopes and into channels. The significance of net infiltration beneath channels in washes relative to sideslopes and ridgetops depends on the frequency and magnitude of runoff events.

In the current conceptual model, net infiltration at Yucca Mountain is characterized as an episodic, transient process depending primarily on the length of time saturated or near-saturated conditions are maintained at the soil-bedrock interface, or, at a depth of 6 m in deep alluvium, and the effective conductivity of the underlying bedrock or alluvium. Net infiltration is determined as the rate of water percolation into bedrock or below a depth of 6 m in alluvium, and is limited by the effective permeability of the bedrock or alluvium. Evapotranspiration is assumed to be negligible in bedrock or below a depth of 6 m because no evidence of plant roots have been found beyond a 5 m depth. The potential for saturating the soil-bedrock interface is determined by the timing, frequency and intensity of precipitation: the depth, field capacity, and porosity of the soil cover; potential evapotranspiration, actual evapotranspiration (which is a function of the available moisture in the soil profile), and the lateral re-distribution of surface water. Lateral redistribution of soil moisture is assumed to be negligible because tho moisture-retention potential in the soil to divert flow laterally is relatively small. A detailed description of the actual determination of net infiltration is given in FLI96.

VI.1.1.3 Unsaturated Zone Flow

The most important data for understanding unsaturated zone flow come from several surface-based drill holes and from the ESF, which is an 8-km-long tunnel through Yucca Mountain. Considerable amounts of data are available on rock-matrix saturations, water potentials, and temperatures; on chemical composition and isotopic abundances of ground water and mineral deposits; on air permeability and air-pressure fluctuations; on rock types and mineralogy; on fault locations and offsets; on fracture density and orientations; and on matrix permeability and saturation/desaturation parameters. In addition, there is information on the upper boundary condition (i.e..infiltration) from a series of weather stations and shallow drill holes instrumented with neutron probes, and there is information on climatic effects from a variety of paleoclimate studies and from analogues such as present-day Ranier Mesa.

The first detailed conceptual model of unsaturated zone flow at Yucca Mountain was proposed in USG84. Since then, the majority of the data collected has been in general agreement with these ideas and concepts (LBL96). Most subsequent conceptualizations of unsaturated zone behavior are largely refinements of this model, revised to accommodate newly-acquired data. Newly-acquired data include isotopic analyses, concentration ratios of ions dissolved in matrix rocks and perched water zones, calcite fracture fillings, and thermal modeling of vertical temperature gradients. Perhaps the most significant change from early conceptual models has been the recent acquisition of new isotopic data which indicate the presence of "fast paths" for water moving through the unsaturated zone. This topic is discussed in more detail in a subsequent section.

The following presentation of the unsaturated zone flow conceptual model is taken primarily from USG84. Where appropriate, the published literature is referenced when describing refinements or revisions that have been made to the USG84 model. The conceptual model is presented as if it were an established physical reality. One must bear in mind, however, that the proposed model is probably not the only reasonable description that could be made of the system. Following the description of the conceptual model is a discussion of critical unknowns, their effects on unsaturated zone flow, and results of numerical modeling studies.

Percolation of infiltrated water through the exposed fractures of the Tiva Canyon welded unit is relatively rapid because of the large fracture permeability and small effective porosity of this unit compared to the alluvial material. Therefore, a large proportion of the infiltrated water normally is percolated sufficiently deep within the fractured tuff to be unaffected by the evaporation potential that exists near the surface. Depending on the intensity of the infiltration, percolation downward through the Tiva Canyon welded unit may occur without a significant change in rate. A small proportion of the water percolating through the fractures slowly diffuses into the matrix of the Tiva Canyon welded unit. Downward flow in the matrix is very slow because of the small effective hydraulic conductivity of the matrix. During dry periods, some of the diffused water flows back into the fractures and probably reaches the land surface by vapor diffusion. The mass of water involved during this process is likely to be negligible compared to the mass of percolating water.

The densely fractured Tiva Canyon unit, with small matrix porosity and permeability, overlies the very porous, sparsely fractured Paintbrush unit. A marked contrast in material properties exists at the contact between these two units; depending on the magnitude of the infiltration flux, this contrast could impart a significant lateral component of flow. Flow of water through fractures of the Tiva Canyon unit occurs rapidly until it reaches the contact. At this point, the velocity is significantly decreased because of the greater effective porosity and lesser hydraulic conductivity of the Paintbrush unit. As a result, lateral, unsaturated flow of water above this contact can occur. Perched water may occur above this unit if displacement along faults has created significant differences in permeability on opposite sides of the fault.

Although the conceptual model of Montazer and Wilson (MON84) hypothesized that perched water may occur at the contact between the Tiva Canyon welded (TCw) unit and the Paintbrush nonwelded (PTn) unit, no such occurrences have been observed in either surface-based boreholes (ROU99, p. 170-174; BOD97, Chapter13) or in the Exploratory Studies Facility (ESF). Based on field observations in boreholes and in the ESF, the existence of perched water above the repository horizon is believed by DOE to be unlikely (DOE98). In addition, three-dimensional modeling of flow in the unsaturated zone beneath Yucca Mountain resulted in no formation of perched water at this contact or within any lithostratigraphic interval above the repository horizon (BOD97). Although contrasting matrix properties at the TCw/PTn contact result in high matrix saturations (FLI98, Table 7), the permeability of the PTn is sufficiently high to allow downward drainage of water without perching. Furthermore, three-dimensional simulation of ground water flow using the base-case parameter set and base-case infiltration indicates that little lateral movement occurs as water travels from the mountain surface to the repository horizon (BOD97, Chapter 20).

Additional relevant information with respect to the likelihood of whether significant lateral flow may be occurring is also tied to the conceptual model of Montazer and Wilson (MON84). Although their conceptual model hypothesized that the ratio of horizontal to vertical hydraulic conductivity of the Paintbrush nonwelded (PTn) unit was 10 to 100, subsequent laboratory analysis of core samples and field-scale air-injection tests indicate that the PTn is not as strongly anisotropic as first envisioned. Comparison of air-injection permeability values (LEC97) with laboratory core values (FLI98, Table 7) indicates that although greater, the air-permeability values for the PTn fall in the upper range of the core values or differ by no more than a factor of ten (CRW98, Section 5.3.3.1.2.3). This similarity between the field air-injection and laboratory core permeability values indicates that the permeability of the PTn is much more isotropic at the two scales than that of the welded units and that the PTn has some fracture permeability (LEC97, p. 29). Further, the similarity of air-permeability values for the PTn from both air-injection testing and pneumatic monitoring (CRW98, Section 5.3.3.1.2.4) indicates that the PTn is not strongly anisotropic. Taken together, these data, as well as other available data, indicate that the tendency for lateral flow in the PTn is not as strong as envisioned in the 1984 conceptual model (ROU99, p. 123-124). This conclusion is supported by three-dimensional simulation of flow using base-case parameter sets in conjunction with base-case infiltration, which, as mentioned above, resulted in little lateral movement as water flows from the mountain surface to the repository horizon (BOD97, Chapter 20). Therefore, the DOE assumes that steady-state vertical percolation into the Topopah Spring welded unit is essentially the same as vertical percolation into and through the PTn.

The saturated hydraulic conductivity of the Paintbrush nonwelded unit in the direction of dip is 10 to 100 times greater than saturated hydraulic conductivity in the direction normal to the bedding plane. The combination of dipping beds and differences in directional permeability creates a downdip component of flow. The magnitude of this component depends on the magnitude of the principal hydraulic conductivity ratio. The permeability contrast may be sufficient to decrease vertical percolation into the underlying Topopah Spring welded unit to almost zero. In this case, water would flow laterally downdip until structural features are encountered that create perching conditions or provide pathways for vertical flow.

As water moves downward through the PTn, the effect of high porosity and low fracture density progressively moves water from fractures into the matrix. Except for areas where fast paths may exist (such as faults), beyond a certain depth in the PTn, flow may be almost entirely in the matrix. Travel times through the matrix of the PTn are thought to be relatively long because the matrix of this unit appears to act as a "sponge" which dampens out episodic infiltration pulses.

Although the 1984 conceptual model of Montazer and Wilson implied that slow, matrix flow would dominate in the Topopah Spring welded (TSw) unit, DOE believes that subsequent data collection and analysis have demonstrated this not to be the case. For example, in situ measurements of water potential and core measurements of water potential and saturation indicate a deep percolation environment that is generally conducive to sustaining deep fracture flow (ROU99). Water potentials throughout most of the PTn and TSw are very high [greater than -0.3 megapascals (MPa)] and are nearly depth invariant. Thus, the imbibition capacity of the densely welded rocks, at least near fractures, is very small because of low matrix permeabilities and low water-potential gradients across the fracture-matrix interface. In addition, pneumatic data indicate that fracture permeabilities of the densely welded rocks are very high, several orders of magnitude greater than those of the host matrix. The pneumatic data also indicate that the fracture network is globally interconnected throughout the TSw, thus providing a vertically interconnected system of openings to sustain downward liquid flow. Furthermore, three-dimensional simulation of flow in the unsaturated zone beneath Yucca Mountain using the base-case parameter set and base-case infiltration indicates that 80 percent of the percolation flux at the repository horizon occurs as fracture flow (BOD97).

The nature of flow at the contact between the Topopah Spring welded unit and the Calico Hills nonwelded unit depends on whether the vitric or zeolitic facies of the Calico Hills unit is present. The permeability and effective porosity of the vitric facies are much greater than those of the matrix of the Topopah Spring unit, which may result in a capillary barrier where those units are in contact. Conversely, the permeability of the zeolitic facies is about the same as for the matrix of the Topopah Spring unit, resulting in continuity of matrix flux across such a contact.

Flux within the Calico Hills unit may occur with some lateral component of downdip flux, because of the existence of layers with contrasting hydraulic conductivity in the unit. A large scale anisotropy probably is caused by intercalation of tuffs with alternately large and small permeability and by compaction.

Water that flows downdip along the top of the Calico Hills unit slowly percolates into this unit and slowly diffuses downward. Fracture flow is known to occur near the uppermost layers of the Calico Hills unit, but diffusion into the matrix may remove the water from the fractures deeper in the unit and thereby limit flow mostly to within the matrix, except along the structural flowpaths. It is possible, however, that fractures provide significant avenues for rapid flow through this unit. Beneath the southern part of the block, the Crater Flat unit occurs between the Calico Hills unit and the water table. This includes the welded part and underlying nonwelded part of the Bullfrog Member of the Crater Flat Tuff.

Fluxes along many structural flowpaths are probably larger than within the units they intersect. The Calico Hills unit is more ductile than the overlying Topopah Spring unit, which may give the Calico Hills unit fracture sealing properties. In addition, because of the lesser shear strength of this unit compared to that of the Topopah Spring, gouge formation along faults and shear zones is more common. These properties may result in a smaller fracture conductivity in the Calico Hills unit. In the case where the structural flowpaths are hydraulically continuous across the upper contact of the Calico Hills unit, water would be more likely to flow downward without a significant change in its path until it reaches the water table. In cases where the structural flow paths are discontinuous across the upper contact, flow may be diverted downdip along this boundary. Intermediate conditions between the two extreme cases are also possible. Recent numerical modeling (LBL96, ROB96) of flow through the unsaturated zone has provided important insights into the possible characteristics of flow in each subunit of the unsaturated zone. Some of these insights are discussed in the following paragraphs.

Several conceptual models of unsaturated-zone flow at Yucca Mountain have been considered for TSPA-VA. Past TSPAs have focused on the use of equivalent continuum models (ECMs). The strength of the ECM is that it can describe observed matrix saturations at Yucca Mountain. Two problems with ECM are (1) the forced-pressure equilibrium causes capillarity of the small pores to overwhelm gravity-driven flow in the fractures, leading to inaccurate descriptions of disequilibrium situations; and (2) it is computationally inefficient in solving time-variable flows. The generalized-equivalent continuum model (GECM) is very similar to the ECM except that a matrix saturation value less than one is prescribed to increase flow through the fractures. The GECM solves the first ECM problem to some extent, but it suffers from lack of data to define the fracture-flow threshold and the DOE indicates that it is not clear whether it is valid under hydrothermal conditions.

The Weeps model, used in TSPA-93 (WIL94) is a simplified stochastic discrete fracture model that only considers flow through fractures (similar to the discrete fracture conceptual model). It apparently predicted the fast paths observed in the ECF (as indicated by elevated $^{36}Cl/Cl$ occurrences) and can describe observed flow-channel spacing at Rainier Mesa (CRW96).

The DOE cites two problems with the Weeps model: (1) it ignores the rock matrix and thus any potential performance impact of flow in the matrix, and (2) much of the data that it requires have not been collected and might be difficult or even impossible to collect. This model was not used in TSPA-VA because the DOE favored a process-based model that could the calibrated to available site data such as borehole data and perched water data.

Another important flow conceptualization is the dual-permeability model (DKM). The DKM allows computation of flow in pressure disequilibrium in matrix and fracture continua, and the DOE believes it to be a reasonable compromise between the ECM and Weeps models. The DKM conceptual model has the flexibility to represent almost the entire range of possible flow behavior though variation of the fracture-matrix coupling parameter, allowing its behavior to change continuously from the ECM (which is dominated by matrix flow) to a Weeps-type flow almost entirely within the fracture network. Because of its flexibility and ability to model a broader range of unsaturated flow problems, the DKM conceptual model was used in TSPA-VA. However, the DOE points out that the DKM has its own problems, including (1) less computational efficiency than the ECM, and (2) lack of data describing the coupling term between matrix and fractures.

In addition to the conceptual model for fracture-matrix partitioning, the TSPA-VA conceptual model of flow in the UZ at Yucca Mountain includes an extensive perched water zone located between the repository horizon and the water table. The perched water exists because of a low permeability region that diverts flow laterally around the perched water region. Faults are also incorporated into the conceptual model of unsaturated flow and are believed to be pathways of fast flow from the surface down to the water table, giving rise to observed "bomb pulse" near faults in the ESF.

VI.1.1.4 TSPA-VA Abstraction Approach and Implementation

The DOE notes that the abstraction approach and implementation of UZ flow models for TSPA-VA were motivated by components and issues of UZ flow and UZ-flow modeling that have been identified as potentially important to PA calculations of Yucca Mountain. As noted previously, important issues addressed in the abstraction and testing analyses fall into four areas: (1) climate, (2) infiltration, (3) mountain-scale UZ flow, and (4) drift-scale seepage.

For TSPA-VA, uncertainty in future climates was represented by including uncertainty in the infiltration rates. DOE used the UZ flow model to calculate flow fields, using the expected present-day infiltration map, as well as to calculate variations on the expected map. The present-day infiltration map was multiplied and divided by three in the base case to include uncertainty in the infiltration values. The infiltration maps corresponding to the long term average and superpluvial climates were similarly divided and multiplied by three in the base case to develop lower-bound and upper-bound infiltration rates. The UZ flow model was used to generate flow fields for these cases, and sampling of these flow fields in TSPA-VA calculations was weighted the same as for the present-climate flow fields. Sensitivity studies also considered increased uncertainty in the infiltration maps by using factors of five instead of three.

Because of the time scales involved, a measure of uncertainty in mean climate precipitation is not presently available; in TSPA-VA, interannual precipitation variability is used as an estimate of climate precipitation uncertainty. Interannual variability (defined as one standard deviation from the mean) in precipitation in the State of Nevada over the last 100 years has been between 20% and 30% (DEW93). Arid and semi-arid regions can have interannual variability of 50% DEW93). A value of 50% uncertainty in mean climate precipitation was assumed for TSPA-VA. Therefore, although the mean precipitation for the long term average climate is estimated to be 300 mm/yr, it could be as low as 150 mm/yr (0.5 x 300 = 150) and as high as 450 mm/yr (1.5 x 300 = 450). In TSPA-VA, the estimated range of uncertainty in mean precipitation is relatively consistent with the estimated range of uncertainty in infiltration rate.

A quantitative characterization of the spatial and temporal distribution of net infiltration is needed for defining upper boundary conditions for site-scale, UZ ground water flow models in TSPA-VA. Net infiltration is defined as the downward rate of water percolation immediately below the zone of evapotranspiration; it is not necessarily equivalent to the rate of recharge to the underlying SZ. A site-scale net infiltration model was developed to provide temporally and spatially detailed estimates of net infiltration rates over the area of Yucca Mountain (BOD97).

The net infiltration model is primarily a deterministic model of surface and near-surface hydrologic processes, although climatic input involves both deterministic and stochastic processes. All major components of the water balance are solved in daily time increments. Daily results are provided for specified locations for analyzing the temporal distribution of net infiltration. Estimates of present-day and potential future net-infiltration rates are provided as detailed mappings of temporally and spatially varying time-averaged fluxes, which can then be applied to define upper-boundary conditions for the UZ.

VI.1.1.5 Model Calibration

The initial version of the infiltration model was calibrated using the 1984-1995 record of measured water-content profiles from approximately 80 neutron access boreholes and a developed record of daily precipitation for 1980-1995 (FLI96). Records from boreholes identified as potentially problematic because of the accelerated downward percolation of water along the annular space were excluded. Model calibration consisted of both qualitative and quantitative comparisons of measured versus simulated water-content changes for the soil profile.

VI.1.1.6 Unsaturated Zone Flow

The DOE would have preferred not to have had to abstract a model from the unsaturated zone process level model (BOD97). The DOE initially expected that the model would be simplified probably by reduction to two-dimensional or even one-dimensional geometry. The site-characterization investigators and modelers strongly recommended that three dimensions were important to represent Yucca Mountain flow adequately. This recommendation was based primarily on the flow below the potential repository, where the DOE believes there is significant nonvertical flow because of heterogeneity in the locations of the zeolitic layers and perched water. With the direct use of the process flow model, there is no need for testing of abstractions against the process model. The models are tested directly against the data as part of the calibration procedure (i.e., each case must be calibrated).

An important consequence of using a complex three-dimensional flow model is that the number of different cases that can be run is limited by computer-processing time, but even more so by the time needed for analysts to make necessary adjustments by hand for each case (to ensure proper model calibration). However, the DOE's current approach uses several select conceptual models and parameter sets that were determined (by sensitivity analyses) to have a significant impact on performance in order to encompass the range of uncertainty in UZ flow. The DOE has found that aqueous travel times between the repository and water table can vary by several orders of magnitude between different conceptual models.

The three-dimensional process flow model inherently contains several specific assumptions and issues that are listed below:

- Dual-permeability flow modeling (i.e., coupled matrix and fracture continua) is adequate. The DKM is capable of representing a large range of potential UZ-flow behaviors (e.g., fracture-matrix interaction, fracture and flow-channel spacing and geometry effective fracture apertures, and fracture- and matrix-flow velocities all vary greatly as the model parameters vary). In future work, the DOE may consider alternative models (e.g., discrete fractures, fractal fractures, etc.) to complement dual-permeability models, but alternatives were not considered for TSPA-VA.

- Steady-state flow modeling is adequate. Climate changes have been included by using a series of steady states; because of that, the flow could be said to be quasi-steady state rather than steady state. Perturbations to flow caused by repository heating were neglected. Such thermohydrologic perturbations were considered only in sensitivity cases because the waste packages are expected to last through the period when flow is strongly perturbed.

- Hydraulic properties of the matrix can be represented by the range of laboratory measurements. In some cases matrix properties were adjusted to get better fits to matrix-saturation measurements or other data.

- Fracture hydraulic properties can be derived from air permeabilities, fracture frequencies, and fracture orientations measured in drill holes and in the ESF. In some cases, the inferred fracture properties (van Genuchten alpha) were adjusted significantly in order to get better fits to matrix-saturation measurements or other data.

- The van Genuchten/Maulem functional form is satisfactory for use to represent the saturation/desaturation behavior of both matrix and fractures.

- The fracture-matrix connection area (i.e. area available for flow between fractures and matrix) is reduced below the geometric area implied by the fracture spacings used. Physically, this reduction represents effects of channelization of flow in fractures. The amount of reduction was chosen to optimize the fit to matrix-saturation measurements or other data.

- Heterogeneity within a unit does not need to be included. Hydrogeologic units are homogeneous.

- Infiltration at the surface is spatially variable, with the variability given by data in FLI96. Sensitivity to infiltration was investigated by multiplying the infiltration distribution by a constant factor keeping the same spatial variability.

- The lower boundary of the model is at the water table, which is fixed by drill-hole observations. For future climates, the water-table elevation is incrcased by prescribed amounts.

VI.1.1.7 Base-Case Hydrologic Properties Used in TSPA-VA

Model calibration allowed the DOE to develop what they believed to be the most reasonable estimate of parameters to be used with the UZ model for both liquid and gas flow. It was a combination of the "matrix" and "fracture" parameter sets and was named the "preliminary base case."

The base-case parameter sets used fracture-matrix multipliers that were calibrated to global classifications of welded, nonwelded, and zeolitic stratigraphic units. Together with the variations in present-day infiltration and ranges in fracture parameters, the base case consisted of five calibrated parameter sets:

- Base infiltration ÷ 3 and the van Genuchten air-entry parameter at a minimum for each layer

- Base infiltration + 3 and the van Genuchten air-entry parameter at a maximum for each layer

- Base infiltration and the van Genuchten air-entry parameter at the nominal "best estimate for each layer

- Base infiltration x 3 and the van Genuchten air-entry parameter at a minimum for each layer

- Base infiltration x 3 and the van Genuchten air-entry parameter at a maximum for each layer

VI.1.1.8 Recommendations for Development of Future Parameters

One of the DOE's contractors (LBNL) recommends that the project pursue three-dimensional inversions using available parallel-processing capabilities to minimize the number of assumptions in the inversions (such as the use of one-dimensional submodels that do not capture the perched-water effects). The contractor also recommends that the three-dimensional inversions add data, such as temperature and geochemical measurements, to explicitly constrain infiltration rates, fracture/matrix equilibrium and travel times during the three-dimensional inversions. Use of these three-dimensional inversions would increase the defensibility of the current calibration process. In addition, the creation of a heterogeneous property set should take advantage of the considerable data concerning parameter uncertainties developed in the one-dimensional models and with the heterogeneous distributions provided by Rautman and McKenna (RAU97) to generate a stochastic representation of the parameter fields in the site-scale UZ model.

VI.1.1.9 Sensitivity Studies for Determining Important Hydrologic Properties

The DOE performed a series of UZ simulations to examine the sensitivity of water flow to matrix and fracture permeabilities and van Genuchten properties in a one-dimensional, dual-permeability system. These studies, in part, formed the basis for the DOE's choice of parameters that were used in the base case, as described in a previous section. These simulations are divided into two sets. In the first set, ranges in property values were defined using the properties and mean and standard-deviation values determined from inverse modeling done at LBNL (BOD97). Results from these simulations show that, for the ranges of values considered, the fraction of infiltrating water that travels downward through the fracture continuum is primarily controlled by fracture alpha and to a lesser extent by fracture permeability. In this first set of simulations, the range of fracture alpha values considered was quite large relative to other property ranges and, as a result, its impact on flow behavior was most significant. To reduce the uncertainty in fracture-alpha values, the DOE conducted a subsequent study to derive more reasonable ranges of fracture alpha values. For this study, the DOE relied on published fracture permeability and fracture frequency data.

A second set of simulations based on the new fracture-alpha ranges was then performed. In this set of simulations only two properties, fracture alpha and fracture permeability, were varied over their ranges. There were two important differences between this set and the first set of simulations: (1) a Weeps formulation was used; that is, the matrix-fracture conductance area was reduced by the fracture relative permeability to water, and (2) in addition to using the new fracture-alpha values, different minimum and maximum values of fracture permeability that are consistent with the new fracture-alpha values were also used. Results of this study show that, for the ranges of fracture permeability and fracture alpha values considered, the fraction of infiltrating water that travels downward in the fracture continuum is controlled primarily by fracture permeability.

VI.1.1.10 Fracture-Matrix Interactions

Dual permeability models have been used to explicitly model unsaturated ground water flow and heat through both fractures and matrix. In the DKM, the fractures and matrix are treated as separate discrete continua. Heat, gas, and liquid are allowed to flow between the fractures and matrix, as well as through each continuum. While the DKM is generally more applicable to a wider range of problems than the ECM (e.g., transient flows, high infiltration boundaries), the DKM requires additional information about the coupling between the fracture and matrix continua.

VI.1.1.11 Analysis of Perched Water

Incorporation of perched water data is an important aspect of the UZ-flow-model calibration. The presence of perched-water bodies implies that vertical water fluxes locally exceed the saturated hydraulic conductivities of the perching layers. In order to capture the perched-water phenomena, the UZ-flow model must have a representative geologic/conceptual/trapping model, fracture/matrix properties, and sufficient net infiltration. The resulting model should reproduce hydraulic responses in pumping rests and remain consistent with geochemical data and the areal extent of the perched body.

Perched water can be defined as a SZ not directly connected to the static water table (FRE79). Two criteria must be met for the model to accurately reproduce perched water at Yucca Mountain. The first is that water saturation within a perched-water zone must be sufficiently high to initiate substantial fracture flow (if any fractures are present). The second is that water pressure within the perched-water volume must have values higher than the static atmospheric gas pressure that would be expected at the same elevation. Under these conditions, water will flow freely into a borehole intersecting a perched-water body. Perched water may accumulate where large contrasts in hydraulic conductivity exist between adjacent formation units, where a permeable layer overlies a relatively impermeable layer, or where a well-connected fractured unit overlies a locally unfractured or poorly connected fractured unit. Relative fracture density and fracture permeability have a strong influence on the accumulation of perched water. Perched water may also exist against a fault along a dipping horizontal plane if the fault acts as a barrier to downdip water flow.

As the DOE points out, one of the implications of an existing perched-water body is that the flow path may not be vertical through the UZ to the water table, but rather the water may be diverted laterally to a fault zone or other type of higher permeability channel in order to reach the water table. As a result, a nonuniform recharge rate to the water table is expected. The DOE notes that this has important implications for waste isolation at Yucca Mountain. Existence of perched-water zones along the base of the Topopah Spring welded unit implies that water may partially bypass the underlying zeolitic unit, and consequently some radionuclides may not be retarded by the highly sorbing zeolites.

Bodvarsson et al. (BOD97) detail how the field observed, perched-water data at the Yucca Mountain site were compiled, analyzed, and incorporated into the thee-dimensional UZ flow model. A conceptual model of occurrences of perched water was discussed, and a series of comprehensive computer modeling studies on perched water at the site was completed. A three-dimensional UZ perched-water flow model was then developed to investigate the perched-water phenomena at Yucca Mountain.

VI.1.1.12 Geochemical Analyses

Bodvarsson et al (ibid.) discuss the efforts made in calibrating the flow model to geochemical data. These analyses also provide methods of developing bounds and ranges for percolation flux and infiltration.

VI.1.1.13 Interface Between Unsaturated Zone Flow and Unsaturated Zone Transport

TOUGH2 (PRU91) and FEHM (ZYV97) are two prominent codes for evaluating flow and transport in the UZ for performance assessments. The application of TOUGH2 has focused on site-scale UZ hydrology (BOD97), while the use of FEHM has focused on fluid flow and radionuclide transport (ROB97) at Yucca Mountain. Both UZ hydrology and radionuclide transport are critical components in performance assessment calculations, and methods of coupling these components were investigated for TSPA-VA.

The DOE considered two methods to transfer the UZ flow results to the UZ radionuclide transport model, which was chosen to be the particle-tracking method in the computer program FEHM (ZYV97): (1) use the UZ flow fields calculated by TOUGH2 directly as input to the FEHM particle tracker, or (2) take the stratigraphy and calibrated hydrologic parameters and use them as inputs to a combined flow and transport calculation within FEHM. According to the DOE, the primary advantages of the first option are that preservation of the UZ-flow calibration is assured, and it is not necessary to recalculate the flow and recheck the calibration. The primary advantages of the second option are that the FEHM particle tracker is already set up to use flow fields calculated by FEHM (the first option requires development of a linking program to take TOUGH2 output and generate FEHM input), and there is additional flexibility to refine the computational grid to make the transport calculations more accurate. The first option (flow fields calculated with TOUGH2, radionuclide transport calculated with FEHM), has been implemented in TSPA-VA.

The particle-tracking method used in FEHM is a cell-based model in which particles are routed from grid block to grid block in a manner that preserves the overall residence time through any portion of the model and probabilistically reproduces the migration of a solute through the domain (ROB97). Flow calculation is based on a control volume in which fluid-flow rates into and out of each cell are computed. Since TOUGH2 is an integrated, finite-difference code and FEHM employs a control-volume, finite-element technique, the two codes are compatible from the standpoint of implementation of the particle-tracking technique. The required inputs for FEHM to use an externally developed flow field are: (1) grid-connectivity information and cell volumes; (2) fluid-state variables for computing density, fluid saturation, and rock porosity at each grid point; (3) internodal fluid-mass-flow rate for every connection in the numerical grid; and (4) fluid source and sink flow rates for each grid block.

VI.1.1.14 Grid and Model Domain for Three-Dimensional Site-Scale Unsaturated Zone Flow Model

Design of the three-dimensional grids was based on a geological framework model. The three-dimensional numerical grids were designed in two steps: (1) using all available surface information to create a horizontal, two-dimensional grid, and (2) integrating data from isopach maps of hydrogeological units to vertically develop the horizontal grid between the ground surface and the water table. This model was a further update of the existing three-dimensional UZ model first developed by Wittwer et al. (WIT92), which was later updated in 1996 (BOD96). The development of this new model, like the old one, started with the definition of the grid block centers that defined a single two-dimensional horizontal grid to use in all the three-dimensional vertical layer sections. After all the nodal points had been located, a numerical grid generator AMESH was used to develop the two-dimensional horizontal grid. These two-dimensional horizontal grids and the sub-layering criteria were used to develop a new three-dimensional numerical grid of the UZ at Yucca Mountain.

New boundaries for the site-scale model were developed as an update to the 1996 three-dimensional LBNL UZ model. These boundaries were based on revised fault maps, the observed shift in water level across the Solitario Canyon, the new infiltration and alluvium thickness maps, the observed pneumatic signals that were observed during the construction of the ESF Tunnel, and the requirements for thermal loading studies. The new boundaries take into account the extensive high-gradient SZ to the north of G-2 and explicitly include the Solitario Canyon Fault in the west by extending the model boundaries to about 1 km west of Solitario Canyon fault. The Bow Ridge fault forms the eastern boundary. The model extends from borehole G-3 in the south to about 1.5 km north of G-2 in the north. These boundaries enclose most of the existing and planned hydrology wells and the wells in which extensive moisture tension data and lithology are used as calibration points for formation properties. The 1997 site-scale model was based on the fault map that provided explicit offsets on Solitario Canyon Fault, Ghost Dance Fault, Iron Ridge, and the Dune Wash Fault, defined by the base of the Tiva Canyon.

One primary objective in the selection of grid boundaries was to minimize boundary effects resulting from thermal loading at the repository horizon, while investigating the influence of the major faults on the hydrological and thermal-hydrological response of the UZ at ambient conditions and during thermal loading. The modeled area covers nearly 43 km^2 and is bounded by Bow Ridge fault on the east; extends 1 km west of Solitario Canyon; is bounded by the plateau of high pressure gradient about 1.5 km north of G-2; and extends about 1 km south of the ESF south ramp. In this grid, the "East Block Repository" area is modeled as a locally refined area with an average grid of 100 x 100 m and accounts for proposed extension of the potential repository to the north. The resulting two-dimensional grid contains a maximum of 1,470 aerial grid-block nodes in each layer. The two-dimensional grid extends about 1 km west of the Solitario Canyon in order to explicitly model both the Solitario Canyon Fault and its associated

Iron Ridge fault branch to the south. Explicit modeling of the area west of the Solitario Canyon also allows for specification of the 40-m shift in the water table west of this fault. This grid was used to perform general site-scale UZ modeling and for detailed studies related to thermal loading of the repository.

VI.1.1.15 DOE Recommendations for Future Work

The DOE asserts that there is a need to harmonize the differences between the grids based on the USGS geological framework model and the geological model in order to select a single geological model for designing future numerical grids. Work is currently underway to integrate the ISM 3.0 geological-framework model into the site-scale UZ-flow model. Integration of the ISM 3.0 geological-framework model with the site-scale UZ-flow model will increase the defensibility of the UZ modeling effort.

VI.1.1.16 Summary of Implementation of the Base-Case Unsaturated Zone-Flow Model in TSPA-VA

The previous sections have detailed the development of the UZ-flow model used in TSPA-VA calculations. Sensitivity analyses have been performed to provide basis for parameters and divided by 3 and multiplied by 3 to yield three present-day infiltration scenarios. In addition, the DOE combined these present-day infiltration scenarios with variations of the fracture air-entry parameter to yield five base-case parameter sets. For each set, two future-climate scenarios were considered by using long-term average infiltration maps. These were either divided by 3 or multiplied by 3 to correspond to the value used in the present-day infiltration scenario. For all UZ ground water flow simulations, the EOS9 module of TOUGH2 has been used. This module implements Richards' equation and assumes that the gas phase is passive.

Once the flow fields have reached steady state, as indicated by a global mass balance within 1% error, the flow fields are used for mountain-scale transport calculations and near-field seepage studies. All developed data that are fed to other TSPA components are submitted to the Technical Data Base. These components are integrated for TSPA-VA calculations using the RIP code.

VI.1.1.17 Sensitivity to Mesh Resolution

All simulations aside from the mesh resolution study use a grid discretization of 0.5 m on a side (i.e., the numerical flow grid has the same resolution as the generated geostatistical permeability field). To study the sensitivity of the simulation results to the numerical grid resolution, the DOE performed additional simulations, with refined grids for a two-dimensional vertical cross section perpendicular to the drift center line. The original 0.5-m x 0.5-m discretization is refined by dividing each grid block first into 4 sub-blocks and then into 9 sub-blocks. The sub-blocks are assigned the same permeability value as the original grid block (i.e., the heterogeneity structure remains unchanged). Results indicate that there is some sensitivity to the grid design, as the derived seepage rates increase when using a finer grid resolution. The DOE believes that this is mainly because the gradients between elements of different permeability are steeper in a simulation with fine sub-gridding, while a simulation with the original grid—identical resolution of heterogeneity field and simulation grid—has smoother transitions as a result of the harmonic weighting of the two neighboring permeability values at element interfaces. The DOE notes that consideration must be given to the fact that an assumed step-change of permeability in the generated random fields is only an approximation of the more smooth transition in natural domains. Therefore, the DOE believes that the original grid design may actually allow for a reasonable representation of natural heterogeneity. The DOE further asserts that if the permeability values for the refined grids were derived by interpolation from the underlying random field to smooth out the strong step-changes, the impact of the mesh refinement would probably be small. DOE also notes that more work along this line will be performed in future studies.

VI.1.1.18 Summary

Following is DOE's summary of important points from the base-case seepage model.

A. Heterogeneity in the flow domain is critical for the calculation of seepage. It causes channelized flow and local ponding, so that the probability of seepage is much larger, and the time required for seepage into the drift is much shorter, than for the case where the flow domain is assumed to be homogenous.

B. The conceptual model for the interaction between fractures and matrix (i.e., X_{fm}) is important for transient flow in the case of episodic percolation events. Field-scale studies like the niche experiment can provide information on the "effective X_{fm}"

value; however, in considering long-term climate changes, the primary interest is seepage under steady-state conditions, so that fracture-matrix interaction need not be considered.

C. In general, seepage time decreases and seepage rate increases with an increase in percolation rate. The relationship between seepage and percolation is not linear, because of the many nonlinear processes involved.

D. Variation among geostatistical realizations is significant (though within the same order of magnitude) and dependent on details of local heterogeneity around the drift. Since such details are not known, a stochastic approach is necessary.

E. Comparison between two-dimensional and three-dimensional runs indicates that the probability of seepage and the seepage-initiation times are similar. The relative seepage rate, however, appears to be different in the three-dimensional runs, due to the possibility of flow in the third dimension.

F. The three-dimensional runs offer the opportunity for evaluating the possible spatial distribution of seepage along emplacement drifts, which cannot be achieved using two-dimensional vertical cross sections. The spacing of seepage locations is dependent on the correlation lengths of spatial heterogeneity.

G. Seepage is insensitive to the van Genuchten β parameter of the fractures. Seepage is sensitive to fracture α and permeability. For steady state, seepage is not sensitive to the matrix hydrologic properties. For transient problems, and for percolation rates lower than those considered here, matrix properties may be more important.

H. There are important questions about the effects of the discrete nature of fracture flow especially the possible role of fractures that dead-end at the drift wall. The preliminary niche-test results appear to fit the base-case conceptual model well, but more analysis (and testing) is needed.

VI.1.1.19 Recommendations

This chapter has detailed the DOE's development of four major components of UZ flow: (1) climate, (2) infiltration, (3) mountain-scale UZ flow, and (4) drift-scale seepage. Issues associated with each component have been presented, along with DOE's abstraction/testing plans that address these issues. The following sections summarize each of the four major UZ-flow components. The impact of each component on performance, along with the DOE's guidance and recommendations for the license application, are also provided.

Climate

The primary purpose of climate modeling was to provide precipitation rates and water table elevations that varied as a function of future climates. Future climate was modeled in TSPA-VA as a sequence of discrete steady states. Only three discrete climate states were considered for TSPA-VA: present-day, long-term average, and superpluvial. Present climate represented relatively dry, interglacial conditions, while the long-term average represented an average pluvial period at Yucca Mountain. The superpluvial represented periods of extreme wetness. The mean annual precipitation (MAP) rates for the present, long-term average, and superpluvial climates were estimated to be 150, 300, and 450 mm/yr, respectfully. These values were used by infiltration modelers to determine appropriate analog sites that had average precipitation rates that were commensurate with the predicted future climate values. The water-table rise from the present-day level (~730 m) was estimated to be 80 m and 120 m for the long-term average and superpluvial climates, respectively. Sensitivity analyses have shown that the overall performance is not sensitive to the duration of the climate cycles. The most significant impact was found to be the abrupt changes in water-table elevation and ground water flow rates that occurred at the transition between climates.

Climate models strongly impact performance through their influence on precipitation and evapotranspiration. These factors, in turn, influence the predicted infiltration in the UZ flow model. Therefore, the magnitude and timing of the prescribed climate states is important to performance.

The DOE believes that additional work is needed to understand the natural variability of current and future climates for Yucca Mountain. In particular the DOE feels that the adequacy of three distinct climate states needs to be addressed further. If distinct climate states are used in future analyses, their number, timing, duration, and the abruptness of the transition between them need better support. Additional modeling is needed to determine how the dose-rate pulses depend on the time of transition between climates, and whether noninstantaneous transitions would lead to lower peak doses. Appropriate climate analogs need to be defined, based on temperature and other factors in addition to precipitation. The superpluvial climate, especially, needs better definition.

Infiltration

Infiltration modeling provides the spatial and temporal distribution of net infiltration as an upper boundary for site-scale UZ-flow models in TSPA-VA. Distributed net infiltration rates were determined for each of the three climate states using the YMP infiltration model. The infiltration model simulated water movement at the ground surface by solving water mass balances using precipitation, a model for evapotranspiration, and available water in the soil profile. Also considered in the model were ground surface elevation, slope, bedrock geology, soil type, soil depth, and geomorphology. The primary driver for the infiltration model was precipitation, which was input using available records or, in some cases, a stochastic model. Daily precipitation records from different locations were used to define the present-day, long-term average, and superpluvial climates in the infiltration model. The sites were chosen based on how well their MAP values matched the estimated values associated with each climate. General results of the infiltration model are as follows:

- The modeled infiltration is highly heterogeneous and clearly correlated with topographic features.
- The highest net infiltration occurs along Yucca Crest.
- Net infiltration is lower in washes.

The spatially distributed infiltration maps were then upscaled to the site-scale UZ-flow model by averaging the simulated infiltration values over each surface element in the UZ-flow model. The DOE used average infiltration for each climate over the UZ-flow model domain of 4.9, 32.5, and 118 mm/yr, respectively.

Sensitivity analyses were also conducted to determine the effects of episodic infiltration on the percolation at the repository horizon. Results showed that the PTn unit effectively damped episodic pulses that were simulated on a yearly cycle, preventing the transient pulses from significantly impacting the percolation at the repository horizon.

Additional sensitivities that used infiltration to estimate the temperature profile in a borehole indicated that infiltration rates that were greater than three times the average present-day infiltration rate did not allow good matches with observed borehole temperatures because of increased advective heat transfer. Therefore, DOE used a factor of three as the upper and lower bounds for the range of infiltrations considered in each climate scenario.

Infiltration strongly affects repository performance because of its influence on mountain-scale unsaturated-zone flow and seepage into drifts (which subsequently affects waste-package-degradation models). The infiltration rates used in TSPA-VA are significantly higher than in past TSPAs. Higher infiltration rates, in general, tend to adversely impact performance. However, the increased infiltration must be considered in conjunction with other TSPA components such as seepage to understand the overall impact on performance assessment.

The DOE believes that the greatest need for improvement in infiltration modeling is explicit inclusion of processes that should be different for future climates, including effects of temperature, cloudiness, vegetation type, surface water runoff/run-on, and snow cover. Even for current conditions, some experts on the UZ expert elicitation panel suggested that runoff and run-on might be more important than is assumed in the infiltration model.

To provide a more quantitative basis for the uncertainty distribution for infiltration, the DOE notes that the infiltration model should be run in a stochastic mode (e.g., Monte Carlo simulation) to derive the infiltration uncertainty from the uncertainties in the input parameters of the model.

Finally, the DOE asserts that analogues with known infiltration, such as Rainier Mesa and Apache Leap, should be used to test and improve the infiltration models and methods.

Unsaturated Zone Flow

The three-dimensional UZ-flow model has been used to calculate unsaturated-ground water flow at Yucca Mountain for TSPA-VA. The model implements the dual-permeability formulation for fracture-matrix interactions and consists of nearly 80,000 elements. Hydrologic properties were determined using both direct measurements and calibration with field data, which included core samples, borehole log data, in situ water potential and temperature measurements, fracture measurements from the ESF, in situ pneumatic data, air permeability tests, and geochemistry data. A great deal of information on the calibration and details of the UZ-flow model development was taken from Bodvarsson et al. (BOD97). In the calibration approach, a number of vertical one-dimensional submodels that corresponded to borehole locations were extracted from the three-dimensional model. The code ITOUGH2 was used to perform simultaneous inverse simulations with these one-dimensional models to optimize hydrologic parameters by matching predicted and observed matrix saturations and moisture potentials. The selection of hydrologic parameters that were estimated by inverse modeling was influenced by sensitivity studies that determined important parameters to UZ flow, including the fracture air-entry parameter, and the fracture-matrix interaction parameter. The properties that were calibrated in one dimension were then used in the three-dimensional site-scale model, which included calibrations for perched water. Additional tests using geochemical data, infiltration data, and alternative weighting schemes were also performed to improve the three-dimensional model and increase confidence in the methods being used.

Results show that the flow through the UZ is predominantly in the fractures for the welded units and predominantly in the matrix for the nonwelded units. High infiltrations resulting from climate changes significantly increased the percolation flux in the vicinity of the repository and decreased the travel time between the repository and the water table. Travel times between the repository and the water table ranged from several days to hundreds of thousands of years. The fastest transit times resulted from flow through-fractures, whereas the matrix contributed to particle breakthrough at the water table at significantly longer times. Perched water, which has been calibrated in the three-dimensional flow model, diverted vertical flow laterally in the three-dimensional model, especially in the northern part of the repository. However, the total travel time of the diverted water was not significantly altered due to the fast flow path through the fractures. Sensitivity results using increased infiltration confirmed the importance of infiltration rates in determining travel times between the repository and the water table. In addition, sensitivity results using the DKM/Weeps alternative model showed that there was more significant fracture flow than in the base case, contributing to faster travel times. Finally, sensitivity studies of the zeolitic matrix permeability showed that increased matrix permeability can result in slower travel times due to increased flow through the matrix. However, decreased matrix permeabilities did not result in significant changes from the base case.

The DOE believes that a significant result of the current TSPA-VA UZ flow calculations relative to earlier TSPAs is that the higher estimates of current and future infiltrations can cause percolation fluxes to be significantly greater and travel times to be significantly shorter. While these effects have a negative impact on performance, the impact of UZ flow in general on the performance calculations must be determined collectively with other system components. For example, high infiltrations are thought to be adverse to performance, but performance calculations have shown that for a period of time, the high infiltration scenarios show a decrease in dose. This counter-intuitive result occurs because the temperatures around the waste package are reduced by the increased infiltration, and the corrosion of the waste packages is reduced. The use of the DKM/Weeps model produced significantly shorter travel times between the repository and water table because of increased partitioning of flow through fractures. As demonstrated in PA calculations, the decreased travel times increase dose rates for periods less than 10,000 years, but for longer times (100,000 and 1,000,000 years), the rapid transport does not significantly impact performance. At these later times, the travel time becomes small relative to the total simulation time, and the decreased travel in the DKM/Weeps model is less important. However, colloid-facilitated transport can be enhanced by increased flow and partitioning in fractures.

The uncertainty in matrix permeability in the zeolitic units resulted in travel times that could differ by several thousand years. Sorbing tracers traveling through the zeolitic matrix were retarded more if the permeability was increased, but little difference was observed if the permeability was decreased. Because the matrix permeabilities in low-permeability units is likely to be less than the reported values because of excluded "nondetect" values, the uncertainty associated with matrix permeabilities may not significantly impact overall performance.

The DOE believes that the most important need in the mountain-scale, UZ flow modeling is a better representation of localized channeling of flow, and in particular, the effects of flow in discrete fractures. The current approach uses continuum models with very coarse spatial discretization, and the adequacy of this approach is not fully established. There are indications from geochemical and isotopic tracers (chloride concentration, ^{36}Cl-to-chlorine ratio and ^{14}C-to-carbon ratio) that channeling of flow might be important. In addition, geochemical, isotopic and temperature data should be integrated into be calibration procedure because such data provide important information about flow through fractures.

The DOE also believes that more information is needed about the role of perched water in UZ flow. The current model assumes that the water is perched on a very-low-permeability underlying layer and flow is forced to go around it. The DOE notes that other interpretations are possible, such as mixing within the perched water and matrix flow out the bottom.

Thermal alterations of flow and thermal hydrology (TH)-chemical or TH-mechanical alterations of hydrologic properties are potentially important. In the current TSPA structure, these effects fall under the TH-component, but it is necessary to determine whether there should be a coupling of TH effects on mountain-scale, UZ flow and transport.

The DOE technical recommendations for improvement of the current mountain-scale UZ-flow model include the following:

- Incorporation of the most recent version of the integrated site model (site geologic framework model)
- More refined numerical grid
- Additional data to gain better estimates of fracture-hydrologic parameters
- Additional inhibition tests of hydrologic properties of the matrix
- Additional measurements of permeability of the zeolitic hydrogeologic units and properties of faults
- Additional studies to better characterize and understand the effects of perched-water
- Creation of heterogeneous property sets that take advantage of the heterogeneous distributions provided by Rautman and McKenna (RAU97) and a stochastic representation of the parameter fields in the site-scale UZ model

Fracture-flow processes should be further investigated with alternative conceptual models and additional field studies, such as niche and alcove studies, the planned east-west cross drift, and the Busted Butte transport study. Other flow processes that need to be further characterized include flow through faults, flow between disparate units (such as at the Paintbrush nonwelded—Topopah Spring welded and Calico Hills vitric—Calico Hills zeolitic interfaces), and fracture/matrix interactions. Finally, the process of model calibration can be further improved by developing two-dimensional and three-dimensional calibrations against field data, which may require using parallel computing techniques.

Seepage

The abstracted base-case seepage model was based on a large number of three-dimensional process-model calculations. The process model consisted of a three-dimensional heterogeneous fracture-continuum field. Three blocks of dimensions 20-m high, 15-m wide and 16.5-m long were evaluated independently within this continuum. The drift was represented by a horizontal open cylinder of diameter 5 m at the center of the lower part of the block. Simulation grid cells were defined to be 0.5 x 0.5 x 0.5 m. Fracture properties were obtained from air-permeability tests of the DST in the ESF Thermal Test Alcove 5 and from evaluation of fracture surveys in the ESF. As a conservative estimate, matrix flow was neglected in seepage simulations used for TSPA-VA, and sensitivity studies were performed to evaluate the effects of fracture-matrix interactions. Sensitivity studies were also performed to determine the effects of episodic pulses, variations to hydrologic properties, and grid refinement.

The process-model results were abstracted by fitting the calculated seepage-fraction and seep-flow-rate distributions with beta probability distributions for which the mean and standard deviation are functions of percolation flux in the fractures. The seepage process model has been tested against recent preliminary data from the ESF niche liquid-release tests, and appears to fit them reasonably well. Finally, seepage sensitivity studies were performed to investigate reduced variance of fracture properties and variations to the fracture aperture.

Seepage into the drifts has a significant impact on performance for several reasons. Seepage controls waste-package degradation because the waste-package corrosion resistance material (Alloy 22) corrodes only in the presence of liquid water. Following the creation of openings through the waste package wall, the seepage volume controls the amount of water that can enter the waste package and dissolve the waste form. The flux of water into and through the waste package in turn controls the release rate of the solubility-limited radionuclides from the waste package. The impact of seepage on overall performance has been found to be important for periods ranging from 10,000 years to 1 million years.

The DOE has identified a number of additional studies that can be addressed in the near future (or are already underway) that the DOE believes will produce realistic and useful results for TSPA-LA. They are listed below:

- One of the key factors that control the spacing between drip seepage locations is the correlation lengths of spatial heterogeneity of the rock unit. The DOE recommends that a further careful study of the fracture distribution along the ESF should be made to provide estimates of these parameters. Field data from the ESF niche study can also yield important information related to this factor.

- The DOE indicates that a more comprehensive parameter-sensitivity study should be made, including sensitivity of drift seepage to the width of the permeability probability distribution function and the spatial correlation lengths of the heterogeneous fields. The occurrence of special features, such as long fractures intercepting the drift, should also be studied. The range of situations and property values used should be representative of the three stratigraphic units in which the potential repository will reside.

For reliable results, the DOE believes that the study needs to be performed with more realizations in the sense of a stochastic analysis and with potentially finer grids. Previous sensitivity studies have indicated that seepage may increase with finer grids.

- Gravity-driven flux in near-field discrete fractures close to the drift wall may increase the probability of drift seepage. Additional study of this possibility is needed.

- The DOE recommends that further study on successive percolation pulses should be carried out, especially since the current calculations seem to indicate that the time frame for the system to recover to its original initial state after the first pulse is very long, perhaps as long as hundreds of years.

The ESF niche test is an important first step in verifying seepage models, but the DOE notes that it is primarily a test of the overall conceptual model of the drift opening acting as a capillary barrier. The test offers little validation of the calculated values of seepage fraction, which the TSPA results show to be the most important aspect of seepage—indeed, the most important aspect of repository performance. Seepage fraction, or the fraction of waste packages contacted by seepage water, is related to the average spacing of seeps along the drift, which is presumably related to quantities such as fracture and fault spacing, permeability distribution, and permeability correlation length. Data on these quantities are needed, but the DOE notes that field data relating them to seep spacing are required in order to gain confidence in the model.

Even more so than for mountain-scale flow, seepage into drifts is potentially strongly affected by channeling of flow and discrete fracture effects. The DOE believes that the adequacy of the current fracture continuum model to represent these effects must be examined, and the DOE further asserts that the only real way to assess its adequacy is by testing it against field data. The DOE suggests that the model could be tested against observed seep spacing at analogue sites such as Rainier Mesa or Apache Leap. The DOE also recommends that additional niche tests should be conducted in all three repository hydrogeologic units--Topopah Spring, Lower Lithophysal, Topopah Spring Lower Nonlithophysal, and Topopah Spring Middle Nonlithophysal (where the first niche test was conducted)--in the east-west cross drift. The main

ESF tunnel does not go through the Topopah Spring Lower Nonlithophysal, but the east-west cross drift is designed to go through all three hydrogeologic units of the repository.

A potentially important issue identified by the DOE that was not addressed is the stability of seep locations over time. In the present models, seeps are assumed to occur at the same locations indefinitely, so that a fraction of the waste packages is always wet (the seepage fraction) and the rest are always dry. If seep locations change with time, more waste packages would be contacted by seeps, but only for a fraction of the time. This effect could result in more waste packages failing, but over a longer period of time, which could be important for performance. Thus, the DOE believes that the consequences of seep movement should be investigated.

Additional needs identified by the DOE are assessments of the effects of episodic percolation pulses, the potential increase in seepage during drainage of thermally mobilized water, the effects of chemical or mechanical alterations in hydrologic properties around the drifts, and the effects of drift collapse or emplacement of backfill.

VI.1.1.20 Unsaturated Zone Transport

Transport from a potential repository source is affected by the sorptive interactions with the rock and the degree of contact between radionuclides and the rock matrix. Some radionuclides, such as ^{99}Tc, do not sorb. Other radionuclides, such as ^{237}Np, move at a slower rate than a nonreactive tracer due to moderate sorptive interaction with various rock types. Still others, such as aqueous ^{242}Pu are found to strongly interact with all rock and, therefore, are relatively immobile. Nevertheless, sorptive interaction is only one part of the mechanism needed to retard the movement of radionuclides. Radionuclides that are transported through fractures cannot sorb onto the rock matrix without some mechanism that allows the radionuclides to contact the rock matrix. (Although the DOE believes that sorption onto minerals along fracture surfaces is likely, difficulty in characterization of this sorption mechanism has lead to the conservative assumption used for the TSPA-VA of no sorption in the fractures.) For example, many radionuclides have been found to strongly sorb to zeolitic rock. However, highly zeolitized rock generally has low matrix permeability, and in some cases, low fracture permeability as well. The low-permeability character will lead to transport pathways that bypass the zeolitic minerals, due to lateral diversion or transport through fractures, severely limiting the degree of contact between radionuclides and zeolitic minerals. Therefore, low levels of zeolitic alteration in the CHn vitric, which do not severely reduce matrix permeability, are found to have more influence on the transport of sorbing radionuclides. The effects of lateral diversion and focused flow in certain regions of the potential repository also tend to reduce the degree of contact between radionuclides and both the CHn vitric and zeolitic rocks. The more evenly distributed percolation flux in the TSw allows for more intimate contact of radionuclides with rock matrix, through matrix diffusion and advection, despite the low matrix permeabilities of the TSw.

Sorptive interactions may enhance radionuclide transport if the aqueous species sorbs to mobile colloids. Colloid-facilitated transport enhances the movement of the aqueous species because the sorptive interaction with matrix is reduced (hence reducing retardation in transport) and colloids may tend to move preferentially through the higher-velocity fracture pathways. In addition to reversible, sorptive type interactions with colloids, radionuclides may also be irreversibly attached to colloids (e.g., coprecipitation during colloid formation). Isotopes of Pu have been identified as radionuclides that are likely to be affected by colloid-facilitated radionuclide transport.

Radionuclides that have little or no sorptive interaction with the welded tuff matrix are expected to migrate through the TSw relatively quickly due to advective transport along fractures. The nonsorbing radionuclides travel primarily through fractures except for transport through the CHn vitric, where matrix flow and transport is expected to dominate. Therefore, transport times to the water table for nonsorbing radionuclides such as ^{99}Tc, and ^{129}I are primarily governed by transport in the CHn vitric.

Another factor that affects travel time to the water table is the lateral diversion of flow above the CHn. Although the lateral diversion increases the transport path length to the water table, the transport pathways are primarily fracture pathways. The diverted percolating flow eventually finds some pathway to the water table. Therefore, lateral diversion can lead to zones of focused flow to the water table, where the flow rates may be locally magnified well beyond the flow rates anticipated for uniform vertical percolation. The travel times for radionuclides transported through a focused percolation zone will tend to be relatively short, including transport through the CHn vitric.

The separation of UZ radionuclide transport from UZ flow is a process abstraction used by the DOE for sensitivity studies and development of the TSPA-VA UZ radionuclide transport model. The DOE combined the two processes in TSPA-VA calculations by using a set of pre-calculated, three-dimensional, UZ flow fields computed with the site-scale UZ flow model. These flow fields are incorporated directly into the 3-D, UZ radionuclide transport model for TSPA-VA.

The waste heat released in the potential repository influences UZ flow and temperature behavior. As for UZ flow, the separation of thermal hydrology and UZ radionuclide transport is a process abstraction. Since the DOE assumes that the thermal-hydrologic effects of the repository do not result in any permanent changes to the mineralogic or hydrogeologic conditions of the UZ, then the effects of the UZ temperature processes on radionuclide transport are assumed to the minor. The DOE's modeling of this process suggests that the time period during which the temperature and flow fields are significantly perturbed occurs prior to the release of most of the radionuclides. Therefore, the DOE has assumed that the thermal-hydrologic effects on the UZ temperature and flow fields have a negligible influence on radionuclide transport. However, the DOE points out that the effects of thermal-hydrology are still important for defining the behavior of the waste package and radionuclide releases from the engineered barrier system. Therefore, thermal-hydrology is included for these subsystem models.

The DOE also notes that the effects of thermal perturbations can also potentially have long-term consequences relative to minerals in the UZ and change both hydrogeologic and transport properties of the system. These types of thermal-hydrologic changes to the system may affect long-term radionuclide transport in the UZ. Although the DOE indicates that their present evaluation of these coupled processes is not complete, they have conducted sensitivity calculations concerning off-normal behavior to address this coupling.

The waste form mobilization process provides the radionuclide fluxes at the emplacement drift boundary for UZ radionuclide transport calculations. The emplacement drift boundary represents a spatial-domain abstraction interface between processes that affect radionuclide transport inside the emplacement drift and radionuclide transport in the UZ. Therefore, the radionuclide fluxes calculated at the emplacement drift wall are a source term for UZ radionuclide transport calculations. The DOE expects this source term to provide radionuclide fluxes at the emplacement drift boundary that will vary as a function of the location in the repository and time.

Saturated zone flow and radionuclide transport calculations use the results of the UZ radionuclide transport calculation to assess the migration to the accessible environment. The water table in the vicinity of the potential repository represents a spatial-domain abstraction interface between processes that affect radionuclide transport in the UZ and SZ. The radionuclide fluxes calculated at the water table due to UZ radionuclide transport are a source term for SZ radionuclide calculations. This source term is expected to provide radionuclide fluxes at the water table that will vary as a function of position on the water table and time. Although the DOE has used no feedback mechanisms between SZ radionuclide transport and UZ radionuclide transport, the position of the water table is recognized as a feedback from SZ flow to UZ radionuclide flow and transport.

Advection

Advection is the movement of dissolved or colloidal material because of the bulk flow of a fluid, which in this case is water. This key transport mechanism can carry radionuclides through the approximately 300 m of unsaturated rock between the potential repository and the water table. Advection is also an important mechanism for radionuclide movement between fractures and rock matrix. In many of the hydrogeologic units, advection through fractures is expected to dominate transport behavior, primarily because the expected flow rates through these systems exceed the matrix flow capacity under a unit gravitational gradient. Advection through fractures is fast because of high permeability and low porosity, with few opportunities for radionuclides to contact rock matrix. A few of the hydrogeologic units have much larger matrix permeability and are expected to capture most of the fracture flow by advection from the fractures to the matrix, causing much slower transport velocities and closer contact of the radionuclides with the matrix. Advective transport pathways result from and therefore follow the flow pathways, which are predominately downward. However, lateral diversion is expected along hydrogeologic unit contacts having strong contrasts in rock properties, particularly in areas of perched water. Flow that is diverted laterally ultimately finds a pathway to the water table through more permeable zones which may be faults.

The detailed geometry of fractures and matrix pore spaces at Yucca Mountain is far too complex to be modeled explicitly. On the other hand, it is important to capture the larger-scale spatial variability, such as differences between welded and nonwelded hydrogeologic units, and the differences in fracture and matrix properties at the local scale. To show this variability, the DOE uses a dual-permeability model for fractured rock. In the dual-permeability model, the fractures and matrix are distinct interacting continua that coexist at every point in the modeling domain. Each continuum is assigned its own hydrologic properties such as permeability and porosity, which may also vary spatially. In general, the fractures are modeled as a highly permeable continuum having low porosity while the matrix is modeled as a much less permeable continuum having higher porosity. The dual-permeability model offers a bimodal approximation to the true spectrum of fracture and matrix properties. More importantly, the dual-permeability model can capture the effects of fast pathways for radionuclide transport from the repository to the water table. This feature is an important improvement over single-continuum models.

The conceptual model for UZ transport is strongly tied to the conceptual model for UZ flow. As described above, advective transport because of flow is the main transport mechanism that can move radionuclides from the repository to the water table. Conceptual models for UZ flow are commonly based on a continuum relationship, known as Darcy's law, which relates volumetric flow rate and the gradient in hydraulic potential. In the case of fractured, porous rock such as the volcanic rock that constitutes Yucca Mountain, these continuum relationships are extended to embrace two coexisting continua, fractures and rock matrix, that interact according to the same constitutive relationships that govern flow in a single continuum. From the standpoint of UZ transport, the need for explicit and separate representation of fracture and matrix flow is because of the extreme disparity in transport velocities that can occur in the two continua. Travel times for radionuclides transported to the water table exclusively in fractures are expected to be about 10,000 times faster than travel times for radionuclides moving exclusively in the matrix. In addition, the transport velocities in the fractures may be sufficiently rapid that radionuclide concentrations in the fractures are in disequilibrium with the matrix. For example, a high concentration of radionuclides entering fractures at the repository may penetrate the entire UZ before establishing a uniform, equilibrated concentration in the rock matrix. Therefore, an explicit and dynamic model of transport through fractures and matrix, as well as exchange between the fractures and matrix, is needed to represent the system. The dual-permeability model provides the necessary level of detail to capture the important differences between transport through fractures and matrix. There are other possible approaches to modeling flow in fractures and matrix rock. However, these other models either do not recognize the important dynamic coupling between fractures and matrix, such as the ECM, or are impractical to implement at the field scale, such as the discrete fracture model (particularly for systems with advective transport in the fractures and matrix, such as a dual permeability system). For these reasons, the flow and transport models for the UZ are based on dual permeability.

In general, flow in the UZ is time dependent or transient. One mechanism responsible for this time dependence is the time variations in the infiltration flux at the surface. The time variation of the infiltration flux may be approximated as occurring over short intervals characterized by changes in weather, resulting in episodic transient flows, or over much longer time periods corresponding to climate changes. Existing information concerning episodic transient flow seems to indicate that such flow may not be able to frequently penetrate through the UZ to the level of the repository because of the dampening influence of the PTn hydrogeologic unit. Episodic transient flow propagating through fractures tends to be absorbed by the PTn unit, resulting in much slower drainage of the episodic flows in lower hydrogeologic units at and below the repository level (ROB97, Section 6.13). For these reasons, the DOE has not incorporated episodic transient flows into the TSPA-VA calculations.

Changes in unsaturated flow because of longer-term changes in climate have a more pronounced influence on UZ flow than episodic transient flow. Sustained changes in infiltration associated with climate change ultimately impact the entire flow field in the UZ. The actual transient period during which the UZ flow responds to a climate change, however, has been found to be less significant (ibid.). The reason is that the change in flow in the fractures, which dominates the flux in most hydrogeologic units, responds relatively quickly to a change in infiltration. Therefore, the quasi-steady flow model was used to estimate the effects of climate change on radionuclide transport. In this model, infiltration rate is assumed to change abruptly when climate changes from one steady flow field to another. Transport calculations simply re-start when climate changes. A distributed source of radionuclides throughout the UZ is derived from transport calculations using the flow field for the previous climate, and a new steady state flow field is selected based on the new climate.

In addition to the change in the UZ flow field, the location of the water table is also assumed to change abruptly at the time of climate change. The three climate states—present day, long-term average, and super pluvial—have successively higher water table elevations to response to the increasing infiltration. If the water table rises with the climate change, the radionuclides in the UZ between the previous and new water table elevations are immediately available for transport. In the TSPA-VA model, water table elevations change by 80 m from present-day to long-term-average climates and by 120 m from present-day to super-pluvial climates.

The dominant flow direction is expected to be mainly downward over large scales. However, local flow field variations are expected to be three dimensional. The importance of these variations lies primarily in the kinds of rock units and fracture characteristics that dominate along the 3-D flow paths. A secondary consideration is that 3-D flow paths from the repository to the water table will necessarily be longer than strictly vertical flow paths. 3-D flow patterns are expected along rock unit contacts with contrasting properties, particularly in zones where these contrasts are believed to be features that create perched water. To capture these effects, the DOE has used three dimensions to model the flow and transport. Spatial variability is captured in the 3-D relationships of the hydrogeologic units and structural features, for example, faults, and in the variations in hydrogeologic and transport properties assigned to the hydrogeologic units.

Matrix Diffusion

Diffusion is the movement of dissolved or colloidal material because of random molecular motion. It is not an effective mechanism for transport between the repository and the water table because of the large distance involved (about 300 m). However, diffusion can play an important role in radionuclide exchange between fractures and rock matrix. In this case, molecular diffusion affects the persistence of a dissolved ion in the fracture flow stream. The relative influence of this mechanism on overall transport through the UZ depends on the rate of movement through fractures as well as the degree of fracture/matrix contact.

Bulk diffusive flux occurs when concentration gradients are present because diffusion is driven by random molecular motion. In addition, the matrix diffusion coefficient is a function of the free water diffusion coefficient, temperature, radionuclide mass, atomic or molecular dimensions and charge, as well as the matrix pore structure and water saturation. The temperature variations are expected to be small over the time period for radionuclide releases to the UZ. The effects of pore structure and water saturation have been shown to depend primarily on the volumetric water content of the rock (ROB97). For rock in the UZ, the water content is relatively uniform spatially. Therefore, as a simplification, variations in the matrix diffusion coefficient are assumed to be primarily dependent upon the radionuclide type, that is, mass, size, and charge. In this case, measurements indicate that the primary difference is between cationic and anionic radionuclides (TRI97). Anionic radionuclides have lower matrix diffusion coefficients than cationic radionuclides; that is, they are transported more slowly by diffusion. Lower coefficients for anionic radionuclides are believed to be a result of size and charge exclusion of the anionic radionuclides from a portion of the pore structure. The surfaces of the pore minerals are generally negatively charged under the chemical conditions of the undisturbed environment.

In general, the direction of radionuclide transport by matrix diffusion between the fracture continuum and the matrix continuum depends on the direction of the concentration gradient. However, the most important influence of matrix diffusion is expected to be on radionuclide transport through fractures. Radionuclides traveling through fractures are always near the matrix relative to the fracture spacing. This proximity is a result of the fracture and matrix geometry where the ratio of fracture aperture to fracture spacing is small. Also, diffusive penetration of the matrix is proportional to the square root of the fracture transport time. Because of relatively fast transport through fractures, most radionuclides diffusing from fractures into the matrix do not penetrate far, relative to the fracture spacing. For this reason, the DOE expects the effects of fracture spacing on matrix diffusion to be negligible, and ignores the effects of finite fracture spacing. Similarly, because of the relatively small fraction of matrix affected by matrix diffusion (that is, diffusive movement from fractures into the matrix is relatively slow), the DOE makes an approximate representation for fracture transport, including matrix diffusion, separately from the advection of radionuclides through the matrix.

Dispersion

Dispersion is a transport mechanism caused by localized variations in flow velocity. These variations cause dispersion of the radionuclides both along and transverse to the average flow direction. Variations in both the magnitude and direction of the velocity contribute to the overall dispersion. This dispersion, under certain limiting conditions, can act in a manner analogous to diffusion, in which mass flux is proportional to the concentration gradient. Dispersion is most important where concentration gradients are the largest—near the front of a propagating plume or along the lateral edges of the concentration field. Dispersion smears sharp concentration gradients and can reduce the breakthrough time, or arrival time at a specific point, for low concentration levels of an advancing concentration front.

Dispersion is included in the transport conceptual model using a standard relationship based on Fick's law between mass flux and concentration gradient (ROB97). The dispersion coefficient in the Fickian relationship is expressed as the product of the mixing length scale or dispersivity, and the average linear velocity. Dispersion is independently represented in both the fracture and matrix continua. However, the DOE does not expect dispersion to play an important role in the UZ transport. The repository emplacement area is very broad, relative to the distance to the water table, and this geometrical arrangement tends to suppress dispersion effects. Longitudinal dispersion becomes secondary to the explicitly modeled variations in transport velocities across the repository because of variations in infiltration. Lateral dispersion is limited by the short transport path from the repository to the water table compared with the size of the source. Also, the explicitly modeled variations in transport velocity caused by the fracture/matrix system tend to dominate dispersion.

Radionuclide Sorption

Sorption is the general term for describing a combination of chemical interactions between the dissolved radionuclides and the solid phases (that is, either the immobile rock matrix or colloids). Any given sorptive interaction is caused by a set of specific chemical interactions such as surface adsorption, precipitation, and ion exchange. However, the sorption approach does not require identifying the specific underlying interactions. Instead, batch sorption experiments are used to identify the overall partitioning between the aqueous and solid phase, characterized as a "sorption" or distribution coefficient (K_d). The strength of the sorptive behavior is a function of the chemical element, the rock type involved in the interaction, and the geochemical properties of the water contacting the rock. Sorption reduces the rate of advance of a concentration front in advective and diffusive transport, and amplifies the diffusive flux of radionuclides from the fractures to the rock matrix through its influence on the concentration gradient.

Numerous rock-water chemical interactions may influence radionuclide transport (TRI97):

- *Ion adsorption* —metal cations sticking to mineral surfaces due to London-van der Waals forces and hydrogen bonding
- *Ion exchange* —substitution of an aqueous cation for the anion in a mineral structure
- *Surface complexation* —coordination of an aqueous cation with a deprotonized metal hydroxide at the mineral surface
- *Precipitation*—generation of a bulk solid phase

The nature and strength of these rock-water interactions are highly dependent on the chemical composition of both the aqueous and solid phases. The conceptual model used to capture all these interactions and sensitivities is the minimum K_d model. This model bounds the distribution of radionuclides between the mobile, or dissolved in the aqueous phase, and immobile, or attached to the solid phase, using a linear, infinite-capacity partitioning model. In this model, the sorbed, or immobile, concentration is equal to the aqueous concentration times the partitioning coefficient. Because of the numerous mechanisms and dependencies known to influence sorption, using a linear partitioning model with a single coefficient provides only a minimum bound for K_d, and hence the immobilized fraction.

Colloid Facilitated Transport

Colloids are potentially mobile in water flowing though the UZ. Since colloids are small solids they can interact with radionuclides through sorption mechanisms. Unlike sorption of radionuclides to the rock matrix, however, radionuclides sorbed on colloids are potentially mobile. Therefore, colloidally-sorbed radionuclides can be transported through the UZ at a faster rate than the aqueous species without colloids. Another form of colloidal radionuclide movement occurs when the radionuclide is an integral component of the colloid structure. In this case, the radionuclide is irreversibly bound to the colloid, as compared to the typically reversible sorption mechanism. The different types of colloids considered in the performance assessment model are clay colloids, iron oxy-hydroxy colloids, spent fuel waste form colloids, and glass waste form colloids.

Thermal-Hydrologic, Thermochemical, and Thermomechanical Processes

The potential repository will perturb the natural system due to the introduction of waste heat and foreign materials. Thermo-hydrologic modeling is done for TSPA-VA to better define the temperature, humidity, and water contact conditions that will affect waste package corrosion, waste form dissolution, and radionuclide releases from the engineered barrier system. The thermal-hydrologic conditions also affect the flow field, and hence the radionuclide transport, through the UZ. However, the thermal-hydrologic process is most significant over the first 2,000 to 3,000 years following waste replacement. Sensitivity studies indicate that most of the radionuclide transport through the UZ will take place after thermal-hydrologic activity has subsided. Thermal-hydrologic processes are not expected to substantially alter UZ radionuclide transport as compared to transport through the undisturbed system. Therefore, the DOE has not incorporated the effects of thermal-hydrologic processes in the UZ radionuclide transport model.

TSPA-VA Approach

Unsaturated zone radionuclide transport calculations are computed using the particle tracking method available in the unsaturated flow and transport code FEHM. This computational method for UZ radionuclide transport is dynamically linked with the TSPA's RIP code for these calculations. A 3-D, dual-permeability model is used for computing radionuclide transport in a fracture/matrix system. Three-dimensional, steady, UZ flow fields, computed with the unsaturated flow code, TOUGH2, are used for the particle tracking transport calculations.

Changes in the flow field due to climate change are accounted for through a quasi-steady flow and transport approximation. The transport model includes the effects of fracture/matrix interaction driven by advective and diffusive exchange between the fracture and matrix continua. The transport model includes the effects of radionuclide sorption in the rock matrix using a bounding, minimum K_d modeling approach. Colloids are included as a mechanism for the transport of plutonium. The model for aqueous plutonium transport allows for reversible sorption of plutonium on colloids. Plutonium releases from the EBS also include a fraction plutonium irreversibly sorbed to colloids.

Radionuclide mass flux at the EBS boundary is provided by RIP for the UZ radionuclide transport calculations. The radionuclide mass flux from any source within a potential repository region is distributed uniformly over the computational grids for fracture nodes in the transport model that lie within the region. Radionuclide mass flux at the water table from the fracture and matrix continua are mixed in a RIP cell and provided to the SZ radionuclide transport model.

The model for unsaturated radionuclide transport incorporates several assumptions. The primary conservative modeling assumptions are no fracture sorption and no colloid filtration. These assumptions clearly result in model predictions having more rapid migration of radionuclides through the unsaturated zone. Assumptions about the influence of thermal-hydrologic-chemical processes, fracture spacing in the matrix diffusion model, and fracture/matrix contact in the matrix diffusion model, are potentially nonconservative.

Long-term Transient Flow and Climate Change

An approximate method was developed for computing UZ radionuclide transport under the long-term transient flow conditions associated with climate change. The approximation was developed due to the computational burden associated with the complete transient flow and transport calculation. The method is based on a quasi-steady flow approximation, in which the flow fields instantaneously change from one steady flow field to another in response to changing infiltration rates caused by climate change. The transport calculations restart upon change in climate using the new flow and water saturation distributions. Radionuclides present in the UZ at the time of climate change are also restarted as a distributed source of radionuclide mass in the UZ flow and transport grid. The method is shown to provide an excellent approximation to the complete unsaturated transient flow and transport problem resulting from climate change.

Colloid-Facilitated Radionuclide Transport

An approximate computational method was developed to treat the effects of radionuclide interactions with colloids. This method is applied in the TSPA-VA calculations to the problem of plutonium transport. Previous TSPA analyses did not include the effects of colloid-facilitated radionuclide transport. The treatment addresses two types of colloidal interactions with plutonium: reversible sorption between aqueous and colloidal plutonium and plutonium irreversibly attached to colloids. For reversibly sorbed plutonium, the approximate colloid facilitated transport method assumes linear, equilibrium partitioning of aqueous and colloidally-sorbed fractions. Colloid movement is represented by advective transport in fractures or matrix with no diffusion of colloids between fractures and matrix, and no colloid filtration.

Unsaturated Zone Radionuclide Transport Sensitivity Investigations

The DOE performed additional sensitivity studies to provide a better understanding of transport parameter sensitivity, identify the range of conditions under which a K_d sorption model may be used to bound geochemical interactions, investigate the effects of episodic transient flow on radionuclide transport, and investigate the effects of fine-scale mineralogic heterogeneity.

DOE Conclusions

The results of investigations into radionuclide transport through the UZ lead the DOE to conclude the following:

- For present-day climate, the average travel time for nonsorbing radionuclides released from the northern portion of the repository is on the order of a thousand years, but for the wetter long-term average climate, the average travel times are tens of years.

- For present-day climate, the average travel time for nonsorbing radionuclides released from the southern portion of the repository is several thousand years, but for the wetter long-term average climate, the average travel time is hundreds of years.

- For most of the mass of strongly sorbing radionuclides, such as plutonium, arrival at the water table is delayed tens to hundreds of thousands of years. Radionuclides that reversibly sorb onto colloids are also delayed; however, irreversibly bound radionuclides may behave as nonsorbing radionuclides.

- Matrix diffusion has little effect on transport of nonsorbing radionuclides. However, combining matrix diffusion with sorption significantly retards radionuclides compared with sorption and no matrix diffusion.

- The TSw unit is the primary barrier to radionuclide transport because of slower fracture transport in this unit compared with the Calico Hills zeolitic unit, and its greater thickness and continuity compared with the Calico Hills vitric unit.

- Alternative flow models like the dual-permeability model with Weeps modeling, which have smaller coupling strengths for effective fracture/matrix contact area, increase fracture-dominated transport, particularly for sorbing radionuclides. However, the magnitude of this effect is not large for weakly sorbing radionuclides.

The following items are viewed by the DOE as the areas where additional work would provide the greatest improvements in the comprehensiveness and credibility of the radionuclide transport model in the UZ:

- Effects of Thermal, Hydrologic-Chemical Alteration—The current model does not account for alteration of the UZ because of thermal alteration of minerals, chemical interactions of repository materials, mineral dissolution, and precipitation. These effects are potentially important to transport behavior in the UZ and need to be addressed. Thermal-chemical alteration could cause reduced matrix sorption and fracture-matrix interaction. These effects could cause increased release rates from the UZ for base case transport results; however, it is expected that existing sensitivity studies bound most of these potentially nonconservative interactions.

- Colloid Filtration—The ability of colloids to facilitate radionuclide transport is a function of their ability to migrate over large distances without being "filtered out" by the host rock. This filtration effect was not included in the TSPA because of inadequate information to bound the mechanism. The filtration effect is particularly important for the fraction of radionuclides that are irreversibly bound to colloids. However, the assumption that there is no colloid filtration is conservative for transport in the UZ.

- Fracture Sorption—The effects of higher infiltration determined in the TSPA-VA guarantee that transport will be fracture-dominated in many of the unsaturated-zone units. Minerals that line fractures are known to sorb radionuclides, but more information is needed to define the distribution and character of the fracture materials so that sorption on fracture surfaces may be included. However, the assumption that radionuclides do not sorb onto fracture surfaces is conservative for transport in the UZ. Although the present sensitivity studies have found that transport is not highly sensitive to fracture sorption, this result requires further investigation to better define the appropriate range of parameters for fracture sorption.

VI.1.1.21 Expert Elicitation and Peer Review Panel

The Yucca Mountain project conducted a UZ Flow Model Expert Elicitation, in which project data and models were presented to a group of experts (mostly from outside the project) so that they could provide an evaluation of the work being done (CRW97). Particular emphasis was placed on estimates of surface infiltration, deep percolation, and the uncertainties associated with each. Each expert estimated probability density functions (PDFs) of infiltration. The mean values of their estimated net infiltration ranged from 3.9 mm/yr to 12.7 mm/yr, and the mean values of their estimated percolation flux at the repository horizon ranged from 3.9 mm/yr to 21.1 mm/yr. These values are commensurate with the simulated average present-day infiltration over the modeled repository (~8 mm/yr) and the simulated average percolation fluxes within the six prescribed repository subregions for the present-day base case (3.9 mm/yr to 11 mm/yr) of TSPA-VA.

Additional topics that were covered during the expert elicitation included spatial variability of net infiltration and percolation flux, temporal variability of infiltration and percolation flux, lateral diversion above the repository, partitioning of fracture and matrix flow, seepage into drifts, modeling issues, and additional data and work requirements. The experts generally agreed that the infiltration map that was used in TSPA-VA captures the general spatial variability of infiltration, but several suggested that more infiltration could occur beneath washes with thin alluvial cover. The experts also agreed that temporal behavior of net infiltration was characterized by episodic events associated with major storm events, but that most of the transient flux was attenuated within the system. With regard to lateral diversion above the repository, most of the expert agreed that contrasts in the hydrologic properties between units would likely cause lateral flow, particularly in the Tiva Canyon welded unit - Paintbrush Turf nonwelded unit contact, but that the amount of diversion was limited to scales of several meters to tens of meters. This is consistent with the results of the TSPA-VA UZ-flow simulations, which show nearly vertical flow above the repository. The experts did not address the issue of lateral diversion caused by perched water below the repository. The experts also estimated that, based on the low matrix permeabilities in the Topopah Spring welded unit, partitioning of flow in the TSw was predominantly in the fractures. Also, the fast-flow component likely represents only a small part of the total flux. This is consistent with simulated results in TSPA-VA. With regard to seepage into drifts, the experts agreed that a capillary barrier will exist around the drifts, diverting a majority of the water around the area of the drifts. This behavior is also consistent with the TSPA-VA simulations for seepage. Finally, the experts recommended a number of additional modeling and data-collection activities that address estimates of infiltration, percolation, and seepage.

In addition to the expert elicitation, the TSPA-VA Peer Review Panel provided input to the UZ flow activities. They recognized the use of environmental tracers (^{36}Cl) as evidence of fast flow paths between the surface and the repository and recommended its use in supporting the conceptual models of UZ flow. The Peer Review Panel also recommended studies to better understand fracture-matrix interaction. Finally, the Peer Review Panel emphasized the need to better understand seepage into drifts.

VI.2 SATURATED ZONE

VI.2.1 Saturated Zone Modeling

VI.2.1.1 Saturated Zone Flow Model Construction

The transport of radionuclides in the saturated zone away from a repository depends on a wide variety of factors including, but not limited to, ground water and host rock geochemistry; advective ground water velocities; radionuclide concentrations and retardation properties; flux rates of radionuclides from the unsaturated zone; the presence of sorbing materials such as zeolites and clays; rock fracture density; fracture-matrix interaction; future climate changes; and anthropogenic influences. Knowledge of the transport properties in the site-scale and regional flow systems would allow researchers to more completely address four of the most important questions surrounding repository performance and regional ground water flow issues in the area around Yucca Mountain:

- What path would radionuclides from the repository follow?
- How fast and how far would radionuclides travel in the saturated zone?
- Where would radionuclides become accessible to the biosphere?

- What will the concentrations of radionuclides be when they become accessible to the biosphere?

The answer to all of these questions is uncertain. The ability to know or predict the answers to these questions depends on performing sufficient scientific investigations over the study area in order to reduce the associated uncertainties to acceptable levels. Some level of uncertainty will always remain, as it is not possible to completely characterize any underground system.

In order to address these issues, the DOE has performed modeling of the saturated zone at Yucca Mountain at a number of different scales, including: regional, site, and sub-site. The ground water flow modeling activities that are most closely linked to the TSPA-VA are a regional scale model that was developed by D'Agnese et al. (DAG97a), a site-scale model formulated by Zyvoloski et al., (ZYV97), and a sub-site scale model that was completed by Cohen, et. al. (COH97).

The regional-scale 3-D flow model was developed by D'Agnese et al. (DAG97a) to characterize the conditions of the present day ground water flow in the Death Valley region. The modeled area is 244 km long and 229 km wide. The numerical code used for the regional flow model was MODFLOWP (HIL92). MODFLOWP is an adaptation of the U.S. Geological Survey 3-D, finite-difference modular ground water flow model, MODFLOW (MCD88).

A smaller site-scale TSPA three-dimensional flow model was formulated by Zyvoloski et al., (ZYV97) to determine the flowpath from the repository footprint, or outline, at the water table to a distance 20 km downgradient, the approximate distance to the nearest domestic well where ground water is extracted. The computer code FEHM (ZYV83) was used to model an area of 20 by 36 km. Originally, it was intended that the regional scale model be used to provide the boundary conditions for the site scale model. Apparently, the authors of the site-scale modeling (COH97), however, did not believe that the calibration of the regional model was sufficient to provide reliable boundary conditions. Therefore, the regional modeling, from the perspective of the TSPA-VA, was used primarily to determine a ground water flux multiplier for the long-term average and superpluvial climate conditions assumed for the base-case TSPA-VA analysis as will be discussed later in this section.

The sub-site scale model constructed by Cohen et. al. (COH97) was also performed in order to assess the effectiveness of the saturated zone as a barrier to radionuclide transport. However, the sub-site-scale model more accurately captures the faulted and variable-thickness stratigraphy than either the regional or site-scale modeling. Thus, allowing for more detailed modeling of processes that cannot be obtained from larger scale models. As will be discussed later in this section, the sub-site scale model was not as explicitly integrated into the TSPA-VA as the larger-scale models.

Conceptual Model of Saturated Zone Flow

Regional Scale Conceptual Model

The current state of knowledge suggests that ground water beneath the proposed repository moves laterally downgradient until the volcanic aquifer pinches out, at which point it discharges laterally into the alluvial aquifer. Radionuclides dissolved in ground water would potentially follow a similar path. Much of the ground water that enters the alluvial aquifer currently moves southward to the primary discharge location at Alkali Flat. Other actual or potential points of discharge for the system include water wells in the Amargosa Desert and springs in the Furnace Creek Ranch area of Death Valley.

Ground water travel times to any of these locations are not well known. Estimates of ground water travel times can be developed by simple calculations or by more sophisticated numerical modeling. In either case, travel time calculations are based on hydraulic gradient, hydraulic conductivity, and effective porosity of the formation through which the water is flowing. Of these three parameters, hydraulic gradients are probably the best known and most easily measured.

D'Agnese et al. (DAG97a) formulated a conceptual model of the Death Valley regional ground water flow system by integrating interpretations of flow system components. Their discussion of the flow system dynamics includes a description of regional, subregional and sub-basin boundaries, as well as the source, occurrence, and movement of ground water in the system. The most pertinent aspects of that discussion are summarized below.

Flow System Boundaries. The Death Valley regional flow system consists of ground water moving through a three-dimensional body of consolidated and unconsolidated materials. The flow system boundaries may be either physical boundaries, caused by changes in bedrock conditions, or hydraulic boundaries, caused by potentiometric surface configurations. The upper boundary of the flow system is the water table. The lower boundary of the flow system is located at a depth where ground water flow is dominantly horizontal and moves with such small velocities that the volumes of water involved do not significantly impact regional flow estimates. The lateral limits of the regional flow system may be either no-flow or flow boundaries. No-flow conditions exist where ground water movement across the boundary is prevented by physical barriers or divergence of ground water flow paths. Flow boundaries exist where ground water potentiometric gradients permit flow across a boundary through fractures or higher permeability zones.

Regional Boundaries. The lateral boundaries selected for the flow system were modified from those described by Waddell et. al. (WAD84). Most system boundaries are no-flow boundaries that result from the presence of low-permeability bedrock. Flow boundaries occur where bedrock has a high enough permeability to allow significant ground water fluxes to enter the system and where a hydraulic gradient exists across the boundary. Faulting and fracturing most frequently cause the enhanced permeability, and ground water flow may occur at various depths through open regional fracture zones. Based on potentiometric and hydrogeologic framework data, areas where inflow may occur from are Pahranagat Valley, Sand Spring Valley, Railroad Valley, Stone Cabin Valley, Ralston Valley, Fish Lake and Eureka Valleys, Saline Valley, Panamint Valley, Pilot Knob Valley, and Soda Lake Valley. Good estimates of flow across these lateral flux boundaries do not exist except for Pahranagat Valley, which has been estimated by Winograd and Friedman (WIN72) to be approximately 20,000 m^3/d. The remaining areas have very little data required to estimate flux volumes; however, the authors (DAG97a) believe that flux across these boundaries should not be dismissed without further investigation.

The flow system boundary in northern Las Vegas Valley near Corn Creek Springs results from the presence of a ground water divide. Ground water recharging from the Sheep and Spring Mountains forms a ground water divide that extends across the valley and separates flow that moves southeast toward Las Vegas Valley from flow that moves to the northwest toward Ash Meadows in the Amargosa Valley.

For numerical simulation, the flow system was subdivided into three subregions that represent the areas where regional ground water flow moves from recharge areas in Nevada toward Death Valley saltpan, the ultimate terminus of the system. Local recharge along the southern boundary of the system and subsurface inflows along parts of the southeastern and southern boundary of the system were not included in the simulation. These model boundaries are based on previously defined flow system boundaries, the potentiometric surface developed for their modeling study, and the hydrogeologic framework. The authors (DAG97a) comment that few data exist that would allow a precise definition of the western and southern extent of the flow system. The western boundary of the flow system is placed to coincide with the eastern edge of the Death Valley saltpan, which is interpreted as the terminal sink of the flow system. Although some ground water that originates on the west side of Death Valley may discharge into the saltpan, this discharge is mostly at Mesquite Flat and is a small volume compared to the contribution from the east (PRU93).

<u>Subregional Boundaries</u>. To define the subregional boundaries, the Death Valley regional ground water flow system was divided into three major subregional flow systems. The names of the subregions reflect the part of Death Valley into which each discharges. For example, the Northern Death Valley subregion discharges into the northern part of Death Valley at Grapevine and Staininger Springs and Mesquite Flats. The Central Death Valley subregion predominantly discharges into the Saratoga Springs area at the southern terminus of Death Valley.

Ground water is thought to flow across the subregional boundaries in three places: (1) across the southeast border of the Central Death Valley subregion from the Amargosa Desert into the Lower Amargosa Valley in the Southern Death Valley subregion; (2) from the Northern Death Valley subregion across a boundary at Salt Creek Springs (just south of Mesquite Flat) into the Central Death Valley subregion; and (3) at the southern end of Death Valley, ground water that has not discharged in the Saratoga Springs area may continue to flow northward from the Southern Death Valley subregion across the subregion boundary to discharge at Badwater Basin in the Central Death Valley subregion.

<u>Numerical Modeling Difficulties and Simplifying Assumptions</u>. The authors (DAG97a) pointed out that previous studies by Prudic et. al. (PRU93) and Waddell (WAD82) showed that it is difficult to utilize computer models to effectively describe ground water flow in an area as geographically large and geologically complicated as the Death Valley region. Prudic et. al. (PRU93) reiterated that many arguments can be invoked concerning the validity of the assumptions and hydrologic values used in simulating ground water flow when such complex geology and hydrology are involved.

In any modeling investigation, it is inevitable that simplifications and assumptions must be used to adapt the complex conceptual model for numerical simulation. The assumptions and simplifications used to develop the Death Valley Regional Flow System (DVRFS) model include the following:

- Ground water in the region flows through fractured volcanic and carbonate rocks, as well as in porous valley-fill alluvium. However, fracture flow simulation is impractical at a regional scale, and, therefore, a porous medium simulation is used. Zones of high hydraulic conductivity are used to account for highly faulted and fractured regions.

- Hydraulic conductivities within each model cell are assumed to be homogeneous and horizontally isotropic. Thus, features smaller than the grid cells are not represented. The authors (DAG97a) believe that this approach is likely to produce reasonable approximations to large-scale flow patterns. Small-scale flow paths, however, are not represented.

- The system can be represented adequately as steady state. Four conditions exist that may violate this assumption. First, the regional flow system still may be undergoing a drying-out sequence following a wetter climate cycle related to the late Pleistocene (PRU93). As a result, current ground water levels and discharge rates may not be in equilibrium with present-day recharge and interbasinal flux rates. Second, and perhaps more important, ground water withdrawals by wells for domestic, municipal, mining and irrigation uses are imposing new stresses on the present-day system. This pumpage is derived initially from ground water, from storage, and subsequently from capture of natural discharge. Incorporating pumping in a steady-state model omits the possibility of deriving water from storage, so that water flowing to wells must be offset by capture of natural discharge, that is, reductions in discharge or induced inflow. Although a transient simulation beginning at predevelopment conditions would avoid this assumption, additional assumptions would be needed to define historic pumping levels. In addition, some current water-level data and some spring-flow rates already reflect changes to the system resulting from development, suggesting that the DVRFS may have already adapted to these changes. For example, the springs at Pahrump Valley, including Manse and Bennetts Spring, have ceased to flow in historic time. Third, the flow system experiences seasonal fluctuations that are not simulated. A resulting annual average condition is simulated. Fourth, hydraulic-head, spring-flow and other data used in model calibration were collected over an interval of many years, and these data are affected by seasonal and yearly changes to the ground water flow system.

Site-Scale Conceptual Model

The major components of the site-scale conceptual model (ZYV97) are presented below.

Geologic Setting. The conceptualization of the geologic setting by Zyvoloski et al., (ZYV97) which, briefly summarized, is that Yucca Mountain is located in the Great Basin section of the Basin and Range physiographic province, and consists of a group of north-south-trending block-faulted ridges that are composed of volcanic rocks of Tertiary age that may be several kilometers thick. The basin to the west of Yucca Mountain is Crater Flat, which is comprised of a thick sequence (about 2,000 m) of Tertiary volcanic rocks, Tertiary and Quaternary alluvium, and small basaltic lava flows of Quaternary age. Crater Flat is separated from Yucca Mountain by the Solitario Canyon Fault. West of Crater Flat is Bare Mountain, which is comprised of Paleozoic and Precambrian rocks. Fortymile Wash, a structural trough, delimits the eastern extent of Yucca Mountain. East of Yucca Mountain are the Calico Hills, a mottled assemblage of Tertiary volcanic rocks and Paleozoic rocks. Yucca Mountain teminates to the south in the Amargosa Desert, which consists of interbedded Quaternary and Tertiary alluvial, paludal, and tuffaceous sediments.

These rocks and deposits in the vicinity of Yucca Mountain were classified by the authors (ZYV97) into hydrogeologic units based on hydraulic properties. Where possible, hydrogeologic units identified by previous investigators (LUC96, WIN75) were used. Many of the units are not present in the model area and/or are not expressed at the land surface. In all, sixteen hydrogeologic units are present in the model area.

In general, the hydrogeologic units at Yucca Mountain form a series of alternating volcanic aquifers and confining units overlaying the regional carbonate aquifer. The volcanic aquifers and confining units interbed with undifferentiated valley-fill and the valley-fill aquifer to the south, while structural features delimit the eastern and western edges of Yucca Mountain.

Hydrogeologic Setting. The hydrogeologic framework briefly described by the authors (ZYV97) is that Yucca Mountain is centrally located within the Death Valley ground water basin and also is centrally located within the Alkali Flat (Franklin Lake playa)-Furnace Creek subbasin. The subbasin is assumed to receive water from areal recharge within its boundaries and the authors (ZYV97) believe that it probably also receives water as underflow from adjoining subbasins. Depths to water range from about 3 m beneath Alkali Flat (Franklin Lake playa) to about 750 m beneath Yucca Mountain. Ground water beneath Yucca Mountain flows generally toward the south through fractured volcanic rocks which interfingers with Quaternary and Tertiary valley-fill in the Amargosa Desert.

The climate is arid to semiarid, with Yucca Mountain receiving annual precipitation between 150 mm to 200 mm (HEV92). As a result, stream flow is infrequent and occurs following intense precipitation events which can be very localized. There are no perennial streams.

Vertical Gradients. As is discussed later in this section, the ability to reproduce and understand the vertical flow gradients between hydrostratigraphic units will be an important aspect of model calibration. Therefore, the authors (ZYV97) believe it is important to include them as an explicit component of the conceptual model. The authors (ZYV97) remark that Luckey et. al. (LUC96) examined the vertical relationship of hydraulic head at Yucca Mountain, and found "no unambiguous areal patterns in the distribution of vertical hydraulic gradient around Yucca Mountain." However, they also make the following generalizations as to the distribution of potentiometric levels in the lower sections of the volcanic rocks. Potentiometric levels in the middle volcanic confining unit are relatively high (altitude greater than 750 m) in the western and northern parts of Yucca Mountain and are relatively low (altitude about 730 m) in the eastern part of Yucca Mountain. Based on potentiometric levels that were measured in borehole UE-25 p#1, the potentiometric levels in the middle volcanic confining unit in boreholes USW H-l, USW H-3, USW H-5, and USW H-6 may reflect the potentiometric level in the carbonate aquifer. It is also noted that boreholes UE-25 b#1 and USW H-4 do not seem to fit the pattern established by the other boreholes. Potentiometric levels generally are higher in the lower intervals of the volcanic rocks than in the upper intervals, indicating a potential for upward ground water movement. However, for unknown reasons, at four boreholes (USW G-4, USW H-1, USW H-6, and UE-25 b#1) potentiometric levels in the volcanic rocks are higher in the uppermost intervals than in the next lower intervals.

The potentiometric levels in the Paleozoic carbonate aquifer at borehole UE-25 p#1 are about 21 m higher than in the overlying volcanics. Therefore, a potential for upward ground water movement from the Paleozoic rocks to the volcanic rocks is indicated. Because of the large difference in potentiometric levels in these two aquifers, Luckey et. al. (LUC96) conclude that they seem to be hydraulically separate. This conclusion appears to be supported by hydrochemical data. However, some of the analyses of hydraulic-test data at the C-hole complex indicate a possible hydraulic connection between the volcanics and the carbonate aquifer at the C-hole complex (GEL96). Hence, the vertical hydraulic gradients represent a complex three-dimensional flow system that is not completely understood. Little information is available for vertical gradients away from Yucca Mountain. A more detailed discussion of data limitations and modeling needs will be presented later in this section.

Steady-state Conditions. A comprehensive analysis of water levels from all observation wells at Yucca Mountain (GRA97) shows the fluctuations of water levels for the period 1985 to 1995. The authors (ZYV97) concluded that, in general, most wells at Yucca Mountain show less than 1 meter difference between the maximum and minimum values of water-level altitude during this period. The authors (ZYV97) further conclude that the preponderance of wells with small water level changes and the small fractional changes in saturated thickness at wells with greater changes indicates that assuming that the flow system is at steady state at Yucca Mountain is a reasonable approximation. It should be noted that the modelers simulating the regional scale model (DAG97a) expressed some concern with assuming that the system is or would remain at steady state, and outlined four conditions that exist which may violate this assumption.

Zyvoloski et al., (ZYV97) do discuss, however, that water-level changes have declined by as much as about 10 m (KIL91) in the Amargosa Farms area (southwest corner of the site model) resulting from ground water withdrawals for irrigation. The modelers made no attempt to reconstruct the potentiometric surface for conditions prior to these ground water withdrawals. The potentiometric data dictate a complex three-dimensional flow system, but the authors (ZYV97) have made the following generalizations. There appears to be a general upward gradient from the regional carbonate aquifer into the volcanic rocks. In general, this upward gradient persists in the volcanic rocks. Furthermore, the potentiometric data indicate that most of the flow system is essentially at steady state.

Potentiometric Surface. Because the potentiometric data dictate a complex three-dimensional flow system, a number of different conceptual models of the flow system are possible. In particular, the different conceptual models may result in different potentiometric surfaces. Although the boreholes are open at different depths below the hydraulic head and are open to different geologic zones, water levels in most of the wells appear to represent a laterally continuous aquifer system. The well-connected system may result from the presence of many faults and fractures (TUC95), and, at the scale of the site model, the authors (ZYV97) believe that the ground water flow system may behave as a porous medium. Flow in the volcanic rocks occurs primarily in fractures and secondarily in the matrix of the rock. Therefore, the uppermost aquifer may be unconfined or confined depending upon the areal location of the point being measured (TUC95).

Most of the wells only partially penetrate the hydrogeologic units. This can be important during model calibration because it can lead to significant errors if vertical gradients are large. No attempt was made by the modelers to segregate and analyze water-level measurements associated with specific hydrogeologic units or fracture zones. The authors (ZYV97) believe, however, that the potentiometric surface is probably a reasonable representation of the water table for the following reasons: (1) At Yucca Mountain, water levels at most wells were obtained from the uppermost part of the saturated zone (GRA97); (2) south of Yucca Mountain, wells penetrate a significant thickness of the saturated zone, but in this area most ground water flow is believed to be horizontal and all available data indicate that the vertical-head gradients are negligible; (3) for the case of wells having multiple piezometers, only water levels from the uppermost saturated interval were used in the construction of the potentiometric-surface map.

Large Hydraulic Gradient. Possible differences in conceptual models of the flow system pertain to the representation of an apparent large hydraulic gradient (LHG) on the north end of Yucca Mountain, an area where the altitude of the potentiometric surface appears to change by about 300 meters over a lateral distance of 2 kilometers (CZA94, CZA95). Prior to the construction of borehole USW G-2 in 1981, no water-level data existed at Yucca Mountain on which to base the LHG. As more boreholes were constructed at Yucca Mountain, particularly holes UE-25 WT#6 and UE-25 WT#16, a somewhat better definition of the LHG developed.

On a regional basis, other large hydraulic gradients are associated with a contact in the Paleozoic rocks between clastic rocks and regional carbonate aquifer; however, the cause and nature of the LHG near Yucca Mountain is not clear. Proposed explanations include: (1) faults that contain nontransmissive fault gouge (CZA84); (2) faults that juxtapose transmissive tuff against non-transmissive tuff (CZA84); (3) the presence of a different type of lithology that is less subject to fracturing (CZA84); (4) a change in the direction of the regional stress field and a resultant change in the intensity, interconnectedness, and orientation of open fractures on either side of the area with the LHG (CZA84); or (5) the apparent large gradient actually represents a disconnected, perched or semi-perched water body so that the high water-level altitudes are caused by local hydraulic conditions and are not part of the saturated-zone flow system (CZA94, ERV94). Fridrich et. al. (FRI94) suggest two hydrogeologic explanations for the LHG: (1) a highly permeable buried fault that drains water from tuff units into a deeper regional carbonate aquifer, or (2) a buried fault that forms a "spillway" in the volcanic rocks. Their second explanation, in effect, juxtaposes transmissive tuff against non-transmissive tuff, and is therefore the same as (2) above. Explanation (5) differs from the others in that it does not require a permeability contrast to represent the large gradient, because the LHG is absent, and actually represents a disconnected, perched or semi-perched water body.

For the site-scale model, explanation (1): faults that contain nontransmissive fault gouge was used to represent the LHG using reasonable permeability values by imposing a vertical barrier to horizontal ground water flow. Several of the other alternatives were tested by the modelers but did not yield satisfactory results.

Hydraulic Properties. Knowledge of hydraulic properties is critical to understanding the hydrogeology of Yucca Mountain and is required for numerical models. The authors (ZYV97) obtained information on the hydraulic properties from the following sources: (1) previously published hydraulic analyses for wells at Yucca Mountain conducted during the 1980s; (2) published hydraulic properties for hydrogeologic units obtained beyond the immediate Yucca Mountain area; and (3) recent (1995-97) hydraulic analysis of wells USW WT-10, UE-25 WT#12, and USW SD-7 (OBR97), UE-25 c#1, UE-25 c#2, UE-25 c#3, and USW G-2.

Aquifer tests. Several aquifer tests were conducted in Yucca Mountain boreholes during 1995 and 1996. Single borehole, composite interval tests resulted in transmissivity (i.e., hydraulic conductivity multiplied by thickness) estimates in boreholes USW WT#10, UE-25 WT#12, and USW G-2. The middle volcanic aquifer was the primary hydrogeologic unit tested in boreholes USW WT#10 and UE-25 WT#12. Transmissivity in these boreholes ranged from 7 to 1,800 m^2/day (OBR97). The upper volcanic confining unit was tested in USW G-2 and the mean transmissivity was 9.4 m^2/day. Transmissivity was reported for these boreholes because composite intervals were tested and the thickness of water-producing intervals was unknown. Hydraulic-conductivity estimates obtained from these transmissivity estimates would probably understate the actual hydraulic conductivity because the entire interval thickness does not contribute water to the borehole. Hydraulic properties obtained from single-borehole aquifer tests generally represent flow conditions within tens of meters of the borehole. Given the large degree of heterogeneity in the Yucca Mountain area, individual single-borehole aquifer-test results are not directly appropriate for the scale represented by the site model (kilometers).

Preliminary aquifer tests were conducted at the C-well complex during 1984. Horizontal hydraulic conductivity was about 0.15 m/d in the upper volcanic confining unit and ranged from 3 to 30 m/d within the middle volcanic aquifer (GEL96). Cross-hole aquifer tests during 1995-96 in the C-well complex also resulted in transmissivity and hydraulic-conductivity estimates. During these tests borehole UE-25 c#3 was pumped and boreholes UE-25 c#1, UE-25 c#2, UE-25 ONC-1, USW H-4, and UE-25 WT#3 were used as observation wells. The lower Bullfrog Tuff is the most transmissive interval within the middle volcanic aquifer and hydraulic conductivity range from approximately $1x10^{-5}$ to $7x10^{-4}$ meters per second in the observation boreholes (GEL97).

Hydraulic properties obtained from the cross-borehole aquifer tests at the C-hole complex represent flow properties between the tested boreholes. As such, they may be more appropriate for the scale of the site model than those obtained from single-hole tests. There is evidence that this area has extensive fractures that enhance the transmissive properties of the aquifer system. Northerly and northwesterly trending high angle faults such as the Paintbrush Canyon, Midway Valley, and Bow Ridge Faults have brecciated, offset, and tilted the tuffaceous rocks in the vicinity of the C-hole complex. Extensive tectonic and cooling fractures have been identified in the C-hole complex boreholes (GEL96). The relatively high transmissive properties obtained from C-hole testing are probably due to the intensity of fracturing in this area and may not be representative of the entire Yucca Mountain area.

Recharge. The authors (ZYV97) assumed that recharge to the model area is from the following sources: (1) downward and possible lateral recharge from episodic flooding of Fortymile Wash; (2) throughflow from Pahute and Rainier Mesas, which is hypothesized to result in recharge along the northern border of the study area; (3) throughflow from the northwestern part of the Amargosa Desert; (4) minor recharge from episodic flooding of the Amargosa River channel; and (5) net infiltration from precipitation events. Fortymile Wash is a major southward-draining ephemeral channel located adjacent to Yucca Mountain and it is thought to contribute intermittent recharge to the saturated zone. Water levels in UE-29 a#1 and UE-29 a#2 are affected periodically by streamflow events in Fortymile Wash and Pah Canyon Wash. In various numerical ground water flow models (CZA84, RIC84, CZA85, SIN87), recharge had to be specified in Fortymile Wash to replicate potentiometric levels. Czarnecki and Waddell (CZA84) simulated a flux in Fortymile Wash of 22,140 m^3/d or 256 kg/s. Based on geomorphic/ distributed-parameter simulations, Osterkamp et. al. (OST94) estimated recharge along the entire 95-km length of Fortymile Wash to be about $4.22x10^6$ $m^3/year$ or 134 kg/s. Based on field studies of stream loss, the total recharge in Fortymile Wash is estimated as 0.86 kg/s. Savard acknowledges that this estimate would represent a minimum value based on the inability to account for all reaches of Fortymile Wash, which may have received unobserved runoff and recharge, coupled with the minimum period of streamflow observations.

Discharge. The authors (ZYV97) believe that no natural discharge occurs within the model domain. The nearest natural discharge areas connected to the saturated-zone flow system beneath Yucca Mountain are Franklin Lake playa (also known as Alkali Flat) and possibly the major springs at Furnace Creek Ranch and the valley floor of Death Valley. Although most models of the region (DAG97a, RIC84, CZA84) require a ground water flow path from Yucca Mountain to Death Valley, Czarnecki and Wilson (CZA91) postulate that a ground water flow path from Yucca Mountain to Death Valley (by way of the Amargosa Desert and the Funeral Mountains) was unsubstantiated (but not inconsistent with) with available data. They suggest that ground water from Yucca Mountain ultimately discharges at Franklin Lake playa through evapotranspiration (CZA90).

Discharge through ground water withdrawals occurs within the model domain in the Amargosa Desert for agricultural and domestic use. This discharge, which was estimated in the USGS regional flow model at about 6,300 m^3/d, occurs mostly in the southwestern corner of the model domain. The authors (ZYV97) believe that this discharge may be responsible for the southwestwardly oriented gradient which appears to have persisted since the 1950s (KIL91).

<u>Numerical Modeling Difficulties and Simplifying Assumptions</u>. In the site-scale modeling, the following assumptions are applicable (ZYV97):

- The hydrogeologic framework is an appropriate description of the principal hydrogeologic units and faults.
- Permeability is invariant within each hydrogeologic unit.
- Ground water flow occurs in three dimensions and within the rock mass (which includes both rock matrix and fractures).
- Ground water flow system is isothermal at 44°C (the effect of this assumption was tested by simulating the system at 20°C).
- Hydraulic heads of the potentiometric surface along the north, south, east, and west edges of the modeled area are an appropriate data set for specifying boundary conditions along the sides of the model.
- The system is at steady state so that ground water flow into and out of the flow domain is invariant with time.
- Volumes associated with the finite-element mesh are sufficiently large so as to exceed the representative elementary volume necessary to simulate fracture flow as porous-media flow.

- A no-flow boundary at the base of the model approximates hydrologic conditions.
- The large hydraulic gradient is part of the saturated zone and not an artifact of perched-water occurrence.
- Recharge is assumed to occur only at the top of the model along upper Fortymile Wash; all other nodes on the top of the model are specified as a no-flow boundary.

Assumptions 5 and 8 are not and have not been supported by field data. The authors (ZYV97) found, however, that they both represent an expedient means to assign boundary conditions, which may have affected model calibration. Additional discussion of the site-scale model calibration is presented later in this section.

Sub-Site Scale Conceptual Model

DOE's sub-site-scale conceptual model of the saturated zone at Yucca Mountain scale model also places the saturated zone within a sequence of dipping and faulted tertiary volcanic rocks, underlain by Paleozoic carbonates at depths greater than 1200 meters beneath the water table. The sub-site scale conceptual model, however, places considerably more emphasis on the effects that faults will have on ground water flow than either the regional or site-scale models, as discussed below.

The volcanic rock sequence is comprised of variable thickness tuffs, lava flows, and volcanic breccias. Water levels in boreholes in the immediate area around Yucca Mountain are generally either within or below the Topopah Spring Tuff. Borehole flow meter surveys show that discrete fractured zones are the dominant pathways for saturated zone flow. More than 90% of pumped flow commonly emanates from discrete zones within densely welded sections of tuff, typically located in the central section of a particular unit. Fluid originates from fault zones and other intervals in some boreholes. The high permeability of the densely welded tuff is due to the high density of cooling joints, which generally form a fractured zone subparallel to dip. The Prow Pass, Bullfrog, and Tram Tuff each exhibit moderate to densely welded mid-sections, and are the most permeable units within the saturated tuffs. Non-welded tuff has relatively few open fractures, and is therefore less permeable. These sections are situated above and below the more densely welded intervals within each geologic unit, thereby producing a layered permeability heterogeneity. In addition, the dipping and faulted hydrostratigraphic units produce a heterogeneous distribution of rock units at the water table. The fate of potential radionuclides reaching the water table is therefore a function of the infiltration source in addition to the flow within the saturated zone.

Faults that displace stratigraphic units are pervasive at Yucca Mountain (DAY96). The dominant fault set is composed of steeply dipping normal faults which have offsets on the order of hundreds of meters and which are laterally continuous for kilometers. These faults are north-trending and exhibit a surface spacing of approximately 1 km. When stratigraphic units are displaced by faults, abutment of high permeability intervals against lower permeability intervals can result. In this case, fluid pathways may diverge in three dimensions due to the presence of low permeability structures. If fault zones exist, due to the presence of brecciated rock, for example, they could provide the vertical pathways that link the displaced high permeability zones. Conversely, mineralization within a fault zone may create a flow barrier if a high permeability unit is not made discontinuous by the fault. In either case, fault displacements produce discontinuities in stratigraphic units, which produce large scale permeability heterogeneity. Northwesterly-striking faults with offsets on the order of meters to tens of meters may introduce similar, yet smaller heterogeneities within the blocks bounded by normal faults.

Fluid between faults may be effectively isolated and have travel times orders of magnitude larger than surrounding areas (flow stagnation), a feature suggested by some geochemical data. Such a phenomenon would enhance the storage capability of portions of the saturated zone. The very low horizontal gradient downstream of the repository may be the result of barrier faults or divergence of flow upstream. West of Solitario Canyon Fault water elevations range from 775-780 m above sea level and the hydraulic gradient ranges from 0.02-0.04 (TUC95). Ervin et al. (ERV94) interpreted water to be mounded against the west side of the fault and a splay of the fault. They attributed the influence of the fault to a low permeability fault gouge. However, faults that simply displace units and that do not possess internal permeability may also have considerable effect on flow geometry. Some fault zones may be infiltration sources at the water table, and thereby influence the potential source locations of radionuclides at the water table.

Several researchers have proposed that the high temperature anomalies observed at the water table near the Solitario Canyon and Paintbrush Canyon faults may be due to upwelling of warm water through permeable fault zones that extend into the Paleozoic formations (SZY89). This upwelling could result in dilution of radio nuclides because of the introduction of additional fluid into the tuff aquifer. Conversely, the upwelling could restrict vertical mixing. Vertical flows may also be caused by the large-scale geologic heterogeneity described above. Geologic units have different thermal conductivities, and these differences coupled with the faulted structure could also be a contributing factor to the observed water table temperature anomalies (COH97).

In general, the large-scale heterogeneity created by superposition of the multiple sub-horizonal flow zones, displacement of strata by faults of varying hydrologic properties, and variable thickness and dipping geologic units will result in a complex 3-dimensional flow geometry. Actual flow directions at depth are very likely different from those inferred from water table elevations. In summary, saturated zone flow is affected by (1) the presence of high- and low-permeability faults which offset hydrogeologic units sub-vertically; (2) the heterogeneous permeability distribution within geologic units; (3) the variation of dip and thickness of strata; (4) the heterogeneous permeability distribution at the water table; (5) the distribution of infiltration from the unsaturated zone; and (6) the three-dimensional channelization, hydrologic mixing and dilution produced by the above mechanisms. In addition, saturated zone flow could be affected by upwelling or convection in faults, if faults are connected hydraulically to the Paleozoic units.

Computer Code Selection

Regional Flow Model

The computer code selected by D'Agnese et. al. (DAG97a) to perform the regional flow modeling is MODFLOWP (HIL92). As documented by Hill (HIL92), MODFLOWP is an adaptation of the U.S. Geological Survey 3-D, finite-difference modular ground water flow model, MODFLOW (MCD88) in which nonlinear regression is used to estimate flow-model parameters that result in the best fit to measured hydraulic heads and flows.

MODFLOWP is a block-centered finite-difference code that views a 3-D flow system as a sequence of layers of porous material organized in a horizontal grid or array. The horizontal grid is generated by specifying array dimensions in the x and y dimensions.

Flow between cells in each model layer is controlled by user supplied transmissivity values. Similarly, flow between the layers is controlled by user supplied values of vertical transmission or leakage.

The remainder of the model inputs describing boundary conditions, recharge, evapotranspiration, spring flow and well discharge are specified using arrays or lists of row-column cell locations. The model calculates ground water heads based on the model boundary conditions, and transmissivities.

Site-Scale Flow Model

To model the saturated-zone flow system at the site scale at Yucca Mountain, several simulation capabilities were considered important, including the ability to: (1) simulate 3-D transient ground water flow and heat transport, including 3-D representation of spatially variable permeability, porosity, and thermal conductivity; (2) allow specification of constant pressure, constant hydraulic head, constant fluid and heat flux boundary conditions; (3) represent discontinuous, irregularly shaped 3-D hydrogeologic units; (4) permit specification of dual permeability and porosity representing both fracture and matrix flow; (5) represent hydraulic-head and temperature observation points where they occur in 3-D space; (6) calibrate the model with respect to observations of hydraulic head and temperature through the use of automated parameter estimation techniques; and (7) directly interface the resulting flow model with radionuclide transport models used in Performance Assessment of the Yucca Mountain site. This list includes features of the model not used in the present report, but important for anticipated modeling efforts. The FEHMN simulation code was selected because it possessed these capabilities when coupled with the mesh generation software, GEOMESH (described later in this report), and with the model-independent parameter estimation software, PEST (also described later in this report). The following section discusses the theory for many aspects of FEHMN.

The FEHMN (Finite Element Heat Mass Nuclear) computer code is capable of simulating flow and transport through both the unsaturated and saturated zones. FEHMN is a non-isothermal, multiphase flow and transport code. It can simulate the flow of water and air, and the transport of heat and contaminants, in 2- and 3-D saturated or partially saturated, heterogeneous porous media. The code includes comprehensive reactive geochemistry and transport modules and a particle tracking capability. Fractured media can be simulated using an equivalent continuum, discrete fracture, dual porosity or dual permeability approach. The basic conservation equations, constitutive relations and numerical methods are described in Zyvoloski (ZYV83), Zyvoloski (ZYV86), Zyvoloski and Dash (ZYV90), Reeves (REE94), and Zyvoloski et. al. (ZYV95).

Sub-Site-Scale Flow Model

Modeling at the sub-site scale uses the integral finite difference simulator TOUGH2 (PRU87). TOUGH2 can simulate non-isothermal flow and transport in single and dual-porosity media. TOUGH2 utilizes an integral finite difference formulation, which, in part, enables construction of a mesh with highly variable gridblock geometries that are necessary to properly represent the geologic structure.

Layering and Gridding

Regional Flow Model

DOE's regional flow model developed by D'Agnese et. al. (DAG97a) used 163 rows, 153 columns and 3 layers. The 78,817-cell model is oriented exactly north-south. Grid discretization along both rows and columns was set to 1,500 m. The three model layers represent hydrogeologic units at 0-500 m, 500-1,250 m, and 1,250-2,750 below the interpreted water table; which are 500, 750, and 1,500 m thick. The first and second model layers are interpreted as simulating local and subregional flow mostly within valley-fill alluvium, volcanic rocks and shallow carbonate rocks; the third layer is interpreted as simulating regional flow in the volcanic, carbonate and clastic rocks. The authors (DAG97a) also point out that the use of only one model layer to represent each of the local, subregional, and regional flow paths may potentially result in model error in areas of significant vertical flow, particularly if the vertical flow component is somewhat complicated.

Site-Scale Flow Model

The site model area is 1,350 km^2 and extends 30 km west to east, and 45 km north to south. The model used a detailed three-dimensional hydrogeologic framework model (HFM) to characterize the heterogeneous, porous, and fractured media beneath Yucca Mountain. This approach is different from the regional model in that rather than inserting hydraulic properties into directly into the numerical mesh, the HFM model was first developed so that it could be converted into a tetrahedral mesh, using GEOMESH (GAB96).

The site-scale finite-element mesh is spaced at 1,500 m and consist of 9,279 nodes. The authors (ZYV97) note that this is a very coarse resolution and is only suitable for initial calibration of a preliminary flow model. For example, the upper volcanic confining unit is much more extensive in the model than in reality. Because of the coarse grid increment, offsets across faults are also much less abrupt in reality.

The authors (ZYV97) indicate that a 250-m sampled mesh is planned for the future with improved error checking, which will improve the quality of both the framework model and the numerical grid based on the framework model.

Sub-Site-Scale Flow Model

The model extends 10 km eastward and 15 km northward. However, it covers an area of 108 km^2 because it is not a rectangle. The horizontal mesh has 1993 gridblocks. There are currently 23 model layers that define different hydrostratigraphic units. Including fault gridblocks, the total number of gridblocks is approximately 50,000. Gridblock sizes are highly variable, mostly ranging in size from approximately 50 to 500 m on a side; several approach 1 km^2 near model boundaries. The locations of boreholes correspond to the gridblock nodal points, making conditions at the particular borehole correspond directly to conditions in the gridblock. Horizontal dimensions of fault gridblocks are approximately 150 m x 150 m. These dimensions do not represent the actual fault zone width, but rather are the gridblock dimensions over which fault zone properties are averaged. (Note that for the pure displacement conceptualization of modeled faults, the fault zone is given properties corresponding to the hydrostratigraphic units on either side of the fault, and thus the fault effectively has no width whatsoever.)

The finely discretized region near the center of the sub-site-scale domain corresponds to the area near the C-hole complex, borehole P#1, and borehole ONC#1. This area was finely discretized because transient hydraulic tests can be simulated in this area to design future hydrologic tests and simulate smaller-scale flow processes and effects.

The northernmost model area corresponds to the location of the large hydraulic gradient (FRI94). Several conceptual models have been proposed to explain this feature (e.g., FRI94, BOD96). The hydrogeologic structure beneath the water table in this area is poorly understood, and the authors (COH97) believe that different hypothetical models should be tested by numerical simulation to more fully constrain the possible causes.

The water table defines the top of the model. Use of this surface assumes that the water level measurements in borehole G-2 and WT-6 represent a water table, although two- and three-dimensional simulations of flow geometry do not include the large gradient zone. By defining the top of the model by these water levels, the model can also be modified to simulate perched water in that area. The bottom of the model is defined by the base of the Lithic Ridge Tuff. This unit is a thick confining structure that separates the Crater Flat Tuff aquifer and the lower carbonate aquifer. The higher head anomaly observed in UE-25p#1 deemed indicative of the Paleozoic formation actually first appeared in the older unnamed tuffs just beneath the Lithic Ridge Tuff and above the Paleozoic carbonates (CRA84). The older tuffs lie beneath the Lithic Ridge Tuff. The isopachs (i.e., thickness) of units beneath the Lithic Ridge Tuff and lower carbonate aquifer are unknown, as only p#1 penetrates the carbonate aquifer. Therefore, an isopach cannot be constructed for these intervals. Using the base of the Lithic Ridge as a lower boundary preserves the lower confining structure and still enables consideration of a higher head boundary condition. In addition, Lithic Ridge is the lowermost unit for which an approximate isopach has been developed (CAR86).

Gridblocks are discretized in a manner that preserved the thickness, orientation, dip, and lateral continuity of strata. The vertical dimension of the model is composed of gridblock layers with variable thickness distributions, which are then concatenated to produce a sequence of layers that correspond to the actual vertical distribution of units observed in boreholes. The lateral continuity of hydrostratigraphic units is thus preserved, which is important since many strata exhibit densely welded, high permeability zones parallel to dip. Displacement by faults is also explicitly considered. The number of model layers in areas between faults remains constant at 23. Because not all geologic units are present beneath the water table, several thin layers are present at the top of the model everywhere and are assigned the properties of the unit at the water table at a particular location. All gridblock nodes in the model are connected vertically to the adjacent node(s) located directly on top and bottom of the same column of gridblocks. The nodes of gridblocks located in regions between faults are also connected laterally to adjacent nodes of the same layer. Fault gridblocks are connected differently, as described below.

The choice and rationale for representing particular faults for the model is described by the authors in a previous report (COH97), a brief summary of which is presented below. Day et al. (DAY96) divide the faults at Yucca Mountain into three main groups. The dominant set is composed of north-trending normal faults that have steep down-to-the-west displacement over most of their length. These faults generally have offsets on the order of hundreds of meters, and define the boundaries of the relatively intact blocks of east-dipping Miocene volcanic strata. They have therefore been termed block-bounding faults. The second set is composed of northwesterly striking strike-slip faults located in the northwest section of the model region. These faults have offsets on the order of meters to tens of meters only. Thirdly, intrablock faults are those not continuous on scales greater than the defined fault blocks and not connected with either set. There are very little data to indicate that the intrablock faults are present below the water table. The linearity and dip of faults with depth, occurrence of fault zones, and fault zone flow properties beneath the water table are mainly unknown. Given the inherent uncertainty of fault properties beneath the water table and the intended modeling objective of investigating the potential effects of the complex geologic structure on flow, only north-trending faults, which have the greatest displacement of any of the fault sets, are considered. Most of these are block-bounding faults. The location of faults comes from the surface location of faults as defined in ISM2.0 (CLA97). Most faults at Yucca Mountain have steep dips on the order of 80°; therefore the general fault structure in the model is preserved by assuming vertical faults.

All faults can be assigned a fault zone with particular flow properties or can simply be treated as displacement-only faults. The gridding scheme enables hydrostratigraphic unit displacement across the fault to be considered realistically, as described above.

Initial and Boundary Conditions

Regional Flow Model

Specified-head boundary conditions surrounding the entire model are based on interpolation of measured head data. The slope of the potentiometric surface toward the southwest may be indicative of ground water withdrawals that were not specified in the model. Discharge by pumping wells occurs in the Amargosa Desert in the southwest part of the model domain, but this pumping was not explicitly represented in the model. However, the influence of these well withdrawals is implicitly reflected in the specified-head lateral boundary conditions applied along the southern boundary of the model. No-flow boundary conditions were specified along the base of the model. Specifically, the model boundaries used for the regional study are the following:

- In layer one, all lateral boundaries were designated as no-flow except along the western boundary at Death Valley, where constant head boundaries are designated at Cottonball, Middle and Badwater Basins, and Saratoga Springs. Head values along this boundary were defined using the potentiometric-surface map developed for the modeling study and reflect the nearly perennial ponds supported by ground water flux out of the system.

- In layer two, all lateral boundaries were designated as no-flow because at these depths flow is believed not to cross the lateral boundaries.
- In layer three, the lateral boundaries were designated as no-flow except at flow locations along the northern and eastern boundaries. These were assigned constant-head values to reflect possible or perceived interconnections along buried high transmissivity structural features with regional flow paths in adjacent valleys outside the model domain. The head values were selected to correspond to measured water levels.

Site-Scale Flow Model

A key concern addressed in the site-scale flow modeling is the compatibility of the regional flow model and the site-scale flow model. Although, ideally, the output from the larger-scale regional model would be used as direct input for the boundary conditions to the site model, the authors (ZYV97) point out several factors, however, that make such an interface impractical. First, the geologic model is defined in more detail at the site scale, so an exact piecing together of the models is impossible. Second, the regional model, focusing on larger-scale issues, does not have a detailed representation of geology near the site and does not attempt to include features such as the large hydraulic gradient in the calibration. Because of these differences, the models are compared with each other for consistency, rather than coupled more directly.

Hydraulic-head data are considered to be more accurate than flux data within the site model, and for that reason were chosen for specifying boundary conditions for the model despite the influence that such a constant-head boundary is likely to have on a model being calibrated to hydraulic-head observations. Specified-head boundary conditions are based on the potentiometric surface that includes the large hydraulic gradient. However, no measured vertical head distributions at the boundaries of the model exist. The regional model (DAG97a) does provide coarse estimates of vertical hydraulic head, but these were not used in assigning the boundaries at the site model. An appropriate set of hydraulic-head values on the outside nodes of the model consistent with the potentiometric-surface data was computed for use in specifying constant hydraulic-head boundary conditions.

Improving the representation of the lateral boundary conditions is considered by the authors (ZYV97) to be of primary concern for future modeling efforts. Alternate ways to specify boundary conditions within the site model exist. These include but are not limited to: (1) specifying constant heads only along the top edge of the model (this was not done because no flow would be allowed at the remaining nodes along the sides); (2) specifying flux explicitly (this was not done because of the difficulties in redistributing flux from the regional model onto the

sides of the site model); or (3) projecting hydrostatic head from the top edge down the outside faces of the model (this was not selected because it forces flow to be horizontal).
As noted previously, one concern with specifying hydraulic heads on all model sides, while calibrating using hydraulic heads within the model, is that the specified heads are likely to dominate the simulated heads at the observation locations. The severity of this problem was tested in independent numerical experiments using a model developed by Sandia National Laboratory of a subdomain that included Yucca Mountain. The results indicated that specified pressure (constant head) boundary conditions could be applied while still observing changes in model simulated pressures as a result of changes in model permeability values. Because the site model covers a substantially larger area than that of the Sandia model, application of specified head boundary conditions was considered to be less of a constraint. However, the use of any specified-head boundary condition will have some constraint on model calibration. As a result, the fluxes in and out of the model will have to be checked against any available data.

Sub-Site-Scale Flow Model

The local-scale saturated zone model is situated such that the western and eastern sides are nearly perpendicular to the hydraulic gradient. Constant head boundary conditions are therefore placed along the western and eastern sides of the model. A uniform and constant head is assigned to the entire vertical column of gridblocks that underlay a particular gridblock at the water table. In addition, constant head conditions are assigned to gridblocks along the sides in the northwestern corner in the area of the large hydraulic gradient where the potentiometric contours are not perpendicular to the model sides. The latter condition assumes the high gradient area represents a water table gradient, and it maintains the observed high gradients along the sides of the high gradient area. Calibration still considers the high gradient area, however, since assignment of different permeabilities in this area will produce different fluxes and hence head profiles downstream. The northern side of the model immediately downgradient from the high gradient area and the full southern side of the model are no-flux boundaries. The relative difference in hydraulic head between gridblocks along head boundaries represents the relative elevation change between gridblocks.

Model Parameterization

Regional Flow Model

Flow Parameters. The regional model lumped aquifer properties into 10 hydrogeologic units. In reality, aquifer property variation is considerably greater; however, the properties were lumped into a limited number of categories to facilitate the simulations. The subsurface materials of the hydrogeologic framework model were initially classified into eight rock conductivity units (RCUs). Each RCU represents mean hydraulic conductivity of several subsurface materials whose interpreted characteristics, such as rock type, depth, and degree of fracturing resulted in very similar hydraulic conductivity values.

Because each of the three model layers contained several hydrogeologic framework model units, multiple RCUs were associated with each finite-difference model cell. The RCU occupying the largest volume in the finite-difference flow model cell was assigned to each cell. To reduce the number of parameters that would need to be estimated, the authors (COH97) reclassified the layer maps by combining the eight RCUs into four hydraulic-conductivity zones (K-zones) representing large (K1), moderate (K2), small (K3) and very small (K4) hydraulic-conductivity values. The resulting K-zones were not contiguous; each K-zone included cells distributed throughout the model. The 50th percentile K-value for each of the zones was used for the initial hydraulic conductivity values assigned to each K-zone. Transmissivity values for the model layers were calculated by multiplying the applicable K-zone values by layer thickness.

Evapotranspiration. The authors (DAG97a) expressed evapotranspiration (ET) in terms of a linear function based on three variables: (1) land-surface altitude, (2) extinction depth, and (3) maximum ET rate (MCD88). Each of these variables was specified from data sets including ET area maps. Extinction depths were assigned for each unique ET area based on information about plant type and ranged in value from 0 to 15 m. Each of these data sets was resampled to a 1,500 m grid. Since the Death Valley saltpan was simulated as a constant head boundary, it was not assigned an ET rate.

Recharge. To define ground water recharge, a recharge potential map was resampled to a 1,500 m grid and reclassified into an array for MODFLOWP containing four zones associated with high (RCH3), moderate (RCH2), low (RCH1), and no (RCH0) recharge potential parameters. Each parameter defines a percentage factor that represents the amount of average annual precipitation that infiltrates. Average annual precipitation is defined by a multiplication array in MODFLOWP. These zone and multiplication arrays, therefore, along with the parameter values, define the recharge distribution for the model area. In initial parameter-estimation runs, recharge rates based on fixed percentages were lumped into a single recharge parameter (RCU) for simplicity.

Springs. The regional springs data set was utilized to specify the row-column locations of spring nodes. All but three groups of springs were thought by the authors (DAG97a) to discharge from deep regional flow paths, and were, therefore, assigned to layer three. Sand Springs, Indian Springs and Cactus Springs are interpreted as discharging from more localized flow paths in model layer 2. Springs were specified using the general-head boundary package for which the altitude and conductance of spring orifice are assigned. Because the conductance term is poorly known, springs were grouped according to geographic location and a conductance parameter (GHB) assigned for each of the groups of springs.

Pumping Wells. The MODFLOWP well package was used to simulate the amount of ground water pumped from the system. Because most of the water pumped from the wells is relatively shallow ground water, all pumping wells were located in the first model layer. The water-use well data set was used to specify the grid-cell locations and approximate ground water volumes being removed from the model domain. The authors (DAG97a) believe that approximate pumpage rates probably exceed actual values, so they assigned two parameters to make it easy to modify simulated pumpage. The two parameters are multiplication factors representing the percentage of pumpage included in the simulation. WEL2 represents the parameter applied to the Pahrump Valley area, which bears the majority of ground water withdrawal in the region. WEL1 represents the parameter applied to the remainder of the model domain. Pumping rates were obtained from the regional model (DAG97a).

Observation Data. Measured hydraulic heads and spring discharges were used by MODFLOWP during parameter estimation (i.e., calibration) to provide values to define the objective function for the model simulation (i.e., to see how well the model results matched actual field measured values).

Faults and Geologic Structure. The regional model does not incorporate some structures explicitly. In the regional model, northeast-southwest trending regional structures are identified as zones of large permeability and northwest-south-east trending regional structures are identified as zones of small permeability. Because of the large-scale of the regional model, hydraulic properties of such features used in that model may not be appropriate at the scale of the site model. The area underlying Fortymile Wash was also identified as a zone of large permeability in the regional model. Because the site model does not explicitly consider many structural features, the hydraulic conductivity ranges for these hydrogeologic units are much larger than those defined for the regional flow model.

Site-Scale Flow Model

Potentiometric Data. Hydraulic-head values from eighty boreholes, located within the model area, were used in model construction. Twelve of the boreholes (USW H-1, USW H-5, UE-25b 1, USW H-6, USW H-4, USW H-3, UE-25p 1, UE-25c 1, UE-25c 2, UE-25c 3, and two unnamed boreholes) have multiple piezometers. Forty-five of the boreholes are either uncased or have fifty percent or more perforated casing. Twelve boreholes are cased, while the presence or absence of casing is unknown for eleven of the boreholes. Many of the boreholes are "dry" until a fracture zone is intercepted, at which point the water level in the borehole rises to a static level. Because of long open or perforated intervals, many boreholes intercept multiple permeable zones. As a result, the hydraulic head in many of the boreholes represents a composite head.

Permeability Zones. In FEHMN, nodes are grouped into zones in which rock and hydraulic properties, and boundary conditions may be specified. There are 16 zones used in the model that define nodes pertaining to hydrogeologic units with specific permeability and porosity values. Permeability values used in the model are considered preliminary. Only the nodes closest to Fortymile Wash and Solitario Canyon Fault are represented explicitly as fault or fracture zones. In the numerical model, Solitario Canyon is a separate permeability zone and forms a barrier to flow.

The permeability values used in the model are derived partly from a sequence of parameter-estimation simulations. Permeability specified for the middle volcanic aquifer ($1.6 \times 10^{-14}\,m^2$) is about three orders of magnitude less than values reported by Geldon (GEL96, p. 70) for tests at the C-wells. The authors (ZYV97) provide a possible explanation for this discrepancy which is that the C-hole tests reflect hydraulic conditions in locally faulted and intensely fractured rock. The possibility of such a condition was tested to a limited extent by specifying a vertical zone, extending approximately 5 km southeast from the C-wells, with a larger permeability of 1×10^{-11} m^2. The small increase in the resultant sum of squared residuals (23,262 m^2) over that of simulation 40 (23,163 m^2) indicates that the model was insensitive to such a zone and that such a zone might be possible. This zone would be consistent with northwest-southeast oriented faults in the area. The small change could also be an artifact of the density of observation points near this zone of large permeability coupled with the small horizontal hydraulic gradient. However, because of the non-unique nature of the model, an overall large permeability (1×10^{-11} m^2) for the entire middle volcanic aquifer also is possible, but would require a considerably different combination of permeability values for the other hydrogeologic units to achieve calibration. Investigating the possibility of a zone of large permeability would be more appropriate using a more finely sampled hydrogeologic framework model and associated finite-element mesh.

Large Hydraulic Gradient Zone. To reproduce the LHG on the north end of Yucca Mountain, where the apparent water-table altitude changes about 300 meters in a distance of less than 2 km, an additional zone was defined within the model as an east-west barrier to flow. Large head residuals (i.e., errors during calibration) had occurred at the wells defining the LHG prior to the definition of this zone. Because no independent geologic evidence for a structure exists, and because the length of such a structure is in question, the coordinate defining the eastern extent of this zone was selected as a parameter and allowed to vary from the western limit of the zone to the eastern edge of the model during earlier scoping simulations. Model fit was best when the zone was extended to the eastern edge.

A single zone extends from the top of the water table to the bottom of the model, and is one node thick that, in essence, forms a 2-D plane. The present model zonation results in uniform permeability changes over the entirety of the upper volcanic aquifer, the upper volcanic confining unit, and the middle volcanic aquifer wherever they occur within the model.

The authors (ZYV97) note that an alternate approach to representing the LHG would be to further subdivide the zones defining the upper volcanic aquifer, the upper volcanic confining unit, and the middle volcanic confining unit along the east-west occurrence of the LHG. This subdivision would then allow reduction of the permeability of these units where they occur to the north of the gradient, producing a 'spillway' model (FRI94). The authors (ZYV97) also point out that a 250-m resolution mesh would better represent the large hydraulic gradient as well as the fault and hydrogeologic unit distribution, coincident with the LHG as portrayed by Fridrich et. al. (FRI94).

Solitario Canyon Fault Zone. Based on hydrologic and hydrochemical data, the Solitario Canyon fault appears to act as at least a partial barrier to ground water flow. Currently, the authors (ZYV97) have not specifically simulated the Solitario Canyon fault in the model. However, they have included a hydraulic conductivity zone to better reproduce the approximately 50-meter change in hydraulic head across the Solitario Canyon fault system. Its exact correlation with Solitario Canyon fault is approximate owing to the coarseness of the grid. This zone was introduced after initial attempts to simulate the 50-m change in head resulted in large hydraulic-head residual values (i.e., errors). No hydraulic-test data exist to provide information about the permeability of the Solitario Canyon fault zone.

Fortymile Wash Recharge Zone. Many lines of evidence indicate recharge occurs in upper Fortymile Wash. Therefore, the authors (ZYV97) placed a zone in this area to specify recharge in upper Fortymile Wash. The zone consists of seven nodes each with a uniform mass recharge rate of 0.22 kg/s.

Sub-Site-Scale Flow Model

Hydrogeologic Units. Permeabilities of the Topopah Spring units for the sub-site-scale model are derived from Bandurraga et al. (BAN97). These values are the averaged values from inversion of pneumatic data from the unsaturated zone. The sources of data are described in Bandurraga et al. (ibid.). The values shown are derived from analysis of fracture traces and results of air-injection tests.

Luckey et al. (LUC96) provide apparent hydraulic conductivity values for saturated zone units, as obtained from pumping and other hydrologic tests conducted in the 1980s. The authors (ZYV97) observe that no single value of permeability for each unit can be assigned, given the inherent heterogeneity in the system and general paucity of data. The values chosen by the authors (ibid.) for each unit fall within the range of values available, and also maintain the contrast in unit permeabilities due to their geologic structure. Thermal properties of each unit are derived from laboratory tests on rock core (BRO97), and from analysis of temperature profiles in boreholes (SAS88). These values are very well constrained relative to the hydrologic properties. Porosity values are representative of the fracture porosity. An effective fracture porosity has been difficult to determine for all flow models at Yucca Mountain, and simulations presented later in this section illustrate the highly variable flow estimates obtained using different porosities. The authors (ZYV97) apply a single-continuum model that considers fracture porosity for most units since fractures are the dominant fluid pathways in the saturated zone. The authors (ibid.) further believe that the fracture-dominated flow conceptualization is supported by two lines of evidence: (1) borehole tracejector surveys have consistently shown water derives from several discrete fractures or fractured zones (e.g., WAD84); and (2) permeability calculations from pumping tests are many orders of magnitude larger than matrix permeability (e.g., GEL96).

Drill-hole data for boreholes in the saturated zone were carefully reviewed by the authors (ZYV97) to establish correlations, note discrepancies, and delineate hydrostratigraphic units for the model. The geologic unit thickness values used to construct the model are defined by lithologic logs (CLA97). These may be an apparent thickness, since faults may intersect the borehole within a particular unit. For example, the thicknesses of the Tram Tuff and Lithic Ridge Tuff in borehole p#1 are very likely less than their true values because a fault observed in the borehole separates the units.

The Lithic Ridge Tuff located beneath the Tram Tuff and the lava flows and flow breccias situated between the Tram and Lithic Ridge units are included in the model. A layer of lava flow and flow breccias was penetrated in boreholes H 1, H 6, G-1, G-2, and H-5. The observed thicknesses are 119, 253, 118, 24, and at least 176 m, respectively. This unit is located between the Lithic Ridge and Tram Tuffs of the Crater Flat Tuff, which are adjacent in the rest of the model area. Most of the unit in each of these holes is altered to clays and zeolites (MAT96). The unit therefore is considered a confining unit (i.e., low permeability). The isopach (i.e., thickness) of the thin lava flows and breccias and the associated underlying thin bedded unit beneath was constructed using the observed thicknesses and zero thickness constraint imposed by nearby boreholes H-3, H-4, b-1, and WT-6, in which the unit was not observed (ZYV97).

The Lithic Ridge and lavas are lumped into a single lower confining structure due to their common low permeabilities. This confining structure exhibits large variations in its thickness over the model area, which may have implications for where large vertical gradients are observed.

In the remaining upper stratigraphic units, an important hydrogeologic feature results because of the intersection of the water table with the dipping units. Different units are located at the water table in different areas. In addition, the actual thickness of each unit beneath the water table will be less than its total thickness.

<u>Selection and Representation of Faults in Model</u>. Eleven (11) faults are modeled explicitly. The fault locations in the sub-site-scale model are generally preserved as they occur at the surface. Due to the disparity in scales between geologic mapping and model discretization, several

closely-spaced faults observed in the field are represented as one model fault, or one model fault accounts for the offset across two nearby faults.

Faults are represented as continuous gridblock bands, which preserve the natural continuity of faults. Fault displacement makes the contact area between different units on either side of the fault vary, depending on the fault offset. At large fault offsets, hydrostatigraphic units may be completely discontinuous at the fault and abut against different hydrostratigraphic units. Fault displacement also varies along strike.

The column of gridblocks located along fault traces uses a special node-connection scheme that enables proper representation of the large scale heterogeneity created by fault displacement. Due to fault displacement, hydrostratigraphic units partially to fully abut against other units on the adjacent fault side. The number of vertical gridblocks at fault traces is 46, which provides the additional nodes needed to account for the fractional contract area that connects a particular unit on one side of the fault to a unit on the other side. Both displacement-only faults and fault zones with particular permeabilities were modeled. The authors (ibid.) point out that a bulk fault zone property could later be modeled by setting the properties of fault gridblocks to different values. This is done when considering a fault as a zone of differing hydrologic character from that of the surrounding units.

Model Calibration

<u>Regional Flow Model</u>

Calibration of the regional model by strictly trial-and-error methods was judged by the authors (DAG97a) to be both ineffective and inefficient; therefore, nonlinear regression methods are used to estimate parameter values that produce the best fit to observed heads and flows.

<u>Conceptual Model Testing</u>. During calibration, a number of conceptual models were evaluated using the regression methods in MODFLOWP. A best fit to hydraulic-head and flow observations was calculated for each conceptual model. Evidence of model error or data problems were investigated after each model run. These analyses were used in conjunction with independent hydrogeologic data to modify, and hopefully improve, the existing conceptual model, observation data sets, and weighing. No modifications were made simply to improve

model fit; supporting independent hydrogeologic criteria were also needed before modifications were made.

To perform the conceptual model testing, the authors (DAG97a) adjusted the location and type of flow system boundaries in the north and northeast parts of the model area to test the premise that the regional flow system could be receiving interbasinal flux from adjacent basins. Although water-level data exist adjacent to the model boundaries, considerable uncertainty remains concerning the existence of such fluxes and their volumes.

Modification to the numerical model involved increasing or decreasing the size of the constant-head boundaries, moving the locations of the boundaries to different model layers, and adding new constant-head boundaries to the northeast. In general, these modifications provided very clear results. The optimal location for the constant-head boundaries used to simulate interbasinal flux conditions was the third layer. Locating the constant-head boundaries in the upper layers of the model often led to extremely large deviations from observed heads.

The most appropriate boundary conditions between Sand Spring Valley and Emigrant Valley were evaluated. Simulating a constant-head boundary in this region instead of a no-flow boundary resulted in extremely large residuals for heads (100 m too high) in the northern part of the model domain, and large residuals for spring flows (simulated flows 50 percent too large) at both Ash Meadows and Furnace Creek Ranch. As a result, this boundary was redefined as no flow boundary. The constant-head boundaries at Railroad, Stone Cabin and Ralston Valleys, however, were needed to simulate spring flows close to measured flow at both Grapevine Springs and Oasis Valley. The constant-head boundary at Pahranagat Valley was needed to match to the measured domain and spring flows at Ash Meadows.

Hydrogeologic Framework Testing. Four types of hydrogeologic framework variations were considered during calibration of the regional model. These include: (1) adjustment of hydraulic conductivity zones to improve numerical stability; (2) addition or refinement of hydraulic conductivity zones to better define hydrogeologic units or geologic structures included in the 3-D hydrogeologic framework model; (3) addition of hydraulic conductivity zones to better represent interpreted geologic structures that were not included in the hydrogeologic framework model; and (4) addition of new hydraulic conductivity zones required to better represent faulted terrains supplying ground water to springs and discharge area.

Recharge Distribution Determination. The initial distribution of recharge areas was changed during model calibration to determine the sensitivity to their extent and magnitude. Initially, a single multiplication array was used to describe the rate of recharge, and a single multiplication parameter defined to adjust this rate. Initial modeling indicated that the model results were very sensitive to this single recharge parameter. The large residual errors suggested that the use of a single recharge parameter was an oversimplification, and that parameters in multiple recharge areas would have to be estimated with the available data.

A detailed evaluation that had been conducted by the authors (DAG97a) to delineate various zones of recharge potential was used to divide the single recharge parameter into four zones. Each was assigned a parameter that represented a percent of average annual precipitation that infiltrates. In the final model, RCH0 and RCH1 were assigned values of 0 and 1 percent, RCH2 and RCH3 were estimated by regression and were variable, ranging from 1 to 10 percent and 10 to 30 percent, respectively.

Calibration Results. After calibration, the regional model was evaluated to assess the likely accuracy of simulated results. This is accomplished by comparing measured and expected quantities with simulated values. The quantities included in the comparisons are (1) hydraulic heads and spring flows, which were matched by the regression; (2) hydraulic conductivities, vertical anisotropy, and percent of precipitation that infiltrates, all of which were represented by parameters estimated in the regression; and (3) water budgets.

An advantage of calibrating the model using nonlinear regression is the existence of substantial methodology by which to evaluate model results. As will be demonstrated, these methods produce a more thorough evaluation than is normally accomplished and reported when calibrating using trial-and-error methods. The thorough analysis produces a good understanding of the strengths and weaknesses of the model, and the likely accuracy of simulated results and associated confidence intervals and other measures of parameter and prediction uncertainty.

The authors (DAG97a) believe that the model reproduces the measured hydraulic heads and estimated water-budget components reasonably accurately. They also believe that the estimated parameter values include all aspects of the system that are most important for steady-state simulation, and the parameter values that produce the best match between simulated and observed hydraulic heads and flows; that is, the parameter values estimated by the regression, are all reasonable.

Because the weighted residuals are not entirely random, some model error may be indicated. This is related to the occurrence of large positive weighted residuals for hydraulic heads and large negative weighted residuals for spring flows. In addition, weighted residuals are not normally distributed. The authors (DAG97a) believe that additional calibration may significantly improve model accuracy. They further conclude that the model is a reasonable representation of the physical system, but evidence of important model error exists.

One of the more apparent factors contributing to model error is the vertical discretization of the regional system into three layers. While a three-layer model is an improvement on previous 2-D and quasi-3-D models, simplification of the complex 3-D hydrogeologic framework into three layers inevitably results in model error, particularly in areas with significant vertical flow components. The introduced model error may translate into model bias in computed parameters and all quantities computed using them, particularly head and flux. Furthermore, this potential bias may be contributing to closeness of fit calculated for the model. The authors (DAG97a) believe that an evaluation of the extent of model error should be conducted. This evaluation may include a series of cross-sectional or subsystem models with varying degrees of vertical discretization. A comparison of the levels of detail in vertical discretization with the model fit and computed parameter values would give some indication of the potential for model error. They also indicate that the calibrated site-scale model has a flux of 465 kg/s from the south face versus 323 kg/s over the same region for the regional model. This agreement is acceptable considering the compatibility issue raised above. Furthermore, the recharge and discharge flux values themselves, as input into the regional-scale model, have uncertainties that are larger than the computed difference of these two models. Because the difference is within the range of uncertainty of the actual flux values, the authors (DAG97a) consider the two models to be, for all intents and purposes, in agreement with one another.

Site-Scale Flow Model

The calibration of this model was achieved through the use of the model independent parameter estimation software, PEST (WAT94). PEST uses nonlinear least-squares regression to estimate parameters. The benefits of using nonlinear regression include: (1) expedited determination of best-fit parameter values; (2) quantification of the quality of the calibration; (3) estimates of the confidence limits on parameter estimates; and (4) identification of the correlation among parameters.

PEST was selected because of the ability to couple it with FEHMN without significantly changing the FEHMN software. PEST is designed to be used with virtually any model, provided that one can identify: (1) model input files; (2) model output files; (3) commands that invoke the model; (4) observation data; and (5) model parameters. Each of the required input and output files needs to be in ASCII format.

PEST was used to run FEHMN and to vary user-specified model parameters prior to each run such that the weighted sum of the differences between observed and simulated values of pressure, hydraulic head, or temperature is minimized using nonlinear regression. The optimization is accomplished using the Gauss-Marquardt-Levenberg method. The strength of this method lies in the fact that it can generally estimate parameters using fewer model runs than any other estimation method, a definite advantage for large models whose run times may be considerable (WAT94).

As mentioned above, model calibration was attempted using nonlinear least-squares regression to estimate parameter values. Permeability values were modified to achieve a close match to 94 measured hydraulic heads, all of which were equally weighted. Fluxes at the specified-head nodes for the outside nodes were summed for each side of the model for comparison against regional model values. The authors (ZYV97) believed that it may be advantageous to compare flows for smaller parts of each side, but this was not done in the present work.

Several simulations using a pressure-based configuration instead of hydraulic heads, provided experience regarding which parameters tended to be highly correlated, a condition which indicates that the available data are not sufficient to estimate all parameters individually. Hydrogeologic units with similar permeabilities were combined or "lumped" as parameters to gain some insight about the hydrologic importance of areas of large and small permeability. For example, the permeability parameter of the middle volcanic aquifer (mva) was observed to be correlated to the upper volcanic aquifer (uva). Experience has shown that spatially connected hydrogeologic units with similar permeability which are oriented approximately parallel to the direction of ground water flow tend to be highly correlated, preventing independent estimates of their associated permeability values. An initial strategy of the modeling focused on optimizing permeability in those units that appeared to have sufficient information provided by hydraulic-head observation points. In addition, a determination of which potential model parameters were highly correlated was done using PEST by assigning as many model variables of permeability and flux as possible so that correlation among parameters could be evaluated. From these correlations, parameters either could be lumped with other correlated parameters, or set so that parameter estimation could be achieved.

Forty PEST parameter estimation runs were done for various combinations of fixed and estimated parameters. Fixed parameter values are not modified during a run; estimated parameter values are adjusted using nonlinear regression. In most of the runs, one or two parameter values are estimated; at most, five are estimated. Because so few parameters are estimated without a thorough evaluation showing that the other parameters are unimportant, the authors (ZYV97) believe that the regression runs need to be considered as very preliminary. The results of the PEST simulations include 95% confidence intervals for the adjustable parameters, which the authors (ibid.) indicate may or may not be meaningful, depending on many factors in the model construction and parameter estimation processes. A large range in the 95% confidence interval generally indicates that the data contain little information about the parameter. In many instances, minimum values of 95% confidence intervals were estimated as negative values. Use of a log transformation of such a parameter typically would result in a minimum value with a large negative exponent (or essentially a minimum value of zero), indicating that insufficient information was available to provide a good estimate of the parameter.

Sub-Site-Scale Flow Model

The sub-site model was calibrated to the observed water table. The high gradient area is conceptualized as a zone of uniform permeability. Initial simulations used a range of rock properties, and all fault zones were assigned a permeability of 10^{-13} m^2. Steady-state simulations using these parameters showed that the medium gradient across the Solitario Canyon Fault could not be sustained with the assigned fault permeability. Permeability values were adjusted manually and simulations were performed in an iterative manner. Subsequent simulations showed that the dominant areas that needed permeability adjustments were the Solitario Canyon and Iron Ridge faults. The authors (COH97) found that in order to reduce the simulated heads on the eastern side of the Solitario Canyon Fault, a permeability of 10^{-16} m^2 was needed. In order to reduce the heads east of the Iron Ridge Fault to their approximate measured values, the Iron Ridge Fault and neighboring fault to the west were adjusted to a permeability of 10^{-15} m^2. In parallel to fault permeability adjustments, the gradient conditions to the north were observed, and the authors (COH97) found that a permeability of 10^{-15} m^2 for the entire high gradient area enabled the lower heads immediately downgradient from this area to remain within observed bounds.

Water-level matches for boreholes are generally within 1 m, except for those boreholes that are situated immediately adjacent to the Solitario, Iron Ridge, and High Gradient areas. The measured heads are generally taken from Ervin et al. (ERV94). The large discrepancy between measured and simulated heads at borehole H-5 is due to the anomalously high head at H-5, which may be due to an intersection of a Solitario Canyon fault splay with this borehole (ERV94). The model does not consider this splay. The simulated gradient in the northwestern corner of the model is 0.12, compared to the measured gradient of 0.11 (ERV94). A head residual for borehole G-1 results because the low permeability zone within the high gradient area was not extended to this borehole. The authors (COH97) believe that a short extension of this zone will yield a closer match. Gradients calculated from actual field measurements is the low-gradient area range between 0.0003 and 0.0004 (ERV94). The simulated heads in the low-gradient area yield a gradient that ranges between approximately 0.0005 immediately downgradient from the repository, to as much as 0.003 in the area west of C-wells. The Midway and Paintbrush Canyon faults are located in this area, and their displacement results in the complete displacement of the Bullfrog Tuff, the most permeable unit in the model. This discontinuity creates this localized higher gradient. The authors (COH97) believe that such a gradient is possible, as it may occur between boreholes where measurements are not available. The 2-D and 3-D simulations described later in this section show how the Bullfrog abutment at these faults significantly alters the flow field, and reveal the possible fault effects in greater detail.

<u>Using Hydrochemical Data for Calibration</u>. The authors (COH97) reviewed the possibility of using hydrochemical data to facilitate model calibration and concluded that the ground water composition in the region around Yucca Mountain is heterogeneous at the kilometer scale. They also noted that separate domains define the ground water composition of Jackass Flats, Fortymile Wash, Crater Flat, and Yucca Mountain, but at the sub-site scale, it is difficult to distinguish separate domains. All water samples from Yucca Mountain itself plot in a relatively coherent region.

Another of their observations relates to the availability of data. Dozens of chemical analyses that include rare earth and trace elements are now available from springs that sample discharge waters (HOD96). These provide useful end components (although not end member compositions) to the history of ground waters. Similar analyses would be very useful for recharge waters and for wells in the Yucca Mountain area. Without additional samples at greater depths in the saturated zone, the authors (COH97) believe that this assumption can only be tested on the basis of mixing models using existing isotope data.

The authors (COH97) continued their discussion by outlining the data limitations with respect to the ground water chemistry and maintained that uncertainties regarding the saturated zone hydrochemistry abound due to the limited number of boreholes that penetrate the water table near Yucca Mountain and the uncertain quality of some of the existing data.

Predictive Simulations

<u>Regional Flow Model</u>

The predictive simulations of the regional model were all focused on determining the adequacy of the calibration and the appropriateness of the conceptual model(s). Calibration of the regional model using the techniques available in MODFLOWP allowed for estimation of a series of parameters that provide a best fit to observed hydraulic heads and flows. Numerous conceptual models were evaluated during calibration to test the validity of various interpretations about the flow system. Conceptual model evaluations focused on testing hypotheses concerning the (1) location and type of flow system boundaries; (2) extent and location of recharge areas; and (3) configuration of hydrogeologic framework features. For each hypothesis tested, a new set of parameters was estimated using MODFLOWP and the resulting new simulated heads and flows were compared to observed values. Only those conceptual model changes contributing to a significant improvement in model fit, as indicated by a reduction in the sum of squared errors, were retained in the final optimized model.

The final model was evaluated to assess the likely accuracy of simulated results. This was accomplished by comparing measured and expected quantities with simulated values. The quantities included in these comparisons are: (1) hydraulic heads and spring flows, which were matched by regression; (2) hydraulic conductivities, which were represented by parameters that were estimated in the regression; and (3) water budgets. Unweighted and weighted residuals for hydraulic heads show a very good model match with observed conditions in flat hydraulic gradient areas and a relatively good match in large hydraulic gradient areas. Weighted and unweighted residuals for spring flows show somewhat of a bias in that simulated spring flows are generally lower than observed. The difficulty in simulating these spring flows in previous models of this area without imposing discharge by using a specified flux, however, suggests that even the somewhat lower simulated discharges are an improved match with observed conditions. Estimated parameters were evaluated to determine if reasonable values of hydraulic conductivity, vertical anisotropy and recharge rates were obtained. All estimated parameter values are within expected ranges. The MODFLOWP-calculated linear confidence intervals also were well within the range of expected values. Water budgets were evaluated to determine if they were within the range of expected values. The authors (COH97) believe that even with the limited understanding of fluxes in and out of the regional ground water flow system, overall budgets are within the expected ranges for the flow system.

Site Scale Flow Model

In a fashion similar to the regional scale model, the primary objective of the site-scale modeling was also to achieve a calibrated model. Therefore, the predictive simulations are essentially an evaluation of how well the model is calibrated. The authors (ZYV97) used several criteria including how well the simulated hydraulic heads matched those observed in monitoring wells; and how closely estimates of flux from the site model match those determined in the regional modeling.

In general, the model fits the observation well data relatively closely in small gradient areas, but fits more poorly in larger gradient areas. With respect to the model fluxes, a comparison of the regional versus site model predictions indicates fairly large discrepancies. The authors (ibid.) believe, however, that it is more of a problem with the regional model conceptualization than with the site model.

Another flow issue addressed in the site-scale modeling is the effect of temperature on the flow field and on the prediction of flux through the site-scale model. An analysis performed with the site-scale model shows that the model calibration is not significantly affected by the selection of 20°C for model calibration purposes. Computed heads differed by less than 1% between the system simulated assuming 40°C temperature and the system simulated assuming 20°C. The difference in computed flux out of the south end of the model was somewhat larger but still well within the range of uncertainty of the flux in the actual ground water system. Therefore, the authors (ibid.) conclude that the calibrated model at 20°C is acceptable for the present study but recommend that, in future modeling, a more appropriate mean temperature be used to alleviate this concern.

Sub-Site-Scale Flow Model

A number of different types of simulations were performed at the sub-site-scale; including both two- and three-dimensional analyses, simulating matrix diffusion effects, and attempts to match well pumping tests results at the C-hole complex with model predictions as discussed below.

Two-Dimensional Simulations. Two-dimensional cross-sections of the full model are used by the authors (COH97) to study specific scenarios such as the coupled effects of up welling, varying fault and hydrostratigraphic unit properties, and fracture-matrix interactions. Although the 2-D cross sections are a larger abstraction from the actual system then the full 3-D model, the results of 2-D simulations are often easier to understand. In addition, the faster execution time for 2-D simulations enables one to quickly investigate the effects of varying specific properties and thereby guide the design of full 3-D simulations.

Three-Dimensional Simulations. The area of the model corresponding to the small-gradient area was used as an investigative tool to explore and define saturated zone processes by way of hypothesis testing. By using this sub-area of the model only, biases that would be introduced by assuming the true cause of the large gradient zone are avoided. The western boundary of this sub-grid was defined by the 731 m water table contour. The full 3-D saturated zone model is used by the authors (COH97) as an investigative tool to explore and define saturated zone processes by way of hypothesis testing and calibration against hydrologic, thermal, and geochemical data. This approach yields answers to questions concerning the plausibility of various flow and transport scenarios. In addition, unanticipated saturated zone flow processes can be demonstrated and investigated. Three-dimensional simulation of hydraulic tests is also used for model calibration by way of matching pumping test results.

Single and Dual Continuum Models. Although flow in the saturated zone may be dominated by fractures, the interaction of fracture and matrix must be captured in order to understand dilution and mixing. To this end, the authors (COH97) developed two saturated zone grids: (1) single continuum; and (2) dual-porosity. Most of the simulations utilized the standard single continuum model, which represents an effective porous medium as a fracture-dominated system. The single continuum model is used for calibrating the model against measured water table elevations, and for investigation of steady-state flow geometry and flow visualization. The dual-porosity model is used to consider fracture-matrix interaction. The dual-continuum model enables simulation of pumping and tracer tests in dual-porosity media. Matrix properties are derived from unsaturated zone modeling analysis and fracture data.

Simulation of Long-Term Pumping at the C-Hole Complex. Although more than 150 individual aquifer tests have been conducted at 13 boreholes in the vicinity of Yucca Mountain, the C-hole complex is the only multi-hole complex in the saturated zone at Yucca Mountain. The C-wells were drilled to perform multi-well aquifer tests and tracer tests. The authors (COH97) used the sub-site-scale model to simulate a long-term pumping test at the C-wells in order to use C-hole data to calibrate and validate the model. The full three-dimensional model was used to study the drawdown behavior at the six observation wells for the long-term pumping test.

The model uses the regional hydraulic gradient observed for the Yucca Mountain site as an initial condition and the pumping test is then an additional stress on the system. Boundary conditions are constant pressure corresponding to the observed heads (ERV94). Pumping for a total period of 250 days is simulated and the final steady-state drawdowns are reported for the six observation wells.

The matching of the simulated drawdowns to the observed drawdowns was done by a manual trial and error process. A constant withdrawal rate of 9.46 l/s (150 gpm) was assigned to one element (Lower Bullfrog unit at UE-25 c#3). A fine discretization in the vicinity of the C-hole complex was judged by the authors (COH97) to provide sufficient resolution of the distance between the pumping well c#3 and the two neighboring observation wells, UE-25 c#1 and UE-25 c#2. However, the authors (ibid.) believe that a still finer discretization may be needed to fine-tune the performance of the simulation results to the observed transients in the two wells, UE-25 c#2 and UE-25 c#3.

These simulations were intended to show what effects the faulted structure has on pumping test results. This model capability is especially useful since the pumping test results at the C-hole are a function of heterogeneities at the scale of tens to thousands of meters, and it is at this scale that radionuclides may be dispersed within the immediate site area. Since the model has been calibrated by matching results of long-term pumping tests at the C-wells, simulations of pumping tests under different conditions and at different locations can show what data would be obtained, as well as what hydrogeologic signatures could be subject to analysis. Proper test designs for the proposed Second Testing Complex, for example, can also be determined by simulating different pumping test scenarios around faults using the model.

VI.2.1.2 Saturated Zone Transport Model Construction

The saturated-zone flow modeling performed for the Yucca Mountain Project has focused on the key controlling factors influencing the measured head distributions at the site. In this section, issues related to the transport of radionuclides in the saturated zone are presented, which in addition to flow issues, requires that processes specific to the migration of solutes be considered.

The saturated zone radionuclide transport model was constructed by Zyvoloski et. al., (ZYV97), and although the transport modeling was not used directly in the TSPA-VA, the findings of the modeling were used to guide the approach that was taken to address radionuclide transport in the TSPA-VA as discussed in later in this section.

Conceptual Model of Saturated Zone Transport

The site-scale ground water flow model provides the hydrologic framework for determining the direction and rate of movement of radionuclides that reach the saturated zone beneath Yucca Mountain. In addition to flow issues, the migration of radionuclides to the accessible environment depends on transport processes and parameters distinct from the flow model itself. This section presents the authors (ZYV97) conceptual model for transport that includes advective transport of radionuclides, dispersion, diffusion of radionuclides from fractures into the rock matrix and sorption. Within the fractured tuffs, the authors (ibid.) expect the migration of radionuclides to be primarily through regions with higher bulk fracture permeability. They also believe that flow within individual joints probably occurs through channels, rather than as sheet flow through parallel-plate fractures. The authors (ibid.) note that at more distant downstream locations, the migration is likely to be through alluvium, and a model for flow and transport through a porous continuum, rather than a fractured rock, is likely to apply.

<u>Fluid Flow In Fractures</u>

The hydrologic evidence to date strongly supports the model of fluid flow within fractures in the moderately to densely welded tuffs of the saturated zone (e.g., WAD84, WHI85). First, as expected, the hydraulic conductivities measured for core samples in the laboratory are orders of magnitude higher when the sample is fractured (PET84). Also, there is generally a positive correlation between fractures identified using the acoustic televiewer of a borehole television tool and the zones of high transmissivity.

Because the role of fractures is so important to the hydrology in the saturated zone, the permeability distribution and principal flow directions depend strongly on the spatial distribution and orientations of fractures. Karasaki et al. (KAR90), in an attempt to correlate the C-wells fracture data with transmissivity measurements, tentatively concluded that the regions of high transmissivity in the C-wells correlate with fractures oriented to the northeast, with the steeply dipping fractures contributing most to the transmissivity.

Matrix Diffusion - Laboratory and Field Evidence

Instead of simply traveling at the flow rate of the fluid in the saturated zone, radionuclides will potentially undergo physical and chemical interactions that must be characterized to predict large-scale transport behavior. These interactions include molecular diffusion into the rock matrix, sorption on the minerals along the fractures or within the rock matrix, or transport in colloidal form. These phenomena are described below.

When a dissolved species travels with the fluid within a fracture, it may potentially migrate by molecular diffusion into the stagnant fluid in the rock matrix. When a molecule enters the matrix, its velocity effectively goes to zero until the Brownian motion carries it back into the fracture or into an adjacent fracture. The result is a delay of the arrival of the solute at a downgradient location from what would be predicted if the solute had remained in the fracture. In hydrologic tests not involving tracers, the pore water velocity can often be estimated given assumptions about the fracture porosity. For interpreting hydrologic tests, the fracture porosity is usually the correct porosity value because aquifer properties (i.e., transmissivity) from pump testing is controlled by fracture flow. However, the ground water travel time is often computed by dividing the flow path length by this velocity. This estimate is potentially a severe underestimate of the time required for a water molecule to migrate along the flow path. A more accurate definition of travel time for the purpose of predicting transport behavior would take into account matrix diffusion.

There have been several theoretical, laboratory, and field studies performed to demonstrate the validity of the matrix-diffusion model. Grisak and Pickens (GRI80) and Neretnicks (NER80) first applied mathematical models to demonstrate the likely effect of matrix diffusion in flow in fractured media. In these studies, transport was idealized as plug flow within the fracture with diffusion into the surrounding rock matrix. Sudicky et al. (SUD85) applied a similar model to a laboratory experimental apparatus which tracer was injected into a thin sand layer with surrounding low permeability silt layers, showing that matrix diffusion was necessary to model the conservative tracer data. Neretnicks et al. (NER82) reached the same conclusion in their experiments of transport in natural fissures in granite. Rasmuson and Neretnicks (RAS86) extended the concept of matrix diffusion to examine the coupling between matrix diffusion and channel flow usually thought to occur within natural fractures.

Transport models incorporating matrix-diffusion concepts have also been proposed to explain the often conflicting ground water ages obtained from ^{14}C data compared to ages predicted from flow data. Sudicky and Frind (SUD81) developed a model of flow in an aquifer with diffusion into a surrounding aquitard to show that the movement of ^{14}C can be much slower than predicted if only movement with the flowing water is considered. Maloszewski and Zuber (MAL85, 91) reach a similar conclusion with a model for ^{14}C transport that consists of uniform flow through a network of equally spaced fractures with diffusion into the surrounding rock matrix between the joints. Their model also includes the effect of chemical exchange reactions in the matrix, which further slows the migration velocity. Maloszewski and Zuber (MAL85) also present analyses of several interwell tracer experiments that show that their matrix-diffusion model can be used to provide simulations of these tests that are consistent with the values of matrix porosity obtained in the laboratory and aperture values estimated from hydraulic tests. The results are, in all cases, superior to previous analyses that did not include matrix diffusion effects. Finally, of greatest relevance to the saturated zone beneath Yucca Mountain is the C-wells reactive tracer test (REI97), which demonstrates that models incorporating matrix diffusion provide more reasonable fits to the tracer-experiment data than those that assume a single continuum. They showed that a suite of tracers with different transport characteristics (diffusion coefficient, sorption coefficient) produced breakthrough curves that can be explained using a diffusion model that assumes diffusion of tracers into stagnant or near-stagnant water. Finally, Waddell (WAD97) recently reported a similar result for nonsorbing tracers with different diffusion coefficients in a fractured-tuff tracer experiment at the NTS.

Thus, the theory of matrix diffusion is generally thought to be based on sound physical principles, and demonstrations of its effect have been shown in both laboratory-sized specimens and interwell tracer tests. The effect on transport under ground water flow conditions could be extremely large and, thus, should be incorporated into any realistic radionuclide migration model. It is still unclear, however, how DOE will ultimately incorporate these processes (matrix diffusion) into the TSPA-LA since they are currently not considered in the TSPA-VA.

Dispersion. Dispersion is caused by heterogeneities at all scales from the pore scale to the scale of the thickness of individual strata and the length of structural features such as faults. The resulting spreading of radionuclides is important to performance in that it will lead to dilution and should be captured in transport models. As will be discussed later in this section, the TSPA-VA simply assigns a dilution factor, to account for dispersion, rather than modeling dispersion explicitly.

Only the largest heterogeneities are represented as property zone values in the site-scale model; all dispersion caused by smaller-scale features must be represented through the use of dispersion values input into the model. Numerous ground water transport studies have been conducted at a variety of scales, and the results are compiled using the dispersivity as the correlating parameter. It is well-known that dispersivity increases with the scale, or distance, for transport of a solute (NEU90). The only site-specific data comes from the C-wells reactive tracer experiment of Reimus and Turin (REI97) and accompanying tracer tests carried out by the USGS at the C-wells. These experiments yielded estimated dispersivity values that fall in the range of uncertainty of correlations to data collected and compiled at many sites. The authors (ZYV97) believe that this result provides credibility that the dispersivity values used in the field simulations are appropriate. Very little experimental information exists for assigning transverse dispersivity. In the site-scale modeling study, however, the "rule-of-thumb" value of one-tenth the longitudinal dispersivity is used for transverse dispersivity.

Other Transport Processes. Sorption of radionuclides on rock surfaces is another mechanism that will result in retardation. These radionuclide-rock interactions can potentially occur on the surfaces of fractures and within the rock matrix. This distinction is important because the surface-area to fluid-volume ratio and the mineral distributions are probably different in the fractures as compared to the matrix. The lithium tracer in the C-wells reactive tracer experiment was modeled by Reimus and Turin (REI97) using a matrix-diffusion model with the sorption coefficient as an additional adjustable parameter. The matrix sorption coefficient that fit the data agreed quite well with the value determined in laboratory sorption tests, thus providing an additional degree of confidence in the matrix-diffusion model. The fact that the early lithium response had the same timing as that of the nonsorbing tracers, but with a lower normalized peak concentration, is consistent with matrix-diffusion coupled with sorption in the matrix.

Transport of radionuclides on colloidal particles or in colloidal form is a third mechanism that may apply at the field scale. Colloidal particles have the potential to provide a direct pathway through fractures. Strongly sorbing radionuclides such as plutonium may adhere to these particles and move more rapidly than if the radionuclide were confined to the aqueous phase. The size of the colloids may minimize diffusion into the rock matrix, thereby reducing one possible retardation effect. On the other hand, filtration of colloidal material is likely to come into play, thereby potentially resulting in large retardation factors. The key uncertainties identified by the authors (ZYV97) in predicting colloid transport in the field are:

- Whether a continuous pathway exists with large enough pore size to facilitate transport over large distances without filtration or migration into stagnant fluid storage; and

- The uncertainty regarding the relative amount of radionuclide on colloid surfaces versus that in the aqueous phase.

For the first uncertainty, field demonstration of colloidal transport is necessary to prove that this mechanism is important at the field scale. Furthermore, given the complexities of the interactions of colloids with the surrounding rock and geochemical conditions, further laboratory work to characterize these effects is necessary. Other key uncertainties not discussed by the authors (ZYV97) include the relative stability of the colloid in various geochemical environments and potential chemical and physical (i.e., filtration) retardation of the colloid itself.

Summary of Conceptual Model

Summarizing the discussion of fluid flow behavior given above, the saturated-zone transport conceptual model is outlined below:

- Radionuclides enter the saturated zone via the fluid percolating through the unsaturated rock above the water table. The exact nature of this transport is not expected to exert a great effect on the subsequent saturated-zone model, and thus, the saturated-zone transport model can be developed independently from a transport model for the vadose zone, which acts as a boundary condition for the saturated-zone model. Of course, for detailed predictions of radionuclide migration, the spatial and temporal distributions of the input from the unsaturated zone are important.

- Flow occurs within the highly fractured portions of the tuffs near the water table. There is probably not a continuous zone of high permeability to the accessible environment. Assuming there is not a continuous zone, then the low-permeability regions will effectively act as large-scale heterogeneities that give rise to large-scale macroscopic dispersion due to the tortuous nature of flow over the scale of hundreds of meters to kilometers.

- Although the vertical matrix permeability is assumed to be small over the length scale of several hundreds of meters, within a fractured region, vertical permeabilities should be as large as the horizontal permeabilities. Thus, the radionuclide will spread vertically and be present within the entire thickness of a fractured zone. The thicknesses of these fractured zones are difficult to estimate from the present data. However, the extent of fracturing correlates reasonably well with the degree of welding, which is one of the criteria used to define the submembers within a lithologic unit. Therefore, it seems reasonable to assume that the heights of the fracture zones are on the order of the thicknesses of the individual lithologic members, namely 100 to 200 m. This possibility is in contrast to flow zones detected in individual boreholes, where measurements reflect the intersection of specific fractures with the well.

- Fluid flow occurs within the fracture with stagnant fluid residing in the rock matrix blocks. All fractures have large contact areas due to the *in situ* stresses exerted on them at these depths. The conductivity of an individual fracture is probably not a strong function of its orientation because all are on the flat portion of the aperture versus effective-pressure curves. Therefore, the magnitude and direction of the components of the hydraulic conductivity tensor should be controlled by the distribution of joints of various orientations. Fractures detected from geophysical logs are generally oriented in a north-south direction and are, within 30° of vertical.

- Flow within individual joints probably occurs within channels. The fluid travels preferentially within regions of large apertures with large sections of the fracture surface containing stagnant fluid or no fluid where the faces are in contact.

- The surrounding matrix material conducts no fluid under natural ground water flow conditions but is physically connected to the fracture fluid through the pore network. Fluid is stored in this pore space and is important to radionuclide migration (see below). The matrix porosities of interest are those of the rock within the fractured regions. Fractures are generally found within the moderately to densely welded tuffs, so the range of matrix porosities of these tuffs (0.06 to 0.09 for densely welded and 0.11 to 0.28 for moderately welded) more accurately reflect the fluid storage of interest rather than the generally wider ranges of values found within a specific lithologic member.

Computer Code Selection

The FEHMN code was selected for the transport simulations for many of the same reasons it was chosen for the site-scale flow modeling discussed above. Using the same code for both ground water flow and contaminant transport modeling also eliminates model setup inconsistencies that may otherwise arise (e.g., block centered vs. node centered grids).

Layering and Gridding

Grid Generation and Grid Resolution Studies

Several three-dimensional grids were generated in support of the site-scale flow and transport modeling effort. Both structured and unstructured grids were developed, tested, and used for sensitivity analyses and flow calibration studies. Structured grids, commonly referred to as finite-difference grids, are easy to generate, but their block-like structure makes it difficult to represent complicated geometries with all but the finest grid resolution. Unstructured grids, like the common finite-element meshes, are more complicated and may consist of triangles and tetrahedrals. They can, however, represent complicated hydrostratigraphy and topography accurately at fairly low resolution. It should be noted that not all finite-element models are formulated to accommodate unstructured grids, and recent developments now allow finite differences to solve unstructured grids.

As was discussed in Section VI.2.1.1, the hydrostratigraphy represented in the geologic model consists of multiple layers of contrasting fluid flow and transport properties. The grid-generation methods used in the transport study allow the stratigraphy to be honored in numerical grids of different resolution so that comparison studies can be performed to test for grid quality and to determine the resolution required for flow and transport simulations. All mesh generation and manipulation is done with the GEOMESH/X3D toolkit (GAB95, GAB96, TRE96).

A series of six structured grids of increasing resolution was used to compare the flow through the model domain to assess the point at which increasing resolution no longer influences the results. This process identifies the resolution required for an accurate simulation of the flow field. A similar study for two unstructured grids demonstrated that the coarser grid used for calibrating the flow model was sufficiently resolved for accuracy. This section also reports on the development of a technique for selectively refining the numerical grid for transport calculations. The method uses the solute transport pathway determined on a coarse grid to identify regions of the model where increased grid resolution is required. The mesh-generation software refines the grid in those areas. After two or more successive applications of this process, the grid is finely resolved along the pathways of solute plume movement, and numerical error associated with insufficient grid resolution is minimized. The main application of this technique is for refining the revised site-scale model for transport calculations.

Approach. This subsection addresses the construction of computational grids that reflect complex geologic structure for saturated-zone flow and transport simulations. The importance of grids are summarized by the authors (ZYV97) with the following questions:

- What resolution is required to represent geology?
- What resolution is required to represent flow and transport processes?
- Can a grid be optimized to represent features and flow processes while keeping the size relatively small?
- If a flow model is calibrated on a coarse grid, is it calibrated on a fine grid?

The authors (ZYV97) point out that these grids must accurately represent the geologic structure and be appropriate for numerically accurate simulations of flow and transport. That is, any error associated with numerical grid discretization must be constrained within specified truncation error tolerances. Understanding the quality of the grids and the effects of grid-related error is necessary for assessing the quality of the simulations and generating a defensible model.

The process of developing flow and transport models for the saturated-zone studies are divided by the authors (ZYV97) into three parts:

- Developing accurate conceptual models of the geology and hydrologic material properties
- Building the grid and prescribing boundary and initial conditions
- Applying the computational physics models of flow, heat transport, and chemical transport

They provide further explanation by explaining that geologic interpretation, stratigraphic model development, and material characterization are performed based on numerous field measurements. The stratigraphic model populated with hydrologic material properties then provides the basis for computational grid development. They also point out that the ability of the numerical grid to represent the geologic complexity directly affects accuracy of the numerical model's approximation of the actual physical system's response.

GEOMESH/X3D (GAB95, GAB96, TRE96) is described by the authors (ZYV97) as a mesh-generation toolkit that can use the hydrostratigraphic model as input to create a numerical grid that represents accurately complex structures and stratigraphy such as faults, pinchouts, and layer truncations. As well as representing geologic structure, this software maintains and distributes physical and chemical attributes such as porosity, permeability, or percent zeolite. The process of populating the numerical grid with hydrologic and transport properties is described in Robinson et al., (ROB97). This process of generating and populating numerical grids from geologic framework models is automated, thus making the entire process easy to implement with fewer user-induced errors. At any step in the process, numerical resolution can be added to a particular subregion, new boundary conditions can be prescribed, or new attributes can be incorporated.

The authors (ZYV97) believe that the grid quality control issues involved in this automated process cannot be over-emphasized. They indicate that a system that uses only electronic processing of the hydrogeologic data is desirable for a defensible model during the licensing process because the interfaces can be qualified and metrics of goodness of representation can be established. These metrics would likely include a volume comparison between the project database hydrogeologic units and the model hydrogeologic units.

A primary objective of their study is to analyze how accurately grids of increasing resolution capture this complex structure and simulate flow. At what resolution is the geometry of the material distribution accurately represented with a structured grid in order to model fluid flow through the aquifer? Because higher grid resolution is more computationally expensive, this information can be used to determine what the desired accuracy of the result is and at what resolution of grid that accuracy would be attained.

<u>Saturated-Zone Unstructured Mesh from Stratamodel Geological Model</u> Software has been developed to automate the steps required to create a finite-element mesh for flow and transport calculations from a geological framework model.

The steps required to create a grid are:

- Convert Stratamodel Stratigraphic Framework Model (SFM) provided by USGS to hexahedral finite-element grid

- Remove zero volume elements from data structure
- Remove elements with vertical height less than one meter
- Convert hexahedral elements to tetrahedral elements
- Add the points defining the potentiometric surface (surface provided by the USGS)
- Add nodes with specified *xyz* location for measured well-head calibration
- Add nodes above and below well-head calibration nodes to enhance grid quality
- Add buffer zones above potentiometric surface and below bottom boundary
- Assign material values to all nodes
- Optimize the grid connectivity to insure positive finite-element coefficients
- Calculate Voronoi control volumes
- Output node coordinates, node connectivity, nodal volumes, and material and boundary lists

All file conversion, gridding, node distribution, property interpolation, quality checking, and output is carried out within a single integrated gridding tool kit. The authors (ZYV97) believe that this approach insures that the steps taken are reproducible and traceable and modifications to any step in the gridding process can be done without a great deal of labor.

<u>Grid Generation and Property Interpolation</u>. Generation of grids and interpolation of properties from the hydrostratigraphic model onto the numerical grids is performed with GEOMESH/X3D. GEOMESH/X3D is also used for comparing results from different grids, each having different resolution or grid structure. Interpolation with GEOMESH/X3D allows for the superposition on mesh A of the attributes (material number, pressure, saturation, concentration, etc.) belonging to mesh B. This utility is useful when refining a mesh or when comparing meshes of different resolution. The meshes should generally be of the same volume but do not have to coincide exactly. They do not need to have the same discretization, resolution, or element type. Either mesh can be structured or unstructured. For interpolation, a node of mesh A is first located within an element of mesh B. The attributes of the nodes defining the element in mesh B are

then linearly interpolated to the node in mesh A. Output of mesh A from GEOMESH then contains the new attribute values associated with each node. If desired, the mesh-A node is also assigned the material number of the mesh-B element. Elements of mesh A can then be assigned material numbers based on the nodal material numbers that were interpolated from mesh B.

The saturated-zone model domain selected for their grid resolution study is defined by Nevada State Coordinates of 533,340 m to 563,340 m in an east-west direction, 4,046,782 m to 4,091,782 m in the north-south direction, and -754 to 1332 m vertically above sea level. Nineteen materials are assumed located within this volume.

Although a calibrated model must have appropriate heads at each inlet and outflow boundary, to test the resolution of the various grids used, the actual pressure differential between the north and south is not important. For simplicity, a pressure difference of 15 MPa is used for all simulations in this grid resolution study. The isothermal site-scale flow model is run to steady state and the flow out of the model is compared for each grid. The problem was designed to study the errors made only in the representation of the hydrostratigraphy. This was achieved by specifying pressures on the north and south faces of the grid. Thus, the solution is a linear variation in pressure with a corresponding constant flux. Tests with homogeneous meshes confirmed this result. The differences in reported fluxes are a result only of representation errors of the hydrogeologic units. The outlet flux was chosen as the parameter to compare because this parameter is likely to be a primary factor in assessing radionuclide transport to the accessible environment. This flow was obtained by summing the outflow at the south boundary of the model. The flow volumes exhibit asymptotic behavior at higher resolution. Because higher grid resolution is more expensive, this type of analysis is used to determine what the desired accuracy is and at what resolution that accuracy would be attained.

The results of the flux changes with grid resolution can be more easily understood in terms of average grid spacing. The range of grid spacings in the vertical direction is from 696 m to 70 m. The results of the grid resolution study suggest that for saturated-zone flow computations, 100-m vertical grid resolution may be sufficient if structured or finite-difference gridding is used. This resolution is a finer grid than is commonly used in saturated-zone simulations of Yucca Mountain. In the subsection below, runs with unstructured-grid representations are presented to determine the resolution necessary for unstructured grids. The authors (ZYV97) anticipate that the restrictions of grid resolution will be somewhat relaxed if the stratigraphy is captured directly in the unstructured numerical grid. However, note also that this grid resolution study was conducted using total outflow water flux. If a criterion based on radionuclide transport was used, the result would most likely imply the need for higher grid resolution due to the nature of simulating transport using the advection-dispersion equation. The authors (ZYV97) believe that selective grid refinement in the region near the repository and close to the water table in the pathways to the accessible environment will be required for radionuclide transport.

Unstructured Grid Studies. As stated in above, it is anticipated that the unstructured grid would produce closer flux agreement between grids of different resolution than the structured study. To investigate this hypothesis, the authors (ZYV97) generated a finer-resolution model by refining the stratigraphic framework model (SFM). This model has approximately 2X resolution in the x, y, and z directions. The volume of each stratigraphic unit is identical to the lower-resolution model. The boundary conditions used are the same as in the structured grid studies-- that is, a 15 MPa difference between the north and south faces with no flow on the top, bottom, east, and west. Again, the flux flowing out of the south face is compared. The results were 3,290 kg/s for the lower-resolution model (9,279 nodes) and 3760 kg/s for the higher-resolution model (49,895 nodes). The flow rates differ by about twelve percent. The authors (ZYV97) believe that the results indicate that the flow calibration with the lower-resolution model is sufficient but some caution is warranted. The authors (ZYV97) also indicate that time constraints precluded additional resolution studies, and conclude that these studies point to a need to systematically study grid refinement and its relation to both flow and transport.

Grid Refinement Around Plumes. To adequately model contaminant transport through porous media, a computational grid will require refinement beyond that required for flow modeling. This requirement is true of the grid used for USGS/LANL site-scale saturated-zone flow simulations of the regional aquifer beneath Yucca Mountain discussed in Section VI.2.1.1 (CZA97). The authors (ZYV97) of the transport modeling study developed an approach for grid refinement that refines only that part of the grid where most contaminant migration occurs, thus minimizing the number of nodes added to the grid to assure an accurate transport solution. The refinement technique uses the results of a transport solution computed on a grid that is expected to be too coarse for an accurate transport solution. The preliminary coarse grid is then refined in the region where most contaminant migration occurs (e.g., within a specified isoconcentration surface). The flow and transport solution is recalculated on the refined grid. This grid may then be refined again within an isoconcentration surface that is generally of lower concentration than used for the initial refinement. Refinement is complete when the breakthrough curves computed at some compliance point no longer vary within a specified tolerance level. This approach is a form of adaptive mesh refinement that uses the problem solution to guide the refinement process. The technique, which uses the GEOMESH/X3D grid-generation system, was first tested on a rectangular grid with a single porous medium. This case is discussed, as it is useful in explaining the refinement methodology. The technique, tested below, was planned to be employed in FY98 to the 250-m sampled SFM currently being developed by the USGS.

For the single porous media test, a criterion is needed to determine when the grid is adequately refined. The authors (ZYV97) chose to look for convergence in the breakthrough curve at a downstream compliance point. The breakthrough monitoring location was chosen as the uppermost, central node of the grid at the downstream boundary. The authors (ibid.) found that the original constant-concentration source used for grid refinement results in different solute mass-flux input rates with the different grids. Therefore, transport solutions were rerun with the various grids using constant tracer flux so that each simulation would receive the same mass, and the breakthrough curves could then be compared. As the grid is refined, breakthrough to the monitoring point advances slightly in time and the steady-state breakthrough concentration generally increases. This result occurs because the plume exhibits less numerical dispersion around its centerline and with depth. There is little difference between the solutions for the grids with 28,511 and 57,450 nodes indicating that the 28,511-node grid is adequately refined. It should be noted that if values of dispersion or time steps are changed the grid may not be sufficiently refined.

The authors (ibid.) indicate that future work will apply the refinement technique discussed above to the USGS/Los Alamos multiple-material saturated-zone model. Refinement will be based on the concentration of a steady plume generated with the calibrated flow field. Nodes added during refinement are assigned material properties based on the original SFM discussed previously. The original nodes remain in the grid and retain their material properties. Refinement of the USGS/Los Alamos model was not pursued in this study. The authors (ibid.) indicate that the coarse 1500-m spacing of the current SFM is inadequately refined to justify refinement for transport simulations. They further note that an updated SFM with 250-m spacing will be incorporated in future work. The authors (ibid.) also believe that this refined SFM has adequate stratigraphic information to work ideally with the concentration adaptive mesh refinement technique.

Initial and Boundary Conditions

The form of the flow boundary conditions employed in obtaining a calibrated model plays a large role in the model results, especially with respect to subsequent transport predictions. A model calibrated to measured head values is a nonunique solution that must be constrained with measured or estimated flux values at boundaries. Simply put, if only head boundary conditions are used, the total flux is directly proportional to the values of permeability in the model; increasing or decreasing each permeability value by a fixed ratio changes the total flux by that same fraction. At the site scale, the flux values into and out of the flow domain cannot be directly tied to major recharge and discharge values because these occur outside the model domain. Because this is the case, there is a need to tie the flux values into and out of model faces to a larger-scale model. The authors (ZVY97) intend to further investigate the interplay between the calibrated regional model and the site-scale model.

The original plan for the site-scale model was to use fluxes or head data from the regional model as boundary conditions for the site-scale model. However, there are several problems in applying fluxes directly. The first is that the site model has sixteen units represented within its boundaries, whereas the regional-scale model represents only three units in this region. This difference presents problems in assigning fluxes to nodes with widely varying permeabilities. The second problem is that the calibrated heads for the regional model deviated the most from well data near the northern boundary of the site-scale model. Thus, fluxes were apt to be most inaccurate in that region. Because of these problems, the fixed head boundary conditions were derived from measured head data. Because of the fixed head conditions, solutions are valid for permeability ratios only. Fluxes must therefore be compared to those predicted by the regional-scale model to insure consistency.

Because of the need for finer resolution (primarily in the *z* direction), the site-scale model was developed with a smaller horizontal extent than previous site-scale models. The model dimensions are approximately 30 km by 45 km. The compilation of all relevant data was done by the USGS, and these data were then organized into a Stratigraphic Framework Model. The SFM provided the basis for all grid generation. The grid building effort produced 15 grids for testing. The grid used in the calibration was on a 1500 x 1500 m areal spacing that consisted of 5,485 nodes, 29,760 elements, and 40,548 internode connections. The calibration of this model is described in section VI.2.1.1. A good calibration on an initial modeling exercise was obtained, but large flux values pointed to a systematic error in the geometric part of the flow terms. This problem was subsequently corrected, and the flow results revealed more realistic fluxes. The corrected model results were performed on a grid containing 9,279 nodes, 52,461 elements, and 67,324 internode connections. The increase in the number of nodes was due to the inclusion of model "buffer zones" that play no part in the solution but improve the definition of the potentiometric surface. These zones are assigned values of zero for both porosity and permeability and, therefore, do not enter into the fluid flow calculation. Only the layers sandwiched between the upper and lower buffer zones are part of the flow model itself.

The source term boundary is treated as a mass-flux introduction to the saturated zone.

Model Parameterization

In section VI.2.1.1, a number of unwanted features in the geologic framework model of the current site-scale model are described, that make it difficult to produce accurate transport results in the vicinity of Yucca Mountain. These features do not significantly impact the calibration of the flow model but make simulations problematic. In parallel to producing this calibrated site-scale model, the USGS has been developing an updated geologic framework model with more up-to-date geologic interpretation near Yucca Mountain. The authors' (ZYV97) plan is to develop grids and calibrated flow solutions on this revised model in FY98 and to use this revised flow model as the platform for performing radionuclide transport calculation.

The main difference between the two framework models is that the discretization of the revised-site SFM is finer (250 m) than the older-site SFM (1500 m). This difference leads to smoother transitions between and more realistic representations of the hydrogeologic units. Additional data from the ISM framework model (ZEL96) were incorporated into the 250-m framework model. This approach gives better resolution to the volcanic units. The representation of the upper volcanic confining unit (UVCU, Unit 14) is of importance due to its predominance in the control of the flow beneath the potential repository site. The UVCU appears primarily in the northern half of the 250-m framework model, with relatively isolated bodies in the southern part of the modeled area. The UVCU does not appear as a large body in the central part of the model, as it does in the 1500-m framework model. It appears that the configuration of the UVCU in the 250-m framework model may produce the steep hydraulic gradients in the north, where it exists, and have a less dominant control on the flow field in the southern and central parts, where it does not exist.

With regard to transport, the authors (ZYV97) note that a revised flow model based on this geologic interpretation will correct the problems in the current version and allow realistic simulations from the potential repository to hypothetical accessible environment locations as far as 25 km from the site.

Model Calibration

The transport model used the flow field of the calibrated sub-site model to predict contaminant transport migration directions and velocities. Since there is no contaminant field data (e.g., existing contaminant concentrations in monitoring wells) on which to perform a transport calibration the authors (ZYV97) did not conduct any further model calibration.

Predictive Simulations

Several models and numerical techniques are used to obtain results for radionuclide transport in the saturated zone. First, a technique based on numerical convolution is developed to link the unsaturated-zone breakthrough curves at the water table to the saturated-zone transport system. In this method, the inputs are the mass flux of radionuclides reaching the water table versus time, along with a generic breakthrough curve in the saturated zone, computed as the response at a downstream location to a constant injection of radionuclides at the footprint of the proposed repository. The numerical implementation of the method was verified by performing a full calculation using the actual time-varying input from an unsaturated-zone calculation as input to the saturated-zone model. The method allows a variety of input flux curves to be computed quickly without recomputing the saturated-zone calculation each time. Assumptions inherent to the convolution technique include steady-state flow and linear transport processes, which, for sorption, implies that the linear-sorption isotherm model must be used. The authors (ZVY97) believe that the linear-K_d sorption model is not overly restrictive because one can select a K_d value that conservatively bounds the sorption behavior predicted by a nonlinear-sorption isotherm model.

Before proceeding to more complex site-specific models, a simplified three-dimensional flow and transport model is presented to examine the importance of several transport parameters that are difficult to investigate fully with the current site-scale models. Dispersivity is established as one of the key uncertain parameters that influence the concentration (and hence dose) at accessible environment compliance points. The transverse dispersivity is actually a more sensitive parameter for dilution because it governs the degree of lateral spreading of the plume.

Matrix diffusion, established as a valid process in the field test of Reimus and Turin (REI97), affects the breakthrough times at a downstream location but, to a first approximation, does not influence the peak concentration unless radioactive decay is significant. Another important factor regarding matrix diffusion is that it allows radionuclides to contact minerals in the rock matrix that potentially sorb radionuclides. Even small amounts of sorption have a large effect on breakthrough times and peak concentrations. Finally, this simplified model was used to illustrate that the saturated-zone transport system has the ability to dilute spikes of high concentration and short duration that come from bypassing of the unsaturated zone through fractures. Thus, the authors (ZYV97) believe that the saturated zone provides an important component in a "defense-in-depth" strategy in which uncertainties leading to poor performance in one part of the repository system are mitigated by the performance of another radionuclide transport barrier.

To simulate radionuclide transport from the footprint of the repository to a 5-km compliance point, the sub-site-scale model was used. This model was chosen as an appropriate substitute to performing these calculations using the site-scale model because of the more accurate representation of the geology near Yucca Mountain. When the site-scale model is revised to use the new hydrostratigraphic data based on a 250 x 250-m geologic grid, all calculations will be performed with the site-scale model itself. The sub-site-scale flow model captures the large hydraulic gradient and flow through the geologic strata of relevance downstream of the repository footprint, including the Prow Pass, Bullfrog, and Tram Tuffs units. Radionuclides travel to the east and south from the footprint to a 5-km compliance point. Releases into the Prow Pass unit travel in a more easterly direction than releases in the other units; releases into the Tram unit at the south end of the footprint travel almost due south. All releases follow the dipping stratigraphy, indicating downward movement of radionuclides. This effect may be important if upcoming field studies reveal more reducing conditions with depth, because sorption coefficients of ^{99}Tc and ^{237}Np are likely to be much higher and solubilities much lower under reducing conditions.

Transport times to a hypothetical 5-km compliance point under conditions in which the effective porosity is the matrix porosity are on the order of a few thousand years; much shorter transport times result from an assumption of less matrix diffusion. However, the extent of matrix diffusion itself only influences the arrival time rather than the concentration at the downstream location. This effect is in contrast to differences in fluid flux that may occur due to future wetter climates, which result in earlier travel times but may also lower concentrations (greater dilution).

Sorption of radionuclides such as ^{237}Np onto zeolitic tuffs in the saturated zone also leads to significant retardation and longer travel times to a 5-km compliance point.

The results of the sub-site-scale model are then used as input to transport calculations to a hypothetical 20-km compliance point in the site-scale model. Simulations assuming both fracture-like and matrix-like effective porosities in the fractured tuff were performed to investigate the importance of this parameter. In both simulations, the alluvium present along the transport pathways were assigned high porosity. In this set of calculations, the nature of transport in the fractured tuffs is less important as the system becomes increasingly dominated by long predicted travel times in the alluvium. Thus, even if the tuffs are presumed to have a low effective porosity, travel times of 10,000 years or more are predicted in the alluvium alone. Furthermore, the results show that even small amounts of sorption in the alluvium shift travel times to values on the order of 50,000 years, and predicted concentrations at the compliance point are lower than in the absence of sorption. Clearly, for more distant compliance points, the flow and transport behavior of the alluvium becomes increasingly the controlling factor in saturated-zone performance.

The influence of repository heat on saturated-zone flow and transport of radionuclides is also studied using the subsite-scale model. Repository waste heat creates a zone of higher-than-ambient temperature that extends vertically into the saturated zone and along the prevailing flow pathway from the repository. However, the predicted impact on transport of ^{99}Tc to a 5-km compliance point is very small. One outstanding issue related to repository heat is the possibility of temporary or durable changes to the permeability and porosity due to temperature-dependent rock-water interactions. If these effects turn out to be minor, then repository waste heat has minimal influence on the migration of radionuclides through the saturated zone.

Integrated transport predictions are presented in which are linked to the unsaturated-zone transport model of Robinson et al. (ROB97) with the subsite-scale model to predict the transport of the key radionuclides ^{99}Tc, ^{237}Np, and the isotopes of plutonium. In Robinson et al. (ROB97), the authors investigated the performance of the unsaturated-zone system for different infiltration rates that could result from changes to the present-day climate. These predictions of radionuclide mass flux at the water table are input to convolution calculations to predict the combined unsaturated/saturated-zone performance at 5 km. For the unsaturated-zone performance predicted in Robinson et al. (ROB97), the integrated response in the saturated zone for ^{237}Np and ^{99}Tc is a direct consequence of dilution of percolating unsaturated-zone fluid with flowing saturated-zone ground water. Therefore, poorer predicted unsaturated-zone performance under wetter future-climate scenarios translates directly to higher predicted concentrations in the saturated zone. Sorption onto zeolites in the saturated zone should provide a considerable delay in arrival times for ^{237}Np. For plutonium, rather than climate change or sorption to the host rock, the key factor influencing concentrations is the propensity of plutonium to sorb to mobile colloids.

Regarding the nature of flow and transport in the fractured tuffs, the authors (ZYV97) experimented with different flow and transport models to investigate different methods of simulating this dual-porosity system. A dual-porosity particle-tracking model for transport was invoked, and the influence of matrix diffusion properties was examined. The results follow those of the matrix-diffusion conceptual model, but several factors argue against its use in large-scale transport model predictions. First, the particle-tracking module does not at present handle the dispersion coefficient tensor formulated as longitudinal and transverse components. Furthermore, although the diffusion model accurately simulates the case of diffusion into an infinite matrix continuum, finite fracture spacings are not part of the model as currently constituted. Therefore, particle tracking cannot be used in site-scale models. A finite-element dual-porosity solution was also investigated. As expected, the dual-porosity flow simulation yielded virtually identical steady-state results to the single-continuum model. Transport results captured the two extremes (fracture-dominated and pervasive matrix diffusion) but failed to produce accurate results for small but non-negligible diffusion into the rock matrix.

VI.2.1.3 TSPA-VA Implementation of Saturated Zone Modeling Analysis

The Saturated Zone Flow and Transport Technical Basis Document for the Total System Performance Assessment - Viability Assessment provides a detailed description of the means by which the saturated zone flow and transport modeling, as presented in sections VI.2.1.1 and VI.2.1.2, has been integrated into the total system performance. The following sections outline the basic components of the saturated zone modeling performed in the TSPA-VA.

Synopsis of TSPA-VA Approach

Past TSPAs focused on the biosphere interface located 5 km from the repository. Alternatively, the TSPA-VA is now focused on calculating radionuclide doses 20 km downgradient from the repository; the DOE indicates that this is due to changes in guidance that were based upon recommendations from the National Research Council (NRC95).

As presented in the previous sections, numerical models were used for the purpose of characterizing and understanding the flow and transport at the regional, site and sub-site scales and to perform TSPA-VA calculations. The conceptual models, upon which the numerical models were developed are based upon all available data and knowledge about the saturated zone. Likewise, the TSPA flow and transport models were developed based upon site knowledge, input from the workshops and expert elicitations, as well as insights provided by the numerical modeling results.

To support TSPA-VA calculations a base-case numerical model was developed for the saturated zone to evaluate the migration of radionuclides from their introduction at the water table below the repository to the release point to the biosphere. In order to estimate the uncertainty associated with the base case scenario, sensitivity analyses were also performed.

A hierarchy of models was used to simulate the movement of ground water and the transport of radionuclides in the saturated zone. Explicit, two- and three-dimensional modeling was not used to simulate radionuclide concentrations because it can generate numerical dispersion, which artificially lowers the concentrations, particularly when matrix diffusion is occurring. The TSPA 3-D saturated zone flow model as described in the preceding sections was used only to determine flowpaths through the saturated zone and potential impacts due to climatic change which are discussed later in this section. The TSPA 1-D saturated zone transport model was developed based on the flow paths from the 3-D flow modeling and used to determine concentration breakthrough curves at a distance of 20 km for unity release of radionuclides from six streamtubes. The saturated zone transport component of the analysis was linked to the transport calculations for the unsaturated zone through which contaminants migrate downward in percolating ground water from the repository to the water table (e.g., the spatial and temporal distributions of simulated mass flux at the water table). The linking was accomplished by using the convolutional integral technique to combine the unit breakthrough curves calculated by the TSPA one dimensional saturated zone transport model with the time-varying radionuclide sources from the unsaturated zone. Changes in the saturated zone flow and transport system in response to climatic variations were incorporated for the three discrete climate states (dry, long-term average, and superpluvial) considered in the other components of the TSPA-VA. Specific discharge and volumetric ground water flow rate in the saturated zone stream tubes were scaled in transport simulations to reflect climate state. The saturated zone transport results were linked to the biosphere analysis by the simulated time history, or system response as a function of time, of radionuclide concentration in ground water produced from a hypothetical well located at the biosphere interface. The biosphere was assumed to be located 20 km from the repository. Radionuclide concentrations in the hypothetical well water were then used in the biosphere component to calculate doses received by the public.

For the base case, uncertainty in the saturated zone system was evaluated through Monte Carlo variation in the input parameters used in the TSPA one dimensional saturated zone transport model. Primarily, the uncertainty in radionuclide transport parameters was evaluated. The one-dimensional saturated zone transport model was used to calculate 101 unit breakthrough curves (100 Monte Carlo simulations and the expected value or base case). The results of the one dimensional saturated zone transport calculation are located in a "family" of unit radionuclide concentration breakthrough curves. For each TSPA-VA Repository Integration Program (RIP) realization, a saturated zone unit breakthrough curve was randomly selected for use in the convolution integral method.

The TSPA-VA sensitivity studies were designed to examine five of the key issues related to the base case saturated zone analysis assumptions. The sensitivity studies were performed to provide information about the importance of these issues with respect to repository performance. The effect of dilution in the saturated zone and vertical transverse dispersivity was investigated to address concerns from the Saturated Zone Expert Elicitation Panel. The impact of including heterogenity and large-scale flow channelization in a three-dimensional flow and transport model was also studied. A two-dimensional dual-porosity transport model was used to calculate radionuclide concentrations to examine the effect of the base case assumptions of a single continuum and using effective porosity as a surrogate for the matrix diffusion process. In addition, alternative conceptual models of colloid-facilitated plutonium (Pu) transport were developed and implemented for sensitivity analysis.

TSPA Flow System Conceptualization

Regional-Scale Saturated Zone Flow Model. The regional-scale 3-D flow model for the TSPA-VA was developed by D'Agnese et al. (DAG97a) to characterize the conditions of the present day ground water flow in the Death Valley region. The numerical code used for the regional flow model was MODFLOWP (HIL92). MODFLOWP is an adaptation of the U.S. Geological Survey 3-D, finite-difference modular ground water flow model, MODFLOW (MCD88).

The finite-difference mesh used for the USGS regional flow modeling consists of 163 rows, 153 columns, and three layers. The grid cells were oriented north-south and were of uniform size, with side dimensions of 1,500 m. This results in a modeled area that is 244 km long and 229 km wide. The layers represent conditions at 0-500 m, 500-1,250 m, and 1,250-2,750 m below the estimated water table. The first and second layers were designed to simulate local and sub-regional flow paths mostly within the valley-fill alluvium, volcanic rocks and shallow carbonate rocks. The third (lowest) layer simulates deep regional flow paths in the volcanic, carbonate and clastic rocks.

From the perspective of the TSPA-VA, the most important output from the USGS regional scale model was information to determine a ground water flux multiplier for the long-term average and superpluvial climate conditions assumed for the base-case TSPA-VA analysis. The ground water flux multipliers were used to calculate a ground water flux for each of the climate states relative to present day conditions which is required as input to the TSPA one-dimensional saturated zone model discussed later.

With respect to model calibration, the TSPA-VA states:

> *These results* [calibration], *suggest that additional calibration may significantly improve model accuracy. This analysis suggests that the model is a reasonable representation of the physical system, but evidence of model inaccuracies exists. Inaccuracies in the simulated ground water fluxes in the flow model are generally proportional to uncertainty in the overall ground water budget of the region. The model continues to undergo development for future use by the YMP and the environmental restoration program at the Nevada Test Site.*

<u>Site-Scale Saturated Zone Flow Model</u>. Note: In a number of places the TSPA appears to be inconsistent with the actual reference documents. For example, in Milestone SP25CM3A (ZYV97) that describes the site scale modeling work it is indicated that the modeled area is 30 by 45 km, rather than 20 by 36 km as indicated in the TSPA.

The site-scale flow model developed by Zyvoloski et al., (ZYV97) and used to support the TSPA-VA was developed using FEHM (ZYV83). The 3-D flow model that was developed incorporated an area of about 20 km by 36 km to a depth of 950 m below the water table. The model grid is a uniform orthogonal mesh with 500-m x 500-m x 50-m elements.

The results of the site-scale model calibration appear to be better than that for the regional scale model. The results of the site-scale saturated zone flow model were used in the TSPA to estimate flow path lengths and directions through each of the hydrostratigraphic units downstream from the repository. This was done via a particle-tracking analysis, which only simulates advective flow and does not account for dilution due to dispersion. The calculated flow path lengths were incorporated into the 1-D saturated zone transport simulations discussed below.

The TSPA states, with regard to limitations, in the site-specific flow model:

> *The main concern is related to the problem of large numerical dispersion inherent with the use of a relatively coarse grid (cell size is 500 m x 500m x 50 m) when performing transport calculations. The desire to minimize spurious transverse dispersion for the SZ analyses necessitated the use of 1-D streamtubes for the transport calculations of the SZ analysis, which could be more finely discretized (grids spaced at 5 m intervals).*

<u>One-Dimensional Saturated Zone Transport Model</u>

The TSPA 1-D saturated zone transport model was developed to simulate the radionuclide concentration breakthrough curves that form the basis of the TSPA-VA calculations performed with the RIP computer program. Each radionuclide was transported separately in the analysis. The DOE indicates that they chose the 1-D transport simulation method because *of the desire to eliminate spurious dilution of the radionuclide concentration resulting from numerical dispersion, which can occur in coarsely gridded 3-D solute transport simulations.*

The DOE goes on to state that *Solute transport simulation using a 1-D numerical model precludes dilution from transverse dispersion, by definition. The dilution from transverse dispersion was explicitly specified in this modeling, as a post-processing step. This dilution factor was treated as a stochastic parameter, as described in Section 8.4.2.* Essentially, the DOE dilutes the concentrations of the radionuclides reaching the down gradient well by a factor of 1 to 100, which they obtained from the expert elicitation panel estimates.

The six stream tubes for the 1-D transport simulations can be conceptualized as follows: They are a combined width of 3,000 m and range between 10 and 20 m in vertical depth. This depth is important as it will have a significant impact on dilution. The volumetric flow rate of the ground water through each streamtube was determined at the water table from flow simulations using the site-scale flow model developed by Bodvarsson et al. (BOD97) for the unsaturated zone. The cross-sectional area of each streamtube was specified to be proportional to the volumetric ground water flow area. The specific discharge within the streamtubes in the saturated zone was 0.6 m/y for current climatic conditions.

Simulations of the radionuclide transport in the saturated zone for the TSPA-VA calculations were performed using FEHM. The streamtubes were 20 km long, with regular grid spacing in the tubes of 5 m. The radionuclide 1-D transport simulations were performed assuming a steady, unit (1 g/y) radionuclide mass source at the upstream end of the streamtube (i.e., the water table at the base of the unsaturated zone below the water table). Transport of each radionuclide was simulated separately in the 1-D simulations. Transport simulations with the 1-D stream tube approach implicitly assume complete mixing of the radionuclide in the volumetric ground water specific to each streamtube.

The convolution method was used in the TSPA-VA calculations to determine the radionuclide concentration in the saturated zone, 20 km downgradient of the repository as a function of the transient radionuclide mass flux at the water table beneath the repository.

<u>Implementation with the RIP Computer Code</u>

With the exception of the potential for colloidal transport of plutonium, all of the saturated and unsaturated zone flow and transport parameters were sampled independently in RIP. At each time step within the RIP simulation, the current climate state and the radionuclide mass flux at the water table for each of the radionuclides from each of the six source subregions were passed to the convolution integral subroutine. The convolution integral subroutine calculated the concentration of each radionuclide for each of the six streamtubes at the 20 km distance from the repository for that time step, including reduction of concentration from the dilution factor as discussed in the next section. The simulated radionuclide concentrations were passed by the RIP simulator to the biosphere component of the TSPA-VA at this point for dose calculation.

Development of Parameter Distributions and Uncertainty

The DOE indicated that the key uncertain parameters in the analysis were the following: (1) effective porosity in the volcanic units and the alluvium/undifferentiated valley-fill unit; (2) distribution coefficients for sorbing radionuclides; (3) the ratio of the radionuclide mass in aqueous and colloidal forms for colloid-facilitated transport of plutonium; (4) longitudinal dispersivity; (5) the fraction of flowpath through the alluvium; and (6) the dilution factor.

A seventh uncertainty that should have been included is the degree to which fractures and matrix are interacting (i.e., importance of matrix diffusion).

Uncertainty in radionuclide transport through the saturated zone was incorporated in the TSPA-VA by varying key transport parameters for 100 realizations. All input parameters required for the transport model were assumed to be either stochastic with an associated distribution or constant. If the parameter was assumed to be stochastic, its distribution was determined and then sampled using the Latin Hypercube Sampling module of the RIP code to obtain 100 sets of input parameters. Since LHS tends to underestimate the variance on the mean, the DOE should ensure statistical convergence.

The Saturated Zone Expert Elicitation Panel provided input for the input parameters and distributions. For example, the panel estimated that the dilution factor ranged between 1 and 100 with a median value of about 10.

VI.2.1.4 Saturated Zone Information Needs

TSPA-VA Identified Needs

Regional Scale Flow Modeling

The Death Valley regional flow system consists of ground water moving through a 3-D body of consolidated and unconsolidated materials. The 3D hydrogeologic framework model described the characteristics of this saturated volume. The upper boundary of the flow system is the water table. The lower boundary of the flow system is located at a depth where ground water flow is dominantly horizontal and moves with such small velocities that the volumes of water involved do not significantly impact regional flow estimates. The lateral limits of the regional flow system may be either no-flow or potential-flow boundaries. No-flow conditions exist where ground water movement across the boundary is prevented by physical barriers or divergence of ground water flow paths. Flow exists where ground water potentiometric gradients permit flow across a boundary.

For purposes of conceptualization and subsequent numerical simulation, the limits of the flow system for the regional model were selected based on reevaluation of previously defined flow system boundaries, the potentiometric surface developed for the regional modeling study, and the hydrogeologic framework model. Very little hard data exist to support a precise definition of the western extent of the flow system. The western boundary of the flow system is therefore placed to coincide with the eastern edge of the Death Valley saltpan which is interpreted as the terminal sink of the flow system.

The water budget for the Death Valley regional ground water flow system is difficult to compute, because inflow and outflow volumes are poorly defined for many areas. In addition, the large size of this regional system precludes the comprehensive and accurate assessment of all inflows to and outflows from the system. Previous attempts to estimate water budgets for various parts of the flow system did not use consistent boundaries, so the budgets cannot be readily compared. The regional model uses a lumped-budget approach; each component of the ground water budget is defined by a single lumped value even though it may have been calculated originally for separate areas in the basin. This lumped-budget approach permits an encapsulated view of the system, but the authors (ZYV97) point out that errors are inevitable in the estimates. Short of physical measurements modeling is probably the best means of resolving these errors.

Problems with the regional model are indicated by weighted residuals that are not entirely random, indicating some model error. This is related to the occurrence of large positive weighted residuals for hydraulic heads, where simulated hydraulic heads are distinctly lower than the observed values, and large negative weighted residuals for spring flows, where simulated flows are distinctly less than observed flows. The problem is also related to nonnormally distributed less extreme weighted residuals. These results, combined with the previously discussed observation that every model update considered thus far, significantly improved model fit, suggests that additional calibration may significantly improve model accuracy. While the authors (ZYV97) believe that the model is a reasonable representation of the physical system, evidence of important model error exists.

Site-Scale Flow Modeling

Objectives of the modeling. The authors (ZYV97) outlined the objectives of the site-scale model as the following:

1. Provide a large-scale description of the hydrogeologic framework of the site saturated zone flow system based on a sampling of 1500 m by 1500 m mesh;

2. Provide a mechanism to extend model calibration and sensitivity testing of parameters used in the model;

3. Provide the flow field for doing preliminary transport simulations and estimates of ground water travel time through the use of additional transport related capabilities within FEHM; and

4. Provide initial estimates of permeability for 16 hydrogeologic units from the SFM and two additional zones of small permeability and recharge at Fortymile Wash.

Model Limitations

The authors (ZYV97) outlined the model limitations as follows:

1. **Simulations are restricted to fully saturated conditions from the water table and below.** Although the model was built using a framework model that extended to land surface, the unsaturated zone was not included as part of the flow model. The unsaturated zone was omitted because of time constraints and the long execution times for forward simulation runs associated with two-phase flow problems.

2. **The model does not account for variations in temperature within the flow system.** Temperature varies within the ground water flow system and may be a useful constraint in identifying acceptable model representations of both temperature and hydraulic head. The preliminary status of the model limited the extent to which temperature could be evaluated. Furthermore, the temperature of the system was specified at a uniform 44°C which may be too high to represent the average temperature.

3. **It is likely that the flow model is non-unique.** Coordinated adjustments in permeability values (either higher or lower by some multiplier) might lead to similar hydraulic head distribution and calibration. Because fluxes were not specified explicitly at either the upgradient or downgradient ends of the model, the

model is less constrained as it would be with fluxes included in the calibration. However, because some permeability values (of admittedly minimal accuracy) were specified explicitly throughout the parameter estimation, the model was partially constrained which likely caused the parameter estimation process to converge in many instances.

4. **The large hydraulic gradient is poorly understood and greatly affects model calibration, simulated permeability values, and flux.** Additional data and testing are required to adequately characterize this feature. Testing and reconfiguration of monitoring intervals within borehole USW G-2 could be done to provide permeability, flow-survey, temperature, and hydraulic-head data at different depths, particularly for the middle volcanic aquifer. Construction of additional boreholes in the large hydraulic gradient area, such as a corehole into the middle volcanic aquifer adjacent to drillhole WT-6, could provide useful vertical gradient, hydraulic-head, saturation, and permeability data. The authors (ZYV97) believe that the site-scale model was successful in representing the large hydraulic gradient through the incorporation of a vertical barrier to flow, but other representations are possible.

5. **Flux into the site model domain is poorly defined and remains one of the most elusive of model variables.** The quality of the model is in part a measure of the understanding of the distribution and amount of recharge within the model domain. Comparison of fluxes into and out of the model is dependent on available data, which although greatly lacking will not likely be improved substantially through additional field studies. Water levels within the flow system could still be adjusting to recharge supplied during climatically wetter conditions. If such a condition exists, the effect may be too subtle to observe with the available hydraulic data. Adjusting water-level conditions could be evaluated using the regional model to replicate conditions necessary to observe the effect of increased recharge under past wetter climates.

6. **Limited hydraulic-test data exist for constraining permeability values used in the model.** Few hydraulic-test data are available that involve multiple observation wells within the model domain from which huge-scale transmissivity or hydraulic conductivity values can be derived. The exception to this condition is the C-hole-complex hydraulic testing which is optimally located for conditions at Yucca Mountain and provides a test involving a large volume of the middle volcanic aquifer. However, the C-hole testing is in a highly fractured area and might not be representative of the entire area. In general, the model does not distinguish between the permeability of the rock matrix, fractures, or faults. It is possible to add large-scale features such as faults explicitly within the model by regridding, but hydraulic characteristics for faults in the saturated zone are not presently available.

7. **Definition of the hydrogeologic units within the model is limited by the sampling interval used (1,500 m).** By sampling the framework model at a smaller interval (for example, 250 m) better resolution of the hydrogeologic units could be obtained. but resulting in a larger computation mesh. Experience from the site-scale modeling exercise suggests that this approach is warranted and likely would succeed. However, higher resolution sampling alone may be insufficient to explicitly represent faults.

As noted above, comparisons of flux from the regional model showed almost twice the amount discharging from the southern end of the site model, and substantially different amounts for the north and east sides. The major flux differences between the two models occur in the northeast corner where a large part of the recharge from the north is diverted east and discharges in part because of the interaction of the constant-head boundaries and the imposed east-west barrier needed to represent the large-hydraulic gradient.

The authors (ZYV97) observe that on initial inspection, model match to hydraulic-head data and the resulting distribution of residuals have some problems. Although permeability values for all of the hydrogeologic units used in the model lie within reported literature values, reported values for individual units have large ranges. Furthermore, in the case of the middle volcanic aquifer, values of permeability from large-scale hydraulic testing at the C-hole complex were three orders of magnitude larger than those used in the model. This discrepancy may be indicative of model error, or alternately, the possibility of a local, large-permeability zone not represented in the present model. Finally, any model calibrated using hydraulic heads alone is subject to error in simulated flux.

Improvements suggested by the authors (ZYV97) for future model developments include:

- Conduct sensitivity analyses with regard to which model variables have the greatest effect when varied on the sum of squared residuals for hydraulic head. This would provide a guide for additional field studies to reduce uncertainty in the model.

- Refine hydrogeologic framework model to better define the distribution of the hydrogeologic units. In particular, the upper volcanic confining unit is currently over-represented. This discrepancy substantially influences simulated flow and transport simulations.

- Use higher resolution sampling of the hydrogeologic framework model to better delineate unit offsets caused by faulting. This would result in a denser finite-element mesh, resulting in longer execution times, but would provide a more realistic portrayal of the flow system than is available in the model.

- Add major faults explicitly as surfaces within a refined version of the hydrogeologic frame-work model, so that their potential as barriers to flow or as fast pathways to the accessible environment may be evaluated.

- Decouple permeability parameters for the upper and middle volcanic aquifers to the extent practical during model calibration. This separation of the two primary volcanic aquifers at Yucca Mountain within the model would better represent the permeability distribution.

- Recalibrate the existing model with larger values of permeability in the middle volcanic aquifer and the upper volcanic aquifer.

- Incorporate additional data into the formal model calibration. This could include flux data from the regional model for at least one face of the model and borehole-temperature data to better constrain the solution.

- Fluxes should be extracted from a refined, improved version of the USGS regional model of D'Agnese et. al. (in press) in which the topmost layer has been subdivided to better represent the hydrogeologic units at Yucca Mountain and in the Amargosa Desert.

- Include vertical flux through the bottom of the model based on regional model values.

- Use hydrochemical and isotopic data as a check against flow model results.

Sub-Site-Scale Flow Modeling

For the sub-site scale modeling the authors (COH97) reached a number of conclusions regarding the adequacy of the existing data base. These conclusions/recommendations include:

- The properties of the Bullfrog need further characterization since (a) this unit is by far the most important for flow in the saturated zone due to its large fracture permeability, and (b) it underlies the repository at the water table.

- Fault properties need further characterization due to their obvious effects on flow at the sub-site scale.

- Measurements of fracture porosity must be made so that models can better estimate pore velocity.

- Geochemical sampling that considers vertical hydrochemical variations is needed to understand the 3-D nature of flow in the saturated zone.

- Investigation by numerical simulation of the large hydraulic gradient should be undertaken. The authors (COH97) believe that the existing unsaturated and saturated zone models contain enough geologic detail and process modeling capability to make a credible attempt in this direction. Coupling of the two models can be done to facilitate these analyses.

- Because chemical components undergo mixing and dilution due to flow and fracture-matrix interactions, the processes of flow and transport are coupled and should be considered together.

- Additional hydraulic tests and well placement should be designed to focus on fault properties and the Bullfrog unit

- Extensions of the grid should be made to decrease boundary effects and better model transient pumping tests.

- The grid should be extended spatially to model flow and mixing at greater distances from the repository.

- Advanced visualization techniques should be brought to bear on the problem of elucidating the complex 3-D flows observed in the simulations.

Contaminant Transport Modeling

Conclusions and Recommendations. The authors (COH97) developed the following conclusions and recommendations with respect to the contaminant transport modeling:

- Grid resolution was found to be critical for both flow and transport.

- The transport simulations are very sensitive to matrix diffusion.

- Continue close collaborative effort with the USGS site flow modeling. Continue to update the Stratigraphic Framework Model with the best available data and establish quantitative measures of grid fidelity to the SFM.

- Perform preliminary transport simulations during continued flow calibration efforts. This effort will uncover early possible incompatibilities between the flow and transport conceptual models and will eliminate any problems in sampling frequency that may result in an inaccurate representation of units. This parallel computation may also uncover potential fast paths for radionuclides that can be corroborated or dismissed with supporting thermal or geochemical data. In this way, transport modeling will provide a tool for improving the flow model. By establishing the effect on the radionuclide flux at the compliance boundaries, flow model improvements, such as creating a detailed inlet flux map, may be evaluated with respect to their importance to performance assessment.

- Enlarge the modeling domain of the site-scale model north of the large hydraulic gradient area where the calibration of the regional model is better and the fluxes of the regional model are more defensible. This approach will also allow better redistribution of fluxes from the three-layer regional model to the sixteen-layer site-scale model.

- Use the 250-m sampling of the SFM. This effort will provide sufficient resolution, in the vicinity of Yucca Mountain for transport calculations.

- Use stochastic approach for transport modeling to better characterize uncertainties in the dispersive mixing process occurring at subgrid block scales.

NRC Identified Needs

The NRC is developing a strategy for reviewing the performance of the proposed repository. As currently envisioned, the elements of this strategy necessary to determine acceptability of repository performance are defined by the NRC as key technical issues of the subsystem abstractions. As part of this process, the NRC has developed Acceptance Criteria for the key issues of the DOE TSPA that will ultimately be used to determine the viability of the repository at Yucca Mountain. This NRC evaluation is very relevant in assessing whether the methods and information presented by the DOE have the potential to produce results that are defensible under regulatory reviews.

The two NRC status reports that are most pertinent to ground water flow and contaminant transport are entitled *Issue Resolution Status Report - Key Technical Issue: Unsaturated and Saturated Flow under Isothermal Conditions* and *Issue Resolution Status Report - Key Technical Issue: Radionuclide Transport.*

The following discussion is organized by key technical issues. Under each issue, the NRC's Acceptance Criteria are presented and their assessment as to whether DOE has met the Criteria is provided.

NRC's Issue/Subissue Statement

The NRC developed these Issue Resolution Status Reports with the primary objective to assess all aspects of the ambient hydrogeologic regime at Yucca Mountain that have the potential to compromise the performance of the proposed repository. The secondary objective was to develop review procedures and to conduct technical investigations to assess the adequacy of DOE's characterization of key site- and regional-scale hydrogeologic processes and features that may adversely affect performance. The primary issues identified by NRC with respect to the hydrologic regime are the following:

- Hydrologic Effects of Climate Change
- Present-Day Shallow Infiltration
- Deep Percolation (Present and Future)
- Saturated Zone Ambient Flow Conditions and Dilution Processes
- Matrix Diffusion
- Radionuclide Transport Through Porous Rock
- Radionuclide Transport Through Alluvium
- Radionuclide Transport Through Fractured Rock

The following sections discuss each of the above issues by presenting its relevance to PA, as well as NRC's Acceptance Criteria and resolution status with respect to the TSPA-LA.

Issue Resolution Status

Hydrogeologic Effects of Climate Change

Relevance to PA. For the DOE to adequately demonstrate and quantify in its Total System Performance Assessment (TSPA) the effects that climate change might have on repository performance, the NRC believes that it should consider how these effects interplay with the other factors within and between key elements in the engineered and natural subsystems of the repository. Climate change and its hydrologic effects are important factors that need to be abstracted into three of the key elements of the engineered and natural subsystems: (1) spatial and temporal distribution of flow; (2) flow rate in water production zones; and (3) location and lifestyle of critical group (includes consideration of water-table rise).

A description of the technical basis for review methods and acceptance criteria for the subissues of climate change and hydrologic effects of climate change is presented in NRC97a. An important new paper on Devils Hole was published in 1997; however, at this time the NRC has not changed the previously developed acceptance criteria.

The NRC has previously recommended (NRC97a, p. 8) a pragmatic approach to address climate change. Under this approach, global, enhanced, greenhouse warming would be presumed to last no more than several thousand years, and that, about 3,000 years into the future, the climate at Yucca Mountain will resume global cooling predicted by the Milankovitch orbital theory of climate. Pluvial conditions should be expected to dominate at least several thousand years of the next 10,000 years. According to NRC's analysis past climate conditions were cooler and wetter than today, about 60 to 80 percent of the time.

NRC Acceptance Criteria. In the NRC's Technical Review of the TSPA-LA, it will determine whether DOE has reasonably complied with the Acceptance Criteria listed below:

1. Climate projections based primarily on paleoclimate data are acceptable for use in performance assessments of the Yucca Mountain site. During its review, the staff should determine whether the DOE has made a reasonably complete search of paleoclimate data that are available for the Yucca Mountain site and region, and has satisfactorily documented the results. Staff should determine that, at a minimum, the DOE has considered information contained in Winograd et al. (WIN92); Szabo, et al. (SZA94); and other reports that may become available.

2. The DOE's projections of long-term climate change are acceptable if these projected changes are consistent with evidence from the paleoclimate data. Specifically, NRC staff should determine whether the DOE has evaluated long-term climate change based on known patterns of climatic cycles during the Quaternary, especially the last 500 ky. The current analysis indicates that these cycles included roughly 100,000 year cycles of glacial/interglacial climates, with interglacials lasting about 20,000 years.

3. The NRC will not require climate modeling to estimate the range of future climates. If the DOE uses numerical climate models, NRC staff will determine whether such models were calibrated with paleoclimate data before they were

used for projection of future climate, and that their use suitably simulates the historical record.

4. Values for climatic parameters (time(s) of onset of climate change; mean annual precipitation (MAP); mean annual temperature (MAT); etc.) to be used in DOE's safety case should be adequately justified. This includes determination of whether appropriate scientific data were used, reasonably interpreted, and appropriately synthesized into parameters such as MAP, MAT, and long-term climate variability. The current knowledge about these parameters, coupled with past climate change, will require that, as a bounding condition, a return to full pluvial climate (higher precipitation and lower temperatures) be considered for at least a part of the 10,000 year period (current information does not support persistence of present-day climate for a duration of 10,000 years or more). The current interpretations of paleoclimate data indicate an increase in MAP by a factor of 2 to 3 and a lowering of MAT of 5-10°C (9-18°F) during the pluvial climate episodes.

5. If the DOE uses expert elicitation to arrive at values of climate parameters, the NRC will determine whether the guidance in the Branch Technical Position on Expert Elicitation (NRC96) was followed by the DOE.

6. Bounding values of climate-induced effects (for example water-table rise) based primarily on paleoclimate data will be acceptable. The NRC should determine whether the DOE has made a reasonably complete search of paleoclimate data pertinent to water-table rise and other effects (for example, changes in precipitation and geochemistry) of climate change that are available for the Yucca Mountain site and region, and has satisfactorily documented the results. In evaluating the DOE's analyses, NRC staff should determine whether, at a minimum, DOE has fully considered information contained in Paces, et al. (PAC96), Szabo, et al. (SZA94), and other reports that may become available.

7. It will be acceptable for the DOE to use regional and sub-regional models for the saturated zone to predict climate-induced consequences if these models are calibrated with the paleohydrology data. NRC staff should determine whether the DOE's models of the consequences of climate change are consistent with evidence from the extensive paleoclimate data base. Specifically, climate-induced water-table rise is expected to occur in response to elevated precipitation during future pluvial climate episodes, and the staff should determine whether the DOE's estimates of climate-induced, water-table rise are consistent with the paleoclimate data. The current estimate of water-table rise during the late Pleistocene is 120 m (394 ft). The NRC should determine whether the DOE's assumptions about climate-induced, water-table rise over 10,000 years, if different from 120 m (394 ft), are adequately justified.

8. Based on judgment and analysis, NRC staff will determine whether the DOE has adequately incorporated future climate changes and associated effects in its performance assessments. Current information does not support an assumption that present-day climate will persist unchanged for 10,000 years or more. The NRC staff should keep in mind that the consequences of climate change may be coupled to other events and processes and therefore the projections of water-table rise that are used in total system performance may be different from those based solely on climate change.

9. The collection, documentation, and development of data, models, and computer codes have been performed under acceptable QA procedures. If they were not subject to an acceptable QA procedure, they must be appropriately qualified.

Status of Issue Resolution at the NRC Staff Level. In Attachment E of the *Issue Resolution Status Report - Technical Issue: Unsaturated and Saturated Flow* the NRC presents their current concerns related to the potential influence of climate change on ground water flow. The text indicates that the NRC has identified no open items solely related to future climate change and associated hydrologic effects.

Present-Day Shallow Infiltration

Relevance to PA. NRC believes that present-day shallow infiltration is a key hydrologic factor in the isolation of high level wastes within the proposed geologic repository at Yucca Mountain. Present day shallow infiltration should be reasonably understood to provide initial conditions for projecting future hydrologic changes, because the Earth's climate could change significantly during the time that wastes will remain hazardous. Climate controls the range of precipitation that, in part, controls the rates of infiltration, deep percolation, and ground water flux through a geologic repository located in an unsaturated environment. Water flow through a geologic repository and its environs depends on both surface processes (precipitation, evapotranspiration, overland flow, and infiltration) and subsurface processes (deep percolation, moisture recirculation, and lateral flow). Changes in infiltration will likely induce other changes, such as regional fluctuations in the elevation of the water table. Water-table rise would reduce the thickness of the unsaturated zone barrier. Therefore, future changes in climate could alter infiltration from present-day rates and significantly influence the ability of a repository to isolate waste.

The importance of ground water flux as the key parameter for repository performance in an unsaturated zone is well known, and has been further emphasized in DOE's 1995 Total System Performance Assessment (TSPA). On page ES-30 of that report it is stated that:

> *...in the overall TSPA analyses, an over-arching theme comes back again and again as being the driving factor impacting the predicted results. Simply stated, it is the amount of water present in the natural and engineered systems and the magnitude of aqueous flux through these systems that controls the overall predicted performance.... Therefore, information on...[this topic]...remains the key need to enhance the representativeness of future iterations of TSPA.*

Sensitivity studies clearly showed the predominance of percolation flux in estimating cumulative radionuclide releases and peak radiation doses over a 10,000-year period (DOE95).

The DOE's "Waste Containment and Isolation Strategy" (DOE96) likewise states that "performance assessments have shown that seepage into the emplacement drifts is the most important determinant of the ability of the site to contain and isolate waste." This conclusion was reiterated in the DOE's recently published Repository Safety Strategy (DOE98). The importance of infiltration as a hydrologic parameter was also recognized by the NRC in its Iterative Performance Assessment Phase 2. The NRC (NRC95, p. 10-4) states that "Although the flux of liquid water through the repository depends on...infiltration, hydraulic conductivity, and porosity, performance correlates most strongly to infiltration."

In Section 5.1.2 of the DOE's 1998 TSPA-VA, the sensitivity to infiltration is investigated by skewing the probabilities to the higher infiltration rates than used in the base case simulations. The results of this analysis showed relatively small differences in the overall peak individual dose rates largely because other factors such as seepage and waste package corrosion uncertainties.

The NRC believes that, for the DOE to adequately demonstrate and quantify in its TSPA-LA the effects that present-day infiltration might have on repository performance, it should consider how these effects interplay with the other factors within and between key elements in the engineered and natural subsystems of the repository.

NRC97b provides a description of the technical basis for review methods for the issue on present-day shallow infiltration.

NRC Acceptance Criteria. In the NRC's Technical Review of the TSPA-LA it will determine whether the DOE has reasonably complied with the Acceptance Criteria listed below:

(1) The NRC shall determine whether the DOE has estimated shallow infiltration for use in the PA of Yucca Mountain using mathematical models that incorporate site-specific climatic, surface, and subsurface information. The staff will also determine whether the DOE provided sufficient evidence that the mathematical models were reasonably verified with site data. These data would include measured infiltration data and indirect evidence such as geochemical and geothermal data. The DOE may choose to use a vertical one-dimensional (1-D) model to simulate infiltration. However, in that case, the DOE should reasonably show that the fundamental effects of heterogeneities, time-varying boundary conditions, evapotranspiration, depth of soil cover, and surface-water runoff have been considered in ways that do not underestimate infiltration.

(2) The NRC shall determine whether the DOE has: (1) appropriately analyzed infiltration at appropriate time and space scales; and (2) has tested the abstracted model against more detailed models to assure that it produces reasonable results for shallow infiltration under conditions of interest. Recent studies by the NRC (STO96) and the DOE (FLI94, FLI95, FLI96) suggest that shallow infiltration is relatively high in areas where rocks are covered with shallow soils or channels and relatively low in areas where soil cover is deep. In addition, infiltration takes place episodically in time with areas having a shallow soil cover contributing more frequently.

(3) The NRC shall determine whether the DOE has characterized shallow infiltration in the form of either probability distributions or deterministic upper-bound values for PA, and whether the DOE has provided sufficient data and analyses to justify the chosen probability distribution or bounding value. The DOE's expert elicitation on unsaturated zone flow (GEO97) resulted in various estimates of a related parameter, the ground water percolation flux at the depth of the proposed repository. The estimated aggregate mean flux was approximately 10 mm/yr. The panelists estimated the 95th-percentile percolation flux over a range from 10 to 50 mm/yr, with an aggregate estimate of 30 mm/yr. An independent NRC staff assessment of an upper bound for yearly shallow infiltration under present climatic conditions is about 25 mm, which is somewhat less than the aggregate 95th percentile flux estimated by the expert panel.

(4) The DOE's estimates of the probability distribution or upper bound for present-day shallow infiltration need not be refined further if the DOE demonstrates through TSPA and associated sensitivity analyses that such refinements will not significantly alter the estimate of total-system performance.

(5) If used, expert elicitations should have been conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (NRC96), or other acceptable approaches.

6) The NRC will determine whether the collection, documentation, and development of data, models, and computer codes have been performed under acceptable QA procedures. If they were not subject to an acceptable QA procedure, they have been appropriately qualified.

Status of Issue Resolution at the NRC Staff Level. In Attachment F of the *Issue Resolution Status Report - Key Technical Issues: Unsaturated and Saturated Flow* the NRC presents their current concerns related to Present-Day Shallow Infiltration. The text indicates that the NRC staff has identified no open items solely related to Present-Day Shallow Infiltration.

Deep Percolation (Present and Future)

Relevance to PA. The importance of ground water flux as the key parameter for waste isolation at Yucca Mountain is well known.

Deep percolation is related to two of the key elements of the engineered and natural subsystems: (1) quantity and chemistry of water contacting waste packages and waste forms; and (2) spatial and temporal distribution of flow.

The NRC's technical review of the DOE's treatment of deep percolation is to be based on an evaluation of the completeness and applicability of the data and evaluations presented by the DOE. The NRC expects that the DOE will summarize or document the results of all significant-related studies that have been conducted in the Yucca Mountain vicinity.

NRC Acceptance Criteria and Resolution Status. In the NRC's Technical Review of the TSPA-LA it will determine whether the DOE has reasonably complied with the Acceptance Criteria listed below. The results of the NRC's most recent analyses and issue resolutions are also presented.

(1) It will be acceptable for the DOE to estimate present-day deep percolation by using (1) a reasonable upper bound based on available data; or (2) through a demonstration in TSPA and associated sensitivity analyses that further refinement of the estimate will not significantly alter the estimate of total-system performance. In the latter case, the NRC will conduct an independent analysis to judge the appropriateness of the estimate. In the VA analysis, it will be acceptable to use the aggregate distribution for areally averaged percolation flux estimated

through the expert elicitation (i.e., GEO97). The DOE's current infiltration map (e.g., FLI96) may be used to account for spatial variations in percolation.

According to the NRC, the base-case percolation flux as described by DOE appears acceptable at this time because it is similar to that estimated through expert elicitation (GEO97). If this base-case flux is used by the DOE, this acceptance criterion will be met. The status of this issue is open pending review of the DOE's VA.

(2) The DOE's estimate of future percolation will be acceptable if it provides a reasonable basis for assumed long-term average net infiltration and percolation flux. It will be acceptable to apply spatial- and temporal-average values of deep percolation through the use of an abstracted deep percolation model in PA. In arriving at spatial- and temporal-average values: variability is appropriately considered; model parameters are averaged over appropriate time and space scales; and the abstracted model is tested against more detailed models and field observations to assure that it produces reasonably conservative dose estimates. The current understanding is that a vertical one dimensional model, capable of considering heterogeneities and time-varying boundary conditions at the ground surface, may be sufficient for such calculations above the repository, while a vertically oriented, two dimensional model or three dimensional model may be necessary below the repository.

According to the NRC's analysis, the DOE currently (AND98) assumes that long-term average precipitation at Yucca Mountain will be twice as high as present conditions and long-term average percolation will be six times greater. The assumption about long-term average precipitation at Yucca Mountain is reasonably consistent with that recommended in Attachment E (NRC97a). It is not yet clear whether a six-fold increase in long-term average percolation is reasonable. The staff will make that determination after review of DOE submittals.

The NRC staff considers that the LBNL 3-D site-scale model may be too coarse to provide more than a general indication of subsurface processes at Yucca Mountain, but note that significant model refinement may be computationally infeasible. Despite these reservations, the NRC staff endorse the LBNL philosophy of using all available sources of information to calibrate the site-scale model, and agree that, for many purposes, homogeneous effective properties for each layer obtained through inverse modeling may be adequate.

The NRC staff supports the use of the DKM (i.e., dual permeability) approach for site-scale flow modeling as long as the DOE demonstrates that the results bound the effect of episodic infiltration and percolation pulses.

The NRC staff considers that approaches used by the DOE to estimate parameters for flow and transport simulations generally use sound methods, particularly in the most recent work. The NRC staff notes, however, that subgrid heterogeneity is not explicitly and transparently addressed in the approaches, and caution that failure to consider subgrid heterogeneity may lead to qualitatively incorrect results. Small scale modeling of heterogeneous zones is one approach that may be used to support use of uniform properties in hydrostratigraphic units of the site-scale UZ flow model.

The staff have reasons to believe that recharge and percolation in the Yucca Mountain region may increase in the next few decades due to replacement of native shrubs by invading brome grasses. The effect will likely be to replace the zero distributed recharge occurring in the alluvial basins with, perhaps, 1 to 10 mm/yr under current conditions. Recharge in upland areas like Yucca Mountain may also increase. The effect may be significantly greater during pluvial periods. This point is based on infiltration simulations, and on observations of increased streamflows where invasions of Bromus species have occurred in Nevada.

The status of this issue is open pending review of the DOE's VA.

(3) It will be acceptable for the DOE to conservatively assume that the fraction of deep percolation that intercepts disposal drifts also drips onto waste packages. Technical bases should be provided for deep percolation that is considered to bypass emplacement drifts. These technical bases should use field observations, experimental data from the ESF, calculations based on mass balance, tracer studies, and data from natural analog sites. Likely changes in percolation rates and patterns due to climate change should also be considered. Also, the abstracted model used in PA should be tested against more detailed models and field observations to assure that it produces reasonably conservative dose estimates. It is known that the amount of deep percolation into the waste emplacement drifts is sensitive to fast flow in fracture zones. Such flow paths need to be considered in the DOE's calculations

According to the NRC's analysis, the DOE is developing an approach for estimating seepage into drifts. The current DOE approach for drift-scale modeling for isothermal flow is apparently to represent the fracture system as an equivalent continuum with or without incorporating the matrix continuum (NIT97). However, it is not clear that the fracture system can be represented as a continuum at the scale of an emplacement drift based on the average fracture spacings in the repository horizons and the grid size in the numerical model. The NRC believes that alternative approaches will be needed to support estimates of seepage.

Although direct measurement of percolation flux at spatial and temporal scales relevant to modeling at Yucca Mountain is difficult to accomplish, the NRC staff believes that efforts should continue to identify pathways and measure percolation in the field at Yucca Mountain. A number of field tests designed to investigate percolation and seepage rates are planned or currently in progress, notably the alcove and niche infiltration tests and testing planned for the east-west drift in the TSw (WAN98). The direct measurement of percolation flux is encouraged, and the DOE should consider, to the extent practicable, that the proposed east-west drift be allowed to equilibrate with ambient conditions by closing down the tunnel for a period of time. The east-west drift has a significant lateral extent for observing seepage and dripping into the tunnel under ambient conditions, and will cross beneath what are expected to be areas of relatively high infiltration.

Besides providing independent estimates of deep percolation rates, the NRC staff will review whether or not the data used in the methods described in the following sections were extensively incorporated, either directly or as constraints, into the calibration process for the LBNL site-scale numerical model of the flow field (BOD97).

The NRC believes that another possible way that the DOE can demonstrate a reasonable approach is to assume that the fraction of percolating water that contacts waste packages is at least as great as the amount that intercepts disposal drifts. This means that most deep percolation will bypass waste packages because the disposal drifts occupy a relatively small areal percentage of the repository. This approach is probably reasonable and conservative given the tendency of underground openings to divert UZ flow laterally. It may not be reasonable to assume that all packages will receive equal amounts of dripping. Many may receive little or no dripping, while others could experience greater than average dripping over long time periods, especially during pluvial climate episodes.

The issue remains open pending review of DOE's VA and key supporting documents.

(4) It will be acceptable for the DOE to conservatively assume that all deep percolation below the repository level bypasses the bulk of the units of the CHn formation, either by lateral movement above the units or through vertical flow through fractures and faults. Technical bases should be developed for any deep percolation considered to flow vertically through the matrix of the nonwelded zone. Such technical bases should consider spatial and temporal variability and the scales at which model parameters have been-averaged. Also, the abstracted model has been tested against more detailed models and field observations to assure that it produces reasonably conservative dose estimates.

According to the NRC's current understanding, flow will occur predominantly vertically as matrix flow through the nonwelded vitric zones, including those that are slightly altered. Water will tend to perch upon highly zeolitized horizons and move laterally until vertical structures are encountered. Flow through fractures and fault systems will also occur. The NRC staff believes that the heterogeneity of the hydraulic properties and the characteristics of the fractures cross-cutting the units of the CHn are both poorly known. The field-scale UZ transport test at Busted Butte will significantly improve the conceptual model of flow through the CHn, but it will also contribute significant data for characterizing hydraulic properties, thus reducing uncertainty in flow rates below the repository. The DOE is continuing to work on flow below the repository, with one objective being to estimate how much bypass flux is reasonable.

The status of this issue remains open pending review of DOE's VA and reports on results from the Busted Butte hydrologic test facility.

(5) If used, DOE's expert elicitations should have been conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (NRC96), or other acceptable approaches.

The NRC has concluded that the expert elicitation on DOE's unsaturated flow model (i.e., GEO97) was conducted and documented in an acceptable way. Consequently this issue is closed and the staff have no further questions at this time.

(6) The NRC will determine whether the collection, documentation, and development of data, models, and computer codes have been performed under acceptable QA procedures. If they were not subject to an acceptable QA procedure, they have been appropriately qualified.

The NRC has not yet analyzed this issue and determined the path to resolution.

Summary of Deep Percolation Topics That NRC Believes Warrant Further Analysis. Significant variability of flow and transport pathways and travel times is expected to occur at Yucca Mountain due to the natural heterogeneity, stratification, alteration, fracturing, and other characteristics of the site. The extent to which such heterogeneities of the flow system should be incorporated into the DOE site-scale UZ flow model depends on their importance for estimating seepage into the repository and flow below the repository. Conceptualizations of flow in the UZ at Yucca Mountain have ranged from single-continuum models, to equivalent continuum models, to dual- and multiple- continuum models, to discrete-fracture models, as the importance of particular components of the flow system was examined. Given the matrix permeability values (FLI96) and assuming a unit hydraulic gradient, ground water flowing only in the matrix would move sufficiently slowly that it would take many tens of thousands of years for shallow infiltration to go through the repository horizon and arrive at the SZ. In contrast, both geochemical evidence and transient-flow modeling have suggested that a significant amount of ground water flux occurs in the fracture system, and that these fluxes can travel at much faster rates than in the matrix. Fluxes in the fracture systems may move sufficiently fast that some component of shallow infiltration reaches the water table in tens to hundreds of years. Differing conceptualizations of the link between the matrix and fracture systems and flow processes in the fractures cause important differences between alternative conceptual models. The differences in the conceptualizations can have a strong impact on PA modeling and, as such, are the focus of the discussion in this section.

The development of both the repository-scale and drift-scale conceptual models at Yucca Mountain may be partitioned into:

(1) Percolation processes above the repository, which affect the spatial and temporal distribution of water moving through the repository horizon

(2) Percolation processes at the drift scale, which affect the release of radionuclides from the repository

(3) Percolation processes below the repository, which affect the transport of radionuclides from the repository to the SZ

Saturated Zone Ambient Flow Conditions and Dilution Processes

Relevance to PA. This issue is important to repository performance because it constitutes an important potential pathway for radionuclide transport from the repository to the environment and receptor locations. Saturated zone characteristics will influence how future societies may use ground water resources in the Yucca Mountain region. The SZ also contributes to repository performance through: (1) magnitude and direction of ground water flow; (2) geochemical retardation; and (3) dilution of radionuclides. The time of arrival and the concentration of radionuclides at the receptor locations are based on the average ground water fluxes and velocities and the geochemical conditions encountered along the flow paths. Longer residence times will provide opportunity for radioactive decay, and the ground water pathways will affect transport due to retardation and adsorption.

The concentration of radionuclides at the receptor locations is also affected by the dilution processes during transport (dispersion and ground water intrabasin mixing) and pumping. The importance of dilution of radionuclides in the ground water is a central issue for dose reduction in the PA. The DOE TSPA-VA identifies dilution in the saturated zone below the repository as one of the five major system attributes most important for PA.

The Repository Safety Strategy (DOE98) notes that "Significant flow must occur in the saturated zone in order for the radionuclide-bearing flux that percolates to the water table to be diluted. The magnitude of mixing and dispersion also must be established because certain conditions have been noted to lead to persistence of contaminant plumes...However, even persistent contaminant plumes may themselves be subject to significant dilution when mixed with other water in a producing well."

Ambient flow conditions in the saturated zone are related to three of the key elements of the engineered and natural subsystems: (1) flow rates in water-production zones; (2) dilution of radionuclides in ground water (dispersion and well pumping); and (3) location and lifestyle of the critical group.

NRC Acceptance Criteria and Resolution Status. In the NRC's Technical Review of the TSPA-LA it will determine whether DOE has reasonably complied with the Acceptance Criteria listed below. The results of NRC's most recent analysis of the issue are also presented.

(1) The staff shall determine whether the DOE considered conceptual flow and data uncertainties. Uncertainties due to sparse data in some areas or low confidence in the data interpretations (e.g., LUC96; also CZA97) should have been considered by analyzing reasonable conceptual flow alternatives supported by site data, or by demonstrating through sensitivity studies that the uncertainties have little impact on repository performance.

According to the NRC's analysis, the reference Luckey, et al. (LUC96) does an excellent job of describing various conceptual models of site-scale hydrology as they were known at that time. The staff will exercise professional judgment in determining whether DOE has reasonably treated the conceptual and data uncertainties in performance assessments or has shown that they will not adversely impact performance.

This issue is open.

(2) The staff shall determine whether, based on site data, the DOE has reasonably delineated approximate flow paths from beneath the repository to potential receptor locations. Flow paths should consider: (i) aquifers (volcanic, alluvium, and carbonate) and continuity of flow regimes; (ii) flow domains (matrix and fracture); (iii) flow directions; (iv) flow velocities (approximate Darcy fluxes and average linear velocities); and (v) vertical hydraulic gradients, including the potential flow direction between the Paleozoic carbonate aquifer and the volcanic aquifers. Hydraulic and tracer testing along paths to potential receptor locations should be conducted on a scale large enough to include a statistically representative elementary volume in alluvium and in the fracture network in tuffs: A sufficient number of tests should be conducted to reasonably reduce the uncertainty in hydraulic and transport properties of the units downgradient from the proposed repository, including approximate delineation of the southerly zone where the water table transitions from tuffs to alluvium. These values, along with existing data such as that from the C-wells complex (e.g., GEL97), should be used in ground water flux calculations and mathematical models.

According to the NRC's analysis, the lack of hydrologic data for alluvium is a data gap in the DOE's site characterization of saturated zone hydrology. Emphasis should be placed on reasonable determinations of heads, transmissivity, hydraulic conductivity, effective porosity, and dispersion coefficients. The hydraulic and geochemical characteristics of the likely flowpath that exists south of well JF-3 have not been evaluated. It is unknown at which locations the water table transitions from fractured tuff to overlying alluvium. The saturated thicknesses, hydraulic properties, and geochemical properties of alluvium have not been determined for the region that lies between well JF-3 and the Amargosa Desert. The DOE's cooperative well drilling program with Nye County, Nevada could accomplish this if the wells are sited and tested to characterize the hydrology along likely flow paths in a timely manner.

The staff believe that the three-phase SZ testing strategy described in Reimus, et al. (REI97) could, if implemented, significantly improve understanding of the hydrogeologic system. New wells may be needed, but possible locations for such testing using existing wells would include (1) J-12, JF-3, and J-13; (2) H-4, SD-12, and WT-2; or (3) SD-6 and H-5. Other combinations are also possible, and other wells could be expected to respond to long-term pumping tests. Because fractures and faults have preferred orientations, and can act as preferred flow pathways, quantitative studies require that more than one representative elementary volume of rock be sampled.

Based on the available potentiometric head data, flow from the proposed repository is likely to be in a southeasterly direction (i.e., along the natural hydraulic gradient) toward Fortymile Wash. This is the general direction of flow that was interpreted by panelists in a recent expert elicitation on the site saturated zone (GEO98), and is also the flow pattern that is best supported by hydraulic head data. Southeasterly flow is the direction used in the NRC/CNWRA performance assessment model where saturated zone flow and transport are simulated in a series of stream tubes. Radionuclides reaching the saturated zone from the repository along this southeasterly flow path would migrate along fracture-dominated pathways in the tuff aquifers in the general direction of well J-12, and thence, southward in saturated alluvium toward the Amargosa Desert. The southeasterly flow path assumes that the fractured tuff aquifer is an equivalent porous medium at the site scale under isotropic conditions. Treating the aquifer as an equivalent medium at a large scale is supported by the pervasiveness in the tuffs of faults and fractures oriented in many directions, and by results of long-term testing at the C-wells. The NRC staff plans to continue its analysis of the previous and ongoing C-wells testing.

As noted above, ground water flow in the tuff aquifer is dominated by structural features. This causes anisotropic conditions where structures may act as high- and/or low-permeability zones, and this is most evident at small spatial scales. At larger scales the hydrologic properties of interconnected fault and fracture networks are expected to dominate flow conditions. Because of uncertainties about large-scale anisotropy, current DOE simulations assume that ~10-percent of transport pathways never come into contact with saturated alluvium. Data from aquifer pumping tests in the C-well complex are now being analyzed to determine whether large-scale anisotropic effects are evident. There are presently no data concerning the isotropy of saturated alluvium.

The staff's current model is subject to revision as new site data are collected and analyzed. Due to sparse data in some areas and uncertainties in the interpretation, the staff continues to analyze whether there are other viable SZ conceptual flow models which can be supported by available data. For example, the staff is examining whether there is evidence of site-scale aquifer anisotropy that could shift SZ flow patterns significantly away from the direction of the observed southeasterly natural hydraulic gradient.

A promising new approach exists that may greatly improve the isotopic dating of ground waters with the ^{14}C technique, leading to better estimates of average ground water residence times. Residence time is related to average regional ground water velocity. Thomas (THO96) describes the separation of dissolved organic carbon from ground water using reverse osmosis and ultrafiltration methods. The staff believes that this method should be applied to samples collected at Yucca Mountain to provide an independent estimate of the apparent ground water velocities in the system and the average time of travel from principal recharge zones to Yucca Mountain. This technique has been applied to ground water in the vicinity of Devils Hole, and indicates that ground water residence times in the carbonate aquifer feeding Devils Hole are about 2000-3000 years (WIN97), significantly less than earlier estimates.

Information about flow conditions in the Paleozoic carbonate aquifer beneath Yucca Mountain is based on only one well, USW p#1. Heads in this well are about 22 m higher in the Paleozoic carbonate aquifer and lower volcanic confining units than in the Crater Flat tuffs (lower volcanic aquifer), indicating a strong upward gradient. Likewise, heads in the lower volcanic confining units in wells H-1 and H-3 are also higher than in the Crater Flat Tuffs, providing evidence that significant upward hydraulic potentials probably exist over most of the site east of Solitario Canyon. This condition is favorable for waste isolation because an upward gradient, if maintained in the future, would protect the deep Paleozoic carbonate aquifers from contamination. The DOE's cooperative drilling program with Nye County, NV, should provide timely additional data regarding the vertical gradients between the Paleozoic carbonate aquifers and overlying tuffs or alluvium. It should also be noted that large differences in ground water chemistry between the carbonate aquifer system and the Crater Flat tuffs suggest that upward fluxes are relatively small compared to those introduced by lateral flow within the tuffs.

The issue remains open pending review of the DOE submittals (e.g., VA, data for alluvium and tuffs) and staff analysis of effects of large-scale anisotropy. The staff will determine what adjustments, if any, to general flow paths are warranted.

(3) The staff should determine whether the DOE has provided a hydrologic assessment to describe likely causes of the "moderate hydraulic gradient" and the "large hydraulic gradient."

According to the NRC's analysis, at, or west of, Yucca Mountain is a zone of relatively low permeability that tends to restrict flow from west to east. Based on current understanding, the SCF and associated splays are the most likely cause of the 45-m head change known as the "moderate hydraulic gradient." There is evidence that ground water crosses the fault, but actual fluxes are not known. The tendency to restrict flow probably decreases toward the north as fault displacement decreases. The fault displacement reaches a minimum at a hinge point, about one km southwest of well G-2. When completed, well SD-6 located at the crest of Yucca Mountain should be used to conduct pumping tests beneath the western repository block near the Solitario Canyon fault, and to obtain estimates of transmissive properties beneath that part of Yucca Mountain. Hydraulic testing at SD-6 should provide new insights about the nature of the so-called "moderate hydraulic gradient."

Well WT-24 is currently being drilled to improve the DOE's understanding of the so-called large-hydraulic gradient. The NRC believes that a sufficient understanding can be obtained through the drilling and testing of WT-24. Preliminary data show that a perched zone is present near the top of the Calico Hills in this well, and that the regional potentiometric surface is also more than 100 m higher than in wells immediately to the south.
This issue remains open pending submittal and staff review of the DOE reports on the drilling and testing of wells WT-24 and SD-6. Preliminary water-level elevations have been reported (WT-24: 839.5 m; SD-6: 731.5). The data remain preliminary because the wells are still being constructed, and staff await formal reports from the DOE on testing and data collection at these wells.

(4) The staff shall determine whether the DOE has provided maps of approximate potentiometric contours for an area that, at a minimum, includes wells J-1 1 on the east, VH-1, VH-2, and the GEXA Well on the west, UE-29a #2 to the north, and domestic and irrigation wells south of Amargosa Valley (Lathrop Wells). Maps of regional and site-scale recharge and discharge should be provided, along with

site-scale hydrostratigraphic cross sections constructed along the paths to the accessible environment, and flow-net analysis of the site-scale SZ.

The NRC has not completed its analysis of this issue which remains open.

(5) The staff shall determine whether the DOE has characterized key hydrologic parameters in the form of either probability distributions or deterministic bounding values. These parameters include transmissivity, hydraulic gradient, porosity (effective, matrix, and fracture), and effective aquifer thickness. The DOE's parameters should be reasonably consistent with site data.

Based on the NRC's analysis, the DOE is apparently using probability distributions to represent key hydrologic parameters in TSPA, an approach that is acceptable to the staff. Staff will review DOE submittals to determine whether the parameters used are reasonably consistent with site data.

The issue remains open pending the NRC's review of DOE's VA.

(6) The staff shall determine whether the DOE has used mathematical ground water model(s) that incorporate site-specific climatic and subsurface information. Sufficient evidence must be presented to show that the models were reasonably calibrated and that the physical system is reasonably represented. The fitted aquifer parameters should compare reasonably well with observed site data. Implicitly- or explicitly-simulated fracturing and faulting should be consistent with the data in the 3-D geologic model. Abstractions should be based on initial and boundary conditions consistent with site-scale modeling (e.g., CZA97) and the regional models of the Death Valley ground water flow system (e.g., DAG97a,b). Abstractions of the ground water models for use in PA simulations should use appropriate spatial- and temporal-averaging techniques.

The NRC has not yet examined this issue in depth and it remains open pending review of DOE's VA.

(7) It will be acceptable for the DOE to conservatively assume no wellbore dilution at a receptor location. If wellbore dilution is used, a demonstration should be provided that reasonable assumptions have been made about well design, aquifer characteristics, plume geometry, withdrawal rates, and capture zone analysis for the receptor location.

The NRC has determined that currently the DOE is taking no explicit credit for wellbore dilution. This is acceptable to the staff, but is inconsistent with a DOE-sponsored expert elicitation

(GEO98) which concluded that significant dilution can be expected through well pumping. If the DOE takes credit for wellbore dilution in future submittals, the staff will evaluate the information to determine if the acceptance criterion has been met.

This issue is resolved and the staff have no further questions at this time.

(8) It will be acceptable for the DOE to conservatively assume no dilution due to dispersion, or no ground water mixing below the repository footprint, and no mixing of the Yucca Mountain water with water from the north in Fortymile Wash. If intra-basin mixing of ground water is used, a demonstration should be provided that reasonable assumptions have been made about spatial and temporal variations of aquifer properties and ground water volumetric fluxes. If dilution is simulated as dispersion in a numerical transport model, scale-dependent dispersivities, constrained by the analysis in Gelhar, et al. (GEL96), should be used.

The NRC notes that in the recent peer review of DOE's TSPA, panelists observed that the saturated zone model used in the TSPA-VA is likely to result in a non-conservative estimate of dilution due to mixing along the flow path. The model assumes that radionuclides reaching the water table and transported in the ground water would be subjected to widespread and uniform mixing in all of the stream tubes within the flow tube model. If only a small percentage of the waste packages fail, and if the failures are confined to a small area of the repository, which is probably one of the more likely scenarios, the radionuclides will more likely be confined to specific stream tubes and not uniformly mix or spread over all of the stream tubes in the flow tube model. Therefore, the presumed widespread and uniform mixing in the flow tube model is not conservative because it would result in more dilution due to mixing in the flow tube than would actually take place.

For 20-km flowpaths, the DOE appears to be using dilution factors that range from 1-100, with a median value of 12. These estimates were derived from the conclusions of three members of a five-member expert panel (GEO98), and consider dispersion effects. The other two panel members did not estimate the dilution range. The estimates do not include the additional effects of dilution within wellbores or intrabasin mixing. The range and median appear to be conservative because they are reasonably low. The staff will assess the DOE's treatment of dilution in the VA.

(9) The staff shall determine whether the DOE has incorporated key conclusions regarding potential geothermal and seismic effects on the ambient SZ flow system (e.g., NRC92, NWT98).

The NRC's analysis and proposed resolution of this issue remains open pending review of the DOE's VA.

(10) It will be acceptable for the DOE to use estimates and recommendations provided by expert elicitations (e.g., GEO98) as long as the expert elicitation is conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (NRC96) or other acceptable approaches.

The NRC has concluded that the expert elicitation on saturated zone flow and transport (i.e., GEO98) was conducted and documented in an acceptable way. Consequently, this issue is resolved and the staff have no further questions at this time.

(11) The staff shall determine whether the collection, documentation, and development of data, models, and computer codes have been performed under acceptable QA procedures. If they were not subject to an acceptable QA procedure, they have been appropriately qualified.

The NRC's analysis and proposed resolution of this issue are yet to be determined.

Matrix Diffusion in Saturated and Unsaturated Zones

Relevance to PA. Matrix diffusion is related to two of the key elements of the natural subsystems: (1) distribution of mass flux between fracture and matrix; and (2) retardation in water-production zones and alluvium. At Yucca Mountain, the process of matrix diffusion may impact repository performance because ground water flow, away from the repository, occurs primarily in fractures that account for only a small fraction of total formation porosity. In such hydrologic systems, matrix diffusion can attenuate migration of radionuclides in two ways: (1) it can spread them physically from the flowing fractures into stagnant matrix pore water; and (2) rock matrix can provide a vast increase in mineral surface available for geochemical surface reactions (e.g., sorption) as compared to fracture surfaces alone. The extent to which matrix diffusion can affect repository performance is controlled by the rate of solute diffusion from fractures into rock matrix relative to the time scale for flow through the fracture system to the receptor point. When diffusion is very slow relative to the transport time, the impact is negligible in terms of solute arrival time, but there is a slight long-term attenuation of peak solute concentration. If diffusion is fast relative to transport time, the impact is a significant delay in solute arrival at the receptor point. At intermediate diffusion rates, the impact is a modest delay in initial solute arrival time with significant attenuation of solute concentration.

The Repository Safety Strategy (DOE98) noted that concentrations of radionuclides in ground water can be reduced by matrix diffusion and sorption. If matrix diffusion is limited, there can still be sorption on fracture walls, but the depletion effect will be much smaller.

NRC Acceptance Criteria and Resolution Status. In the NRC's Technical Review of the TSPA-LA it will determine whether the DOE has reasonably complied with the Acceptance Criteria listed below. The results of the NRC's most recent analysis of the issue are also presented.

(1) It will be acceptable for the DOE to conservatively assume no credit for matrix diffusion in the UZ. If credit is taken, then matrix diffusion predictions are consistent with evidence for limited matrix diffusion in the UZ including: (i) geochemical data (e.g., YAN96) that provide evidence of geochemical disequilibrium between matrix and fracture waters in the UZ at Yucca Mountain; and (ii) ^{36}Cl evidence for rapid transport pathways to the repository horizon (e.g., FAB96).

According to the NRC, the UZ radionuclide transport sub-model that is currently used in the DOE TSPA model is described by Robinson, et al. (ROB97). From the model description it is evident that effective diffusion coefficients are selected *a priori* and not correlated within the model to fracture or matrix saturation. Although it is possible to simply reduce the value of the selected diffusion coefficient to be consistent with reduced matrix and fracture saturation, there is no analysis provided to show that selected diffusion coefficients are appropriate for the conditions modeled. Additionally, no analyses of the resultant geochemical differences between matrix and fracture water are provided. Thus it is not possible at this time to assess whether the DOE method of abstracting matrix diffusion into UZ radionuclide transport is suitable for predictions of repository performance.

Available information for Yucca Mountain indicates that fracture-matrix interface area is limited to the wetted surface area within fractures. Similarly, effective diffusion coefficients in the UZ are saturation-dependent and should be proportional to the effective saturated cross-sectional area through which solutes can diffuse. Furthermore, TSPA model predictions should be consistent with UZ geochemical data (e.g., YAN96), which suggest that waters within rock matrix at Yucca Mountain have different geochemical signatures than fracture waters; predictions should also be consistent with ^{36}Cl evidence (e.g., FAB96) for rapid transport pathways to the repository horizon.

The DOE should clearly document the technical basis for assumptions used to estimate the transfer term for fracture-matrix exchange in the dual permeability model for UZ transport. The staff has concerns that the residence time transfer function for the dual continuum model is overestimated, because assuming an immobile reservoir neglects the transfer function accounting for particles moving from the matrix to the fracture.

The issue remains open.

(2) It is acceptable for the DOE to conservatively assume that no matrix diffusion will occur in the SZ (i.e., that all solutes will remain in fractures) during transport through saturated fractured rock aquifers. DOE's inclusion of matrix diffusion in SZ transport models for Yucca Mountain should be reasonably supported by both field and laboratory observations. Acceptable field and lab observations include tracer tests that are conducted over different distance scales and flow rates with multiple tracers of different diffusive properties. Transport models should reasonably match the results of the field tracer tests. Rock matrix and solute properties used to justify the inclusion of matrix diffusion in TSPA models fall within a range that can be supported by laboratory data.

The staff believes there is much greater potential for radionuclide retardation in saturated alluvial deposits than in fractured tuffs. From the proposed repository to potential receptors at a distance of 20 km, flowpaths will probably include significant amounts of saturated alluvium. Matrix diffusion in the Tertiary tuffs would then be of minor significance.

The DOE's current assumptions about matrix diffusion are supported to some extent by field and laboratory results to date. However, the amount of matrix diffusion claimed by the DOE from these results has been disputed by the staff and others. A clearer demonstration of the matrix diffusion phenomenon can be made by (1) using tracers with more variation in physical properties and by testing over different length scales and flow rates; and (2) by demonstrating the degree to which matrix diffusion can actually occur within fractured welded and moderately welded tuffs that are known to act as significant flow zones at Yucca Mountain. Zones that contribute to flow in wells have been identified through borehole logging and hydrologic testing. Samples from those zones should be subjected to visual testing techniques of the type described by researchers like Tidwell, et al. (TID97).

The DOE is assuming that matrix diffusion in the saturated zone occurs over a range of porosity described by a log-triangular distribution that ranges from 0.0001 to 0.2, with a mean of 0.02 (2%). The DOE is simplifying the treatment of matrix diffusion by assuming that the range and mean are equivalent to that assumed for effective (advective) porosity and appear to be reasonably conservative with respect to field and lab tests of matrix diffusion and porosity. However, the DOE's basis for selecting of a log-triangular distribution needs to be clarified, and will be examined in the staff's review of the VA.

In the DOE's evaluation of C-wells tracer tests, the staff is concerned that use of the 50% relative solute concentration arrival times to derive the range of effective porosities has an inherent non-conservatism that could be avoided by basing the effective porosity approach on relatively early solute arrival times (e.g., about 10% relative solute concentration). Finally, it appears that, although the matrix diffusion behavior is different for each solute, the DOE is using the same effective porosity for all solutes. If the DOE intends to neglect this variation in solute behavior, the NRC recommends using the effective porosity derived from the least diffusive solute likely to influence performance.

This issue remains open pending review of DOE's VA.

(3) If used, DOE's expert elicitations should be conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (NRC96), or other acceptable approaches.

The NRC's analysis and resolution of this issue are yet to be determined.

(4) Staff shall determine whether the collection, documentation, and development of data, models, and computer codes have been performed under acceptable QA procedures. If they were not subject to an acceptable QA procedure, they have been appropriately qualified.

The NRC's analysis and resolution of this issue are yet to be determined.

Radionuclide Transport through Porous Rock

Relevance to PA. When radionuclides pass through porous rock, the interactions between the dissolved radionuclides and the rock surfaces (e.g., sorption) result in retardation of the velocity of the radionuclides relative to the velocity of ground water. The large surface areas of the porous media tend to enhance sorption and consequently retardation. Furthermore, for those radionuclides whose sorption reactions may be kinetically inhibited, the slower average linear velocities of ground water flow in porous media promote the solid-liquid interaction. If the radionuclides exist instead as particulates or as colloids, they may be filtered out as ground water flows through the constricted pores of the matrix. Sorption of radionuclides on solids and filtration of radiocolloids and particulates in the matrix reduces the radionuclide concentration in the liquid. However, the low permeabilities of the matrix of some hydrostratigraphic units at Yucca Mountain may make some rock inaccessible to radionuclide-contaminated water on the timeframe of repository performance.

NRC Acceptance Criteria. The approach that recent performance assessment efforts have used to simulate radionuclide transport in porous rock involves first establishing a ground water flow field. This flow field is generated as a result of hydrologic modeling of the Yucca Mountain system using site-specific parameters, and can be one-, two-, or three-dimensional, depending on the purpose of the modeling effort and the available data. The flow field representing the spatial distribution of ground water velocities is then adjusted by dividing the velocity vectors by the retardation factor, R_f, for each radionuclide, to yield the radionuclide velocity fields. Current approaches model the ground water flow field as a dual continuum representing both fracture and matrix flow at every point in the system.

The following Acceptance Criteria apply to evaluating the DOE estimates and consideration of radionuclide transport through porous rock:

(1) For the estimation of radionuclide transport through porous rock, the DOE has

a. Determined, through performance assessment calculations, whether radionuclide attenuation processes such as sorption, precipitation, radioactive decay, and colloidal filtration are important to performance

b. (i) Assumed K_d is zero and radionuclides travel at the rate of ground water flow, if it has been found that radionuclide attenuation is unimportant to performance (in which case, Acceptance Criteria 2 and 3 do not have to be met), or (ii) demonstrated that Criterion 2 or 3 has been met, if radionuclide attenuation in porous rock is important to performance

(2) For the valid application of the K_d approach, using the equation $R_f = 1 + \rho K_d/n$, the DOE has

a. Demonstrated that the flow path acts as an isotropic homogeneous porous medium

b. Demonstrated that appropriate values for the parameters, K_d, n and ρ have been adequately considered (e.g., experimentally determined or measured)

c. Demonstrated that the following assumptions (i.e., linear isotherm, fast reversible sorption reaction, and constant bulk chemistry) are valid

(3) For the valid application of process models such as surface complexation, ion exchange, precipitation/dissolution, and processes involving colloidal material, the DOE has

a. Demonstrated that the flow path acts as an isotropic homogeneous porous medium

b. Demonstrated that values for the parameters used in process models are appropriate

c. (i) Demonstrated that the three implicit assumptions (see 2.c.) are valid, if process models are intended to yield a constant K_d for use in the retardation equation; or (ii) determined transport in a fully coupled dynamic system (e.g., PHREEQC, MULTIFLO, HYDROGEOCHEM, etc.)

(4) Where data are not reasonably or practicably obtained, expert judgement has been used and expert elicitation procedures have been adequately documented. If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563 (NRC96) or other acceptable approaches.

(5) Data and models have been collected, developed, and documented under acceptable Quality Assurance (QA) procedures or if data were not collected under an established QA program, they have been qualified under appropriate QA procedures.

Status of Issue Resolution at the NRC Staff Level. Most of the Yucca Mountain geochemical work in the past twenty years has been directed toward determining the retardation of radionuclides in porous rock. Significant progress has been made to address this issue that is important to waste isolation and repository performance. However, in that time, there have been major changes in the conceptualization of the geologic setting of the repository that impact the relative importance of this issue and the consideration of the point of compliance up to 20 kilometers away from the repository. The greater average infiltration results in a greater proportion of the flux bypassing the sorptive porous rock by flow in fractures. A 20 km point of compliance would result in the need to consider the alluvium along with porous and fractured rock. These major changes reduce the relative importance of radionuclide transport in porous rock on performance assessment.

The NRC considers that the subissue has been met for certain radionuclides but not for others. Some of the radionuclides for which the issue has not been resolved on the staff level may be important to performance.

The NRC finds that the approach adopted by LANL to determine minimum K_d values is logical and defensible. By performing batch sorption tests using site-specific materials, followed by confirmatory tests to establish the validity of the assumptions needed for the constant K_d approach, and then selecting the minimum K_d from all the tests, an acceptable value can be obtained.

In summary, the NRC chose three radionuclides as examples to highlight successes and areas needing further work. They are neptunium, plutonium, and uranium. The minimum K_d approach has worked well for neptunium. The staff recognizes that multiple tests have been performed to establish reasonable K_d values for this radionuclide. Consequently, this issue is being resolved for neptunium. On the other hand, although both batch sorption tests and flow-through column tests have been performed to determine a minimum K_d for plutonium, significant inconsistencies occurred. The NRC staff recognizes plutonium as problematic and encourages further work to establish defensible K_d values. For uranium, geochemical modeling suggests that a uranyl silicate phase, soddyite, could precipitate from solution, given the initial ground water composition. Eliminating the possibility that processes other than sorption (e.g., precipitation) may be contributing to the removal of a radionuclide from solution is necessary for establishing a valid K_d. On the other hand, the thermodynamic modeling could be in error based on parameter uncertainties. To date, it does not appear that flow-through column tests were perfomed with uranium. Consequently, the NRC does not believe that this issue has been resolved.

Radionuclide Transport Through Alluvium

Relevance to PA. Current conceptual models of the alluvium incorporated in performance assessments reflect limited information concerning the physical and chemical conditions of alluvium. For example, in the NRC's TPA 3.1 (NRC98), the alluvium is assumed to be crushed tuff similar to the material used in batch sorption experiments. The DOE model abstraction assumes flow as in a sand column driven by the hydraulic gradient. Furthermore, in the TSPA-VA the DOE assumes there are no preferential pathways in the alluvium. This assumption has not yet been tested. However, the occurrence of cut and fill structures formed in the alluvium by braided streams as evident in the walls of Forty Mile Canyon may suggest that preferred pathways exist in the alluvium with the potential to reduce mixing and dilution.

NRC Acceptance Criteria. The DOE considers radionuclide transport a key performance attribute of the natural barrier system in the proposed repository. Retardation of radionuclides through alluvium constitutes a key element of the DOE performance assessment. The NRC requires that the DOE must adequately estimate the transport characteristics of the Yucca Mountain site and appropriately consider radionuclide transport in their assessments of repository performance. The NRC's review process is designed to determine which transport processes have been addressed/assumed by DOE. The review will first identify, whether or not the selected retardation processes are appropriate to the Yucca Mountain system, and second, whether or not they are addressed adequately for those radionuclides of concern.

The following Acceptance Criteria, which are the same as those for radionuclide transport through porous rock, apply to evaluating the DOE estimates and consideration of radionuclide transport through the alluvium:

For the estimation of radionuclide transport through alluvium, the DOE has

b. Determined, through performance assessment calculations, whether radionuclide attenuation processes such as sorption, precipitation, radioactive decay, and colloidal filtration are important to performance
c. (i) Assumed K_d is zero and radionuclides travel at the rate of ground water flow, if it has been found that radionuclide attenuation is unimportant to performance, in which case, Acceptance Criteria 2 and 3 do not have to be met; or, (ii) demonstrated that Criterion 2 or 3 has been met, if radionuclide attenuation in alluvium is important to performance

For the valid application of the K_d approach, using the equation $R_f = 1 + \rho K_d/n$, DOE has

a. Demonstrated that the flow path acts as an isotropic homogeneous porous medium

b. Demonstrated that appropriate values for the parameters, K_d, n and ρ have been adequately considered (e.g., experimentally determined or measured)

c. Demonstrated that the three implicit assumptions (i.e., linear isotherm, fast reversible sorption reaction, and constant bulk chemistry) are valid

For the valid application of process models such as surface complexation, ion exchange, precipitation/dissolution, and processes involving colloidal material, the DOE has

a. Demonstrated that the flow path acts as an isotropic homogeneous porous medium

b. Demonstrated that appropriate values are used in processes models

c. Demonstrated that the three implicit assumptions (as in 2.c.) are valid, if process models are intended to yield a constant K_d for use in the retardation equation; otherwise, determined transport in a fully coupled dynamic system (e.g., PHREEQC, MULTIFLO, HYDROGEOCHEM, etc.)

Where data are not reasonably or practicably obtained, expert judgement has been used and expert elicitation procedures have been adequately documented. If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563 (NRC96) or other acceptable approaches.

Data and models have been collected, developed, and documented under acceptable QA procedures, or if data were not collected under an established QA program, they have been qualified under appropriate QA procedures.

Status of Issue Resolution at the NRC Staff Level. The status of this issue is tied closely to that of the previous issue. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, ground water, chemistry, and physical flow systems of the alluvium. Past efforts have focused on characterizing the geologic media within 5 kilometers of the repository because of the provisions of the then applicable 40 CFR Part 191. With the resultant increase in the length of the flowpath to the biosphere to 20 kilometers, now being understood as consistent with draft 10 CFR Part 63, a significant portion of relatively uncharacterized geologic media has been added to the system.

Although, like the DOE, the NRC has assumed in earlier modeling that the alluvium acts as a homogeneous porous medium, the NRC also recognizes that little or no infomation is available to support that assumption. Furthermore, it is recognized by the NRC that treating the alluvium as a homogeneous porous medium may be nonconservative.

The NRC expects that the series of boreholes to be drilled by Nye County in the alluvium will provide significant information concerning its geologic, and hydrologic characteristics. It is expected that the mineralogy will reflect that used in batch sorption experiments for determining sorption coefficients for radionuclides in tuff. If that is so, the NRC believes that the laboratory work needed to address previous issue (i.e., retardation in porous rock) will also address the retardation issues in the alluvium.

The NRC notes that the DOE will need to defend their conceptualization of the alluvium. If the alluvium is a composite of cut and fill structures resulting from the accretion of braided streams, preferred pathways limiting water-rock interaction may result. If on the other hand, the alluvium is homogeneous, the application of experimentally determined K_ds to calculate retardation factors would be appropriate. The NRC indicates that resolution of this issue will await the geologic and hydrologic information to be collected.

Radionuclide Transport through Fractured Rock

Relevance to PA. Recent site characterization activities involving the radioisotopes ^{36}Cl and ^{3}H provide evidence suggesting fast pathways of ground water flow through the unsaturated zone (FAB96). These fast pathways are proposed to occur as a result of flow down faults and fractures. Also, responses from adjacent wells in large-scale hydrologic pump tests (C-Wells) suggest that preferential pathways may exist in the saturated zone at Yucca Mountain (GEL97). If preferential pathways exist from the repository to the critical group, performance may be adversely affected, because portions of the geologic barrier would be bypassed.

In predicting flow and transport through the unsaturated zone, the TSPA-VA takes no credit for retardation of radionuclides in fractures. The rationale for assigning no retardation in the fractures is based on the hypothesis that there is limited capacity for sorption along fractures, and average linear velocities in fractured rock are high, limiting time for interaction between the dissolved radionuclides and the sorbing minerals lining the fracture walls. However, the presence of specific fracture-lining minerals may provide significant opportunity for sorption of specific radionuclides. For example, the manganese oxyhydroxides may strongly sorb plutonium, uranium, and americium; calcite may strongly sorb or coprecipitate neptunium (TRI96).

Since the TSPA-VA does not explicitly incorporate fractures in predicting flow and transport through the saturated zone the potential sorption effects of the fractures and matrix are, in essence, lumped into a single value. The DOE addresses the associated uncertainty by assigning a range, mean and distribution to the sorption values (i.e., K_ds) for each of the hydrologic units.

NRC Acceptance Criteria. The DOE considers radionuclide transport a key performance attribute of the natural barrier system in the proposed repository. Retardation of radionuclides in fractures in the unsaturated zone and in the saturated zone constitutes a key NRC consideration for evaluating the DOE's performance assessment. The NRC notes that the DOE must adequately estimate the transport characteristics of the Yucca Mountain site and appropriately consider radionuclide transport in its assessments of repository performance. The NRC's review process is designed to determine which transport processes have been addressed/assumed by the DOE. The NRC will first identify whether or not the selected retardation processes are appropriate to the Yucca Mountain system, and secondly, whether or not they are addressed adequately for those radionuclides of concern.

The NRC expected to develop Acceptance Criteria for evaluating the DOE estimates and consideration of radionuclide transport through fractured rock in FY99.

Status of Issue Resolution at the NRC Staff Level. The NRC has yet to develop the Acceptance Criteria for this issue. The DOE has performed some experiments using fractured rock. Whereas the retardation factor in fractures is assumed to be 1 (i.e., no sorption) in performance assessments, due to the uncertainty with regard to radionuclide transport in fractured rock, preliminary experiments suggest that some retardation occurs. For example, neptunium experiments have been performed and show reduced recovery and a delay in the breakthrough relative to tritium and technetium.

Criticality in the Far Field

Relevance to PA. The Total System Performance Assessment-Viability Assessment Methods and Assumptions Report (TRW97) states nuclear criticality scenarios will be evaluated. There are some scenarios that could lead to criticality that may affect performance. For example, Bates, et al, (BAT92) found that plutonium released from glass waste form exists predominantly as colloids. If colloidal plutonium could be efficiently filtered in nonwelded bedded units below fractured strata of the repository horizon, it could accumulate sufficient mass for criticality. Consideration of neutron sorbers or poisons, either contributed from the natural system or from the repository may be important. Differences in the mobility may lead to chromatographic separations of fissile material and poisons. A criticality occurring over a long time could produce increasing amounts of fission products and neptunium. Some of the radionuclides generated in a criticality event could be relatively mobile and, thus, could adversely affect performance. Furthermore, criticality could: (1) generate additional colloids, capable of transporting radionuclides unretarded; (2) affect the ground water flow field; or (3) result in gaseous release of volatile radionuclides.

NRC Acceptance Criteria: To be determined.

Status of Issue Resolution of the NRC Staff Level: To be determined.

NWTRB Identified Needs

In their 1999 Report to Congress the Nuclear Waste Technical Review Board makes a number of observations regarding the potential viability of the proposed repository. The following discussion pertains to issues related to ground water flow and contaminant transport in the saturated zone. As a general consideration, the Board indicates that after reviewing the TSPA-VA it has not identified any features or processes that would automatically disqualify the site.

The Board also notes that the TSPA-VA relies heavily in some cases on formal elicitation of expert opinion. The Board maintains that this was necessary and extremely useful, given the lack of field and laboratory data in certain areas and the equivocal nature of some of the data in other areas. However, the Board expresses a concem that expert opinion should not be used as a substitute for data that can be obtained directly from the site, laboratory and other investigations.

The Board also concludes that a significant amount of additional scientific and engineering work will be needed to increase confidence in a site-suitability determination and license application.

The Board's expressed specific concerns with respect to the data needs of the near field (e.g., waste package) environment. However, with respect to ground water flow and contaminant transport in the saturated zone the Board issued a general statement indicating that long-term studies of the natural barriers also will be needed, primarily to verify projections of water movement within the unsaturated and saturated zones near the repository.

The Board also expressed agreement with a DOE-commissioned peer review panel that two types of additional data are needed to improve the credibility of the total system performance assessment part of the TSPA-VA: (1) fundamental data that are essential to the development and implementation of the models; and (2) data sets designed to challenge conceptual models and test the coupled models used in the TSPA-VA.

Peer Review Panel Identified Needs

The Total System Performance Assessment Peer Review Panel raised a number of concerns related to ground water flow and radionuclide transport in the saturated zone. A discussion of their findings are presented below.

In their introductory remarks to this section the Panel states:

> *The current treatment of saturated zone (SZ) flow and transport at Yucca Mountain is far from satisfactory. In part, this may reflect a higher level of interest and activity in UZ processes during the earlier stages of the project. This, in turn, may have resulted in less progress in SZ activities. Admittedly, the SZ encompasses a much larger volume of the mountain than the UZ. Although it does not involve the complexities of the UZ, it represents a much larger problem for site characterization, flow, and transport.*

The Panel identified three main areas where they believe important weaknesses are present in the current treatment:

- The lack of data for some important parameters
- The incomplete nature or site characterization
- Continuing questions regarding the adequacy of the numerical models

The Panel indicates that the first two areas of weaknesses have forced the DOE to rely primarily on estimates of the expert panel that participated in the Saturated Zone Flow and Transport Elicitation Project (GEO98) for guidance on selecting values for key parameters, including dilution and retardation. As a result of comments and recommendations provided by these experts, "Saturated Zone Flow and Transport Preliminary Draft Chapter 2.9 of TSPA-VA" (CRW98), published on February 13, 1998, has been replaced by a revised interpretation of the SZ flow and transport process. However, it is the opinion of the Panel that inherent problems remain. The Panel believes that additional work on this critical subject is needed. The Panel offers the following specific comments.

Lack of Field Data

The Panel indicates that the lack of field data presents a major difficulty. There is a broad area along the projected SZ flow path from Fortymile Wash to the Armagosa Valley, 10 km or more in length, in which no boreholes have been drilled (a number of the Panel's concerns may be alleviated by Nye County's well drilling/testing program as presented in the following section). The Panel maintains that, for this region, there is a resulting absence of data on key subjects such as: subsurface geology, water table configuration, hydraulic parameters, etc. In other words, the Panel is concerned that the characterization of the SZ flow path over about one half of its 20 km length is currently not complete. In addition, the Panel notes that there is an apparent difficulty in estimating vertical flow in the SZ, the location of the lower boundary, and the lack of account for anisotropy and heterogeneity. Furthermore, the Panel references a more detailed discussion of the serious uncertainties resulting from this lack of data presented in a report submitted to the U.S. Nuclear Waste Technical Review Board (GEL98).

The Panel also explains that the difficulty in evaluating the effects of retardation on radionuclide transport, which is needed in determining dose rate, is another inherent problem. There are two critical aspects to this problem: (1) the division of flow between the matrix and fractures in the SZ zone; and (2) the magnitude of the K_d values to be used.

According to the Saturated Zone Expert Elicitation Panel, ground water flow over the 20-km path from the repository site occurs mostly in the volcanic units and alluvium, and flow occurs in only 10% to 20% of the fractures. As indicated above, field data are needed to verify this picture of the SZ zone. Because K_d values in the matrix (especially for Np) can be 10 to 100 times higher than K_d values in the fractures, it is necessary to know what percentage of the radionuclides are in the matrix of the volcanics. Finally, Gelhar (GEL98), a member of the Peer Review Panel, has also indicated that K_d values cannot be used without knowing how representative they are of field conditions.

Incomplete Characterization of the Site

The Panel believes that characterization of the site remains incomplete. In the TSPA-VA, SZ site characterization affects primarily the description of the flow streamtubes, though the estimation of the permeability field and the water fluxes (in both SZ and UZ). The current approach for estimating the permeability field is based on the calibration of pressure heads. The Panel also points out that, in addition to the problem of lack of data over a substantial region of the SZ as mentioned above, it is known (as acknowledged by the DOE in Chapter 8 of the Technical Basis Document) that pressure data inversion does not guarantee uniqueness in parameter estimates. Thus, potential fast paths in the SZ (such as permeability channels) may be underestimated. The Panel maintains that the implications of such a possibility on the transport of radionuclides are significant and cannot be dismissed.

In the same context, the Panel also raises an issue of numerical resolution in the modeling of regional flow, where only 3 vertical layers (spanning 2,750 m) are used to represent the large-scale hydrology and a typical grid has a linear (horizontal) size of the order of 1,500 m. With such limited resolution, the Panel believes that the intra-grid heterogeneity is seriously misrepresented. Their same concern also applies to the site-scale model, which involves a grid resolution of 200 m. The Panel indicates that, given the large range in permeabilities, which spans 7 orders of magnitude, this limited resolution raises the issue of the relevance of numerical predictions regarding the postulated flow fields.

The assumed water fluxes in the SZ and UZ, their variation with different climates and the recharge from the ground surface downgradient from the repository will also affect the description of the streamtubes. The Panel asserts that the uncertainties pertaining to the characterization of the site, the postulated flux multipliers for the future climates (four for the Long-Term Average and six for the Super Pluvial) are also uncertain. Streamtubes are assumed not to vary with time, regardless of the changes in climate, which is assumed to affect only the volume flux through them. The Panel indicates that this assumption is not consistent with the change in the ratio of the water flux though the UZ and the SZ zones, as shown in Table 3.21, Volume 3, of the TSPA-VA. The Panel further points out that instead of being constant, as required by the assumption of a constant streamtube, this ratio is shown to increase more than twofold as the climate changes from present day to super pluvial conditions.

In the current analysis, it is assumed that recharge along Fortymile Wash enters the ground water to the east of the plume, but it does not enter on top of the contaminated water. Recharge on top of the projected flow path would alter the streamlines significantly, resulting in a substantial layer of clean water above the contaminated water. In his report to the NWTRB, Gelhar (GEL98) suggests that such a layer could be 100 to 150 meters thick. The Panel believes that this potentially conservative feature would call into doubt the basic biosphere model in which a farm family is assumed to pump contaminated water from the plume.

Streamtube Approach

In response to the criticism raised by the Expert Elicitation Panel on the SZ Flow and Transport (GEO98), the DOE drastically revised the model of contaminant transport in the SZ in favor of a new formulation based on flow streamtubes. While the Peer Review Panel believes that the streamtube approach is better than the previous coarse-grid numerical models (200m x 200m, x 20m), it also believes that several issues need to be resolved.

The modeling of dispersion and dilution is treated quite empirically, using overall estimates of dilution, provided by the Saturated Zone Flow and Transport Expert Panel. Since the DOE has similarly provided overall dilution factors instead of a more detailed analysis, the net result is that the interaction of plumes containing different radionuclide concentrations is also treated inadequately, in a generally ad hoc manner. The Panel believes that a numerical approach based on a streamtube formalism, well-resolved near the plume and with a correct representation of dispersion and retardation, is feasible (provided that a good description of the heterogeneity from field data is available). Development of such an approach would permit sensitivity studies to be conducted or the effects various factors, including geostatistics, and would circumvent the necessity to rely solely on estimates from an expert panel and/or empirical corrections. At the same time, the Peer Review Panel raises a concern as to why the modeling of the transport problem is treated differently in the UZ (using a particle-tracking method) and in the SZ (using streamtubes with a dilution factor). The Panel maintains that a unified treatment should be feasible and should be adopted.

On the positive side, the Panel notes the excellent analysis, described in the Technical Basis Document, that relates the dilution factor to transverse dispersivity. The Panel asserts that the proposed convolution approach is quite useful for abstraction, assuming that processes, such as adsorption and retardation, remain in the linear regime, and the flow field is at steady state. The

Panel also notes the advances in the analysis of radionuclide sorption on colloids presented in Chapter 8 of the Technical Basis Document, although these are not included in the current TSPA-VA. The Panel believes that one of the most significant advances is that the process is now correctly treated as being dynamic, rather than irreversible.

The Peer Review Panel raise a point regarding the fracture-matrix interaction. In the TSPA-VA model, flow is assumed to occur only through the fractures; the water in the matrix being stagnant. Instead of explicitly modeling mass diffusion from the fracture to the matrix, the approach taken is to introduce an effective, time-independent porosity for the entire system, in which low porosity values reflect limited diffusion, and high values reflect a more enhanced diffusion. A problem with this representation is that the degree of fracture-matrix interaction is fixed a priori, rather than being a time-dependent process as it is, in reality. Given that retardation is associated with the matrix, this assumption will affect the transport predictions.

The Panel also brings forth an issue regarding the averaging the source concentrations over six areas, which here lie at the interface between the UZ and the SZ. As in UZ transport, this assumption introduces an artificial spreading which will lead to non-conservative estimates, particularly at early times (e.g., within the first 10,000 years) when leakage of radionuclides from waste packages is associated with isolated failures. For such failures, the Panel suggested in its third interim report (WHI98) that it is unrealistic to assume that radionuclides will produce a uniform concentration in the ground water beneath the repository across a flow path that is hundreds to thousands of meters wide. Even if multiple releases were to occur, the waste packages that fail could be close to one another within the repository. Such a situation could occur due to a locally aggressive corrosion environment or the fact that adjoining waste packages share a common fabrication problem.

In response to the Panel's criticism, the DOE conducted a sensitivity analysis of the effect of the source size on the dilution factor at the 20-km point. In this analysis, the degree of the non-conservatism introduced by the approximation made in the TSPA-VA can be assessed. It was found that, as a result of this approximation, the TSPA-VA underestimates the dose rates for the base case parameter values by a factor of 3. A correction was not introduced in the TSPA-VA, however. The Panel agrees with the general results of Arnold's analysis, and recommends that the current TSPA-VA treatment be modified to correct the existing deficiency. In particular, the Panel believes that the method described in the sensitivity analysis by Arnold and Kuzio

(ARN98) should be applied to the assessment of the exposures that would result from human intrusion and from the juvenile failure of a waste package.

Soil Adsorption of Radionuclides

The TSPA-VA analysis of the performance during the first 10,000 years after repository closure indicates that the estimated doses are due primarily to ^{99}Tc and ^{129}I. The doses at later times from ^{237}Np and ^{239}Pu are projected to be larger. This is due to the fact that the transport of these two actinides though the UZ and SZ will be delayed for extended periods by chemical sorption and, therefore, they will not reach the accessible environment in significant concentrations until a considerably later point in time. No retardation credit is taken for ^{99}Tc and ^{129}I (or for three other radionuclides), based on the lack of observed sorption in batch measurements of K_d values in the laboratory. This decision is described in the TSPA-VA as being conservative. However, the Panel points out that field measurements near the Savannah River Plant and in the vicinity of the Chernobyl nuclear power plant, following the accident at that facility, indicate that radioactive iodine deposited on the ground has been retained in the upper soil layer to about the same extent as plutonium and cesium, (STR96; STR97). The Panel has not conducted a literature review on this issue, but believes that it is likely that measurements taken of areas near the Chernobyl site, for example, would also provide relevant data on the retention or lack of retention of technetium in soil. Regarding the retardation of iodine, the Panel notes that additional data sets are likely to be available from environmental measurements taken at the Hanford site, where radioactive iodine was released during spent fuel reprocessing. Although it appears that some fraction of the deposited radionuclides may be transported to ground water (e.g., as with cesium at the Hanford tank farm), field data suggest that radionuclide does not move unretarded through the soil. It is the Panel's view that the DOE, in preparing the TSPA-VA, unduly emphasized the results of laboratory K_d measurements, and did not appropriately consider the results of field measurements of radionuclide concentrations in the soil following releases that occurred as a result of nuclear power plant accidents and past nuclear facility operations. The Panel further notes that the DOE has now recognized this problem and it is being addressed.

State of Nevada/T-Reg, Inc. Identified Needs

The State of Nevada and their consultant T-Reg believe that structural controls on the flow system have not been adequately addressed in the TSPA-VA. To support their position, they have identified a number of items in the TSPA-VA which they believe are incompatible, not well represented, or nonrepresentative of their structurally controlled conceptual flow field. Most of the nonrepresentativeness occurs in the saturated zone, or in the areal distribution of recharge to the water table, via the unsaturated zone. Each of these items is discussed separately.

Saturated Zone

(1) The TSPA conceptual flow model allows particles of water to move orthogonal to the hydraulic gradient. Anisotropic effects due to structure are not considered. This causes the flow path for releases from the repository to move initially eastward and then southeastward to Forty Mile Wash, then curve back to the southwest to the Amargosa Farms area at a 20 km radius. Utilizing anisotropic transmissivities, flow paths are created which are directly south, then southeast and southwest, considerably shortening the flowpath to the receptors.

(2) Flow path properties used in the "six flow tubes" are not representative of the southerly flow path. This is because the TSPA flow path would take the releases into alluvium at a shorter distance than a more southerly flow path. Thus, out of the 20-km compliance distance, less distance is assigned tuff properties and more is assigned alluvial properties. (The TSPA flow path is actually longer than 20 km.) The alluvial properties are generally more favorable for retarding and dispersing the repository releases than the tuff properties and, in fact, now constitute the most important barrier in the saturated zone. A shorter flow path to the receptors would also be taken in the State's conceptualization.

(3) Alluvial properties assigned may not be representative of valley- fill sediments. According to drilling results of Nye County, presented at the Devils Hole Workshop, the valley fill sediments south of Yucca Mountain are not primarily alluvium. Rather they consist of coarse gravels, tufa, basalts, tuffs and lake bed sediments. The State asserts that sorption, retardation, dispersion and effective porosity assumptions used to describe transport through "alluvium" must be justified.

(4) The State believes that fracture zone effective porosities or hydraulic apertures also need to be reconsidered or verified. Porosities ranging up to 10% or more are used currently. The TSPA sampled a distribution of porosities ranging from 10^{-5} to approximately 20% but the mean value centered near 2-3%. The State points out that normally effective porosities for fractured aquifers range on the order of 0.01 to 0.001. These changes would work to increase the flow velocities inversely, making them higher than most base case scenarios.

(5) Eastward expansion of the water table receptor area appears inconsistent with channelized flow through Ghost Dance fault zone. This eastward expansion could add up to about 25% more area over which to average repository releases from the

unsaturated zone. The State believes that this is inconsistent with results of Bodvarson, shown in the TSPA, where his center of mass calculations show eastward movement cut off by the presence of the Ghost Dance fault (If waste is placed east of the Ghost Dance, then some areas of eastward expansion could be envisioned, but only at these positions, not uniformly across the length of the repository.)

(6) The eastward flow path is not consistent with chemistry data of the USGS, presented at the Devils Hole Work Shop, April 1999, or earlier work. These data do not indicate an eastward flow part, but rather a southerly one for numerous isotopes.

(7) The eastward flow path may not be consistent with temperature data. Temperature calculations must be a part of this flow path analyses. Both data sets (temperature and pressure) must be matched before any flow paths can be believed.

(8) The State also questions the NRC well bore dilution numbers and the DOE dilutions based on the idea of rigid blocks separated by transmissive faults. Nye County drilling results indicate three boundaries in one of their pump tests. These boundaries were not distant and depict a situation where by smaller volumes of water would be available for dilution. Their drilling results also show that pumping rates are highly non-uniform ranging from a few gallons a minute to several hundred gallons per minute. To use huge well bore dilution volumes (10^8 gallons per day) at this point is not justified. The DOE flow path dilution numbers are much smaller than the NRC's but still not based on channelized flow and therefore must be justified.

Infiltration

(1) The State points out that the map of infiltration based on Flint is partially inconsistent with their conceptual model of infiltration. While slope, depth of alluvium, evapotranspiration and elevation are definitely important, so may be some other factors. Flint assumes that where thick alluvium is present idle recharge occurs. The State believes that this may not hold true on the steep western slope of Yucca Mountain. The TSPA-VA infiltration model shows a dry area to the west of the crest of Yucca Mountain rather than a wetter one which the State's conceptualization would predict.

(2) The State asserts that it is possible for runoff to go under the alluvium and into fractures, thus being blanketed from potential evaporation. Given that the PTn unit is not present to divert any infiltration in some areas to the west of the repository, then infiltration is possible directly or nearly so into the Topopah

Springs unit, up gradient of the repository. As stated previously, in the State's conceptual model, the western side would be expected to be wetter than the eastern side.

(3) The State also notes that recent correspondence from Steve Brocum, DOE to the NRC, Sandra Wastler, Monthly Progress Report, dated 03-26-99 indicates that water potentials are higher in the East-West Cross Drift (ECRD) and indicate that the rock is wetter and the moisture is more uniformly distributed than expected. The State points out that the structure here is probably important and explains further that tensional north-south trending smaller structures across the mountain block may be channeling the movement of infiltrating water. By cutting across them in an east-west direction, the ECRD has intercepted more pathways than when they bored north-south in the main drift section, parallel to these features.

(4) Flint et al. (FLI96) and the TSPA-VA infiltration model indicate that the net infiltration is lower in the washes. The State generally concurs, except that they believe higher infiltration occurs in the upper reaches of most washes, not along the lower reaches.

(5) The State believes that infiltration at the water table surface may also not be representative, nor consistent with their model. The TSPA-VA infiltration map shows lower infiltration along the Ghost Dance fault area where the State would assume higher infiltration based on the temperature distribution.

(6) The State also notes that Zell Peterman, USGS has shown what appears to be a plume of younger water along the northwest side of the mountain block. The State would expect that this plume would be infiltrating or recharging in that area. The water table map in the TSPA-VA shows it to be relatively dry.

(7) Breakthrough curves simulating the dry (present day) climate conditions (Figure 3-10 of the TSPA-VA) indicate less than 5% cumulative breakthrough for an unretarded tracer at the water table in less than 800 years with 95% breakthrough between 800-12,000 years. The State believes that it is reasonable that if in the north-south trending drifts, ^{36}Cl is seen within 50 years, that when sampled, the ECRD may also yield ^{36}Cl and perhaps more than in the north-south drift. The State asserts that these low percentages of ground water breakthrough are not justified.

(8) Drift scale seepage assumes a 99.5% reduction of net infiltration. While the State would expect some diversion they would also expect that the infiltration rate of water into the drifts would be on the order of that calculated for G Tunnel, i.e., about 3% of the annual average rainfall. This would allow for 4.5mm/vr into the

tunnel. Instead, VA values are orders of magnitude lower. The State notes that these low values need to be supported.

(9) Seepage Fraction, or number of canisters hit by drips is surprisingly low. The State claims that given their concept of fracture controlled drips and data from the DOE that the ECRD is wetter than expected, no confidence can be assigned to this number. The State further notes that testing in Alcove 1, though shallow with high infiltration applied, is indicative of a potential for more wide spread dripping given that 45% of the roof area catchments had contacted drips.

(10) Drips onto packages are assumed stationary during their flow history. The State believes that this may also not be the case for many reasons (hydraulic, geochemical or tectonic), and further suggests that moving them about over time would tend to wet a larger number of packages.

(11) Sorption and matrix diffusion are assumed to always operate together on sorbing species. The State questions whether this a valid assumption, and notes that it allows for more retardation than may be justified if considering them separately.

(12) Volumetric flux via the drift invert assumes 10% porosity, 99.8% saturation, sorption and diffusion. The State contends that if the invert fails over time, or fractures develop due to tectonic activity, then flow would be focused and radionuclides less retarded. The State further notes that no provision for invert failure or degradation has been made in the TSPA-VA.

State's Conclusions

Based on the concerns identified above, the State made the following three conclusions:

(1) If the basic flow pathways and their characteristics are not correctly interpreted or represented, when they possess qualities which can be measured or tested in the field, then little confidence can be placed on analyses, interpretations or designs which have not been or cannot be tested or verified.

(2) The flow fields need to be calibrated against temperature or other independent variables in order to support flow paths selected.

(3) Future TSPAs will have to modified their flow model to be representative of a structurally controlled flow field.

VI.2.1.5 Nye County Drilling and Characterization Program

As part of its Nuclear Waste Repository Project Office Yucca Mountain Oversight Program, Nye County is conducting an Early Warning Drilling Program (EWDP). The purpose of the EWDP is to establish a ground water monitoring system to protect the residents of Nye County in Amargosa and Pahrump Valleys against potential radionuclide contamination of the ground water system as a result of radionuclide releases from a repository at Yucca Mountain.

The program is also intended to provide geologic and hydrologic characterization data to supplement the DOE program. The EWDP boreholes are located in a highly complex geohydrological regime, about 20 km south of the proposed repository location, which has received very little characterization. Near-surface geologic features are valley-fill alluvium which is potentially very heterogeneous and overlays volcanic rocks such as are beneath Yucca Mountain. Data are to be obtained to characterize the geologic features, ground water flow patterns, and ground water recharge.

Eight drillholes were completed during Phase I of the program in 1999. Four of the drillholes were relatively shallow (a few hundred feet), and the other four went to depths on the order of 2,000 feet. Lithologic logs were recorded, and can be seen on the Nye County website, www.nyecounty.com. The website also provides a map showing the locations of the drillholes, most of which were close to, and along the length of, U.S. Highway 95 south of Yucca Mountain.

The program also includes airborne aeromagnetic surveys which are obtaining data are being used to characterize buried geologic features, to provide details on possible fault conduits in the valley-fill deposits, and to help guide selection of the Phase II drillholes, eight of which are planned. An alluvial tracer complex, which would be an interagency effort involving Nye County, DOE, and Yucca Mountain Project contractors to DOE is also planned.

The current status of the program, and descriptions of the EWDP drillholes and reports on program activities and findings, are available at the Nye County website cited above.

VI.2.1.6 Relationship Between the Hydrologic Regime and the 10,000-Year Compliance Period

As shown by preceding discussion, the geohydrologic regime in the Yucca Mountain region is highly heterogeneous, and the models of ground water flow and radionuclide transport reflect this heterogeneity. Flow occurs principally in fractures in volcanic tuffs, and the valley-fill alluvium south of the proposed repository site has been found to exhibit braiding and other structural features such that there may be principal flow channels in this medium as well as in the volcanic tuffs.

Ground water flow paths and rates, and radionuclide contaminant transport by the ground water, therefore depend on the specific small-scale features of the geohydrologic regime. These characteristics may be significantly affected by seismicity, tectonic movement, climate change, and other natural phenomena expected to occur over the next million years.

How the small-scale features will change in response to these phenomena is uncertain. The validity of very long term projections of repository system performance and radiation doses that are based on current geohydrologic conditions and models of these conditions is therefore highly uncertain, and too uncertain to be the basis for evaluation of compliance with radiation protection standards.

As noted by the National Academy of Sciences Committee that developed the technical basis for the EPA's Yucca Mountain standards, (NAS95), the potential for future occurrence of natural phenomena such as earthquakes may be boundable based on current data and evidence of past phenomena. However, bounding the potential incidence of natural phenomena does not and can not capture the changes in small-scale features that are directly important to repository performance and radiation doses that might be incurred at a specific location.

Factors involved in long-term uncertainty for repository performance are discussed in detail in Section 7.3.11 of the BID. The discussion shows that radiation doses for a compliance evaluation period corresponding to the time of peak dose hundreds of thousands of years in the future cannot be reliably evaluated. The dose evaluations would be subject to the uncertainties associated with the small-scale consequences of diverse, episodic phenomena characterized by bounding estimates.

In contrast, a compliance period of 10,000 years captures a reasonable extrapolation of current natural features and phenomena, such as climate, that affect repository system performance. It also captures the effect of the thermal pulse on repository-scale natural and engineered features, and allows reasonable assessment of the occurrence and consequences of improbable but possible repository-scale phenomena such as intrusion of volcanic magma and, for the Site Recommendation repository engineered design, common-mode failure of a drip shield and the underlying waste package. The 10,000-year compliance period would be expected to exclude low-frequency, high-consequence natural phenomena such as high-intensity seismic activity, which dominate the uncertainty associated with long-term dose predictions.

The 10,000-year compliance period is not, however, so short that it excludes phenomena such as temperature changes and low-rate, low-frequency seepage that affect repository system performance and can be reasonably modeled and accounted for. Principles of reasonable expectation can be applied with confidence as a result of a data base of current conditions and an understanding of the phenomena and features that affect performance over the 10,000-year period.

In summary, the site-specific features of the Yucca Mountain region, which include a highly heterogeneous geohydrologic regime and expectation of long-term phenomena that can and will affect the geohydrologic regime in uncertain ways, reinforce use of the 10,000-year compliance period established for the generic 40 CFR Part 191 standards.

REFERENCES FOR APPENDIX VI

AND98 Andrews, R.W. 1998. *Basic Structure, Conceptual Model, and Results of the TSPA-VA,* presentation to U.S. Nuclear Waste Technical Review Board, Performance Assessment Panel, April 23, 1998, Arlington, VA, 74 p.

ARN98 Arnold, B. 1998. *Saturated Zone Flow and Transport Analyses for TSPA-VA*, presentation at the Technical Exchange on Performance Assessment, San Antonio, TX, March 17-19, 1998.

BAN97 Bandurraga, T.M., and G.S. Bodvarsson. 1997. Calibrating Matrix and Fracture Properties Using Inverse Modeling, G. Bodvarsson, T. Bandurraga and Y. Wu, eds, *The Site-Scale Unsaturated Zone Model of Yucca Mountain, Nevada, for the Viability Assessment*, LBNL-40376, Berkeley, CA, Lawrence Berkeley National Laboratory.

BAT92 Bates, J.K., Bradley, A. Teetsov, C.R. Nradley, M. Buchholzten Brink, Colloid Formation During Waste Form Reaction: Implications for Nuclear Waste Disposal, *Science*, 256:659-662, 1992.

BOD96 Bodvarsson, G.S. and Bandurraga, T.M. Eds. 1996. *Development and Calibration of the Three-Dimensional Site-Scale Unsaturated-Zone Model of Yucca Mountain, Nevada.* 24 Chapters, variously cited. Milestone Report OBO2. LBNL-39315. Berkeley, California: Lawrence Berkeley National Laboratory. MOL.19970211.0176.

BOD97 Bodvarsson, G.S.; Bandurraga, T.M.; and Wu, Y.S. Eds. 1997. *The Site-Scale Unsaturated Zone Model of Yucca Mountain, Nevada, for the Viability Assessment.* LBNL-40376. Berkeley, California: Lawrence Berkeley National Laboratory. ACC:MOL.19971014.0232.

BRO97 Brown-Buntin Associates, Inc., 1997, *Background Noise Analysis, Proposed Yucca Mountain Nuclear Depository, Nye County, Nevada,* #97-215, Fair Oaks, California. [MOL.19980714.0030]

CAR86 Carr, M.D.; Waddell, S.J.; Vick, G.S.; Stock, J.M.; Monsen, S.A.; Harris, A.G.; Cork, B.W.; and Byers, F.M., Jr. 1986. *Geology of Drill Hole UE-25p#1 - A Test Hole into Pre-Tertiary Rocks near Yucca Mountain, Southern Nevada.* USGS-OFR-86-175. Denver, Colorado: U.S. Geological Survey. TIC 203184.

CLA97 Clark County 1997. *Particulate Matter (PM10) Attainment Demonstration Plan, Las Vegas Valley Non-attainment Area, Clark County, Nevada,* Final Report, Clark County Board of Commissioners, Las Vegas, Nevada. [243944]

COH97 Cohen, A.J.B.; Oldenburg, C.M.; Simmons, A.M.; Mishra, A.K.; and Hinds, J. 1997. *S4Z: Sub-Site Scale Saturated Zone Model for Yucca Mountain.* Level 4 Milestone Report SP25UM4. Berkeley, California: Lawrence Berkeley National Laboratory. MOL.19971204.0732.

CRA84 Craig, R.W. and K.A. Johnson. 1984. *Geohydrologic Data for Test Well UE-25p#1, Yucca Mountain Area, Nye County, Nevada,* USGS Open-File Report 84-450, Denver, CO, 63 p.

CRW96 CRWMS M&O 1996. Total System Performance Assessment - Viability Assessment (TSPA-VA) Plan. B00000000-01717-2200-00179. Las Vegas, Nevada: CRWMS M&O. MOL. 19970320.0078.

CRW97 CRWMS M&O 1997. Unsaturated Zone Radionuclide Transport Abstraction/Testing Workshop Results. B00000000-01717-2200-00185 REV 00. Las Vegas Nevada: CRWMS M&O. MOL 19980602.0479.

CRW98 CRWMS M&O 1998. *Yucca Mountain Site Description,* Revision 00, September 1998 - (Document ID B00000000-01717-5700-00019) Book 2, Section 5 - Hydrologic System. ACC:MOL.19980729.0051

CZA84 Czarnecki, J.B. and Waddell, R.K. 1984. *Finite-Element Simulation of Ground Water Flow in the Vicinity of Yucca Mountain, Nevada-California.* USGS Water-Resources Investigations Report 84-4349. Denver, Colorado: U.S. Geological Survey. GS920408312142.002; NNA.19870407.0173.

CZA85 Czarnecki, J.B. 1985. *Simulated Effects of Increased Recharge on the Groundwater Flow System of Yucca Mountain and Vicinity, Nevada-California.* USGS Water-Resources Investigations Report 84-4344. Denver, Colorado: U.S. Geological Survey. HQS.19880517.1750.

CZA90 Czarnecki, J. B. 1990. *Geohydrology and Evapotranspiration at Franklin Lake Playa, Inyo County, California,* USGS-OFR-90-356, U.S. Geological Survey, U.S. Department of the Interior, Denver, Colorado. [201103]

CZA91 Czarnecki, J.B., and Wilson, W.E. 1991. *Conceptual Models of the Regional Ground Water Flow and Planned Studies at Yucca Mountain, Nevada,* Hydrological Science and Technology, V. 7, Nos. 1-4, pp. 15-25.

CZA94 Czarnecki, J.B.; O'Brien, G.M.; Nelson, P.H.; Sass, J.H.; Bullard, J.W.; and Flint, A.L. 1994. "Is There Perched Water under Yucca Mountain in Borehole USW G-2?" Abstract. *Program and Abstracts to the AGU 1994 Fall Meeting, December 5-9, San Francisco, California*, 249-250. Washington, D.C.: American Geophysical Union. TIC 226992.

CZA95 Czarnecki, J.B.; Nelson, P.H.; O'Brien, G.M.; and Sass, J.H. 1995. "Testing in Borehole USW G-2 at Yucca Mountain: The Saga Continues". Abstract. AGU 1995 Fall Meeting, December 11-15, 1995, San Francisco, California. *EOS (Supplement), Transactions, American Geophysical Union, 76*, n. 46, F190. Washington D.C.: American Geophysical Union. TBD

CZA97 Czarnecki, J.B.; Faunt, C.C.; Gable, C.W.; and Zyvolski, G.A. 1997. *Hydrogeology and Preliminary Calibration of a Preliminary Three-Dimensional Finite Element Ground Water Flow Model of the Site Saturated Zone, Yucca Mountain, Nevada.* USGS YMP Milestone Report SP23NM3. Denver, Colorado: U.S. Geological Survey. MOL.19980204.0519.

DAG97a D'Agnese, F.A., C.C. Faunt, A.K. Turner, and M.C. Hill. 1997. *Hydrogeological Evaluation and Numerical Simulation of the Death Valley Regional Groundwater Flow System, Nevada and California, using Geoscientific Information Systems*, Water-Resources Investigations Report 96-4300, Denver, CO, U.S. Geological Survey. MOL. 19980306.0253.

DAG97b D'Agnese, F.A., G.M. O'Brien, C.C. Faunt, and C.A. San Juan. 1997. *Simulated Effects of Climate Change on the Death Valley Regional Ground water Flow System, Nevada and California*, Milestone Report SP23OM3, Denver, CO: U.S. Geological Survey.

DAY96 Day, W. C., C. J. Potter, D. E. Sweetkind, R. P. Dickerson, and C. A. San Juan. 1996. *Bedrock Geologic Map of the Central Block Area, Yucca Mountain, Nye County, Nevada,* map, USGS-MI-2601, U.S. Geological Survey, U.S. Department of the Interior, Denver, Colorado. [237019]

DOE95 U.S. Department of Energy. November 1995. *Total System Performance Assessment - 1995: An Evaluation of the Potential Yucca Mountain Repository*, TRW Environmental Safety Systems, Inc., B0000000-01717-2200-00136, Revision 01.

DOE96 U.S. Department of Energy. September 1996. *Highlights of the U.S. Department of Energy's Updated Waste Containment and Isolation Strategy, Yucca Mountain Site, Nevada*, YMP/96-01, Revision 0. Washington, D.C.: OCRWM.

DOE98 U.S. Department of Energy. 1998. *Repository Safety Strategy: U.S. Department of Energy's Strategy to Protect Public Health and Safety After Closure of a Yucca Mountain Repository.* YMP/96-01, Revision 2. Washington, D.C.: OCRWM. ACC:MOL.19980727.0001.

ERV94 Ervin, E.M.; Luckey, R.R.; and Burkhardt, D.J. 1994. *Revised Potentiometric-Surface Map for Yucca Mountain and Vicinity, Nevada.* USGS Water-Resources Investigations Report 93-4000. Denver, Colorado: U.S. Geological Survey. TIC 21852.

FAB96 Fabryka-Martin, J., and Wolfsberg, A. July 1996. *Hydrologic Flow Paths and Rates Inferred from the Distribution of Chlorine-36 in the ESF*, Nuclear Waste Technical Review Board.

FIN93 Finsterle, S. 1993. *ITOUGH2 User's Guide, Version 2.2.* Report LBL-34581. UC-600. Berkeley, California: Lawrence Berkeley National Laboratory. MOL.19941026.0075.

FLI94 Flint, A.L., and L.E. Flint, 1994. *Spatial Distribution of Potential Near Surface Moisture Flux at Yucca Mountain*, Proceedings of the Fifth Annual International Conference on High Level Radioactive Waste Management, Las Vegas, Nevada, pp. 2352-2358.

FLI95 Flint, L.E. and Flint, A.L. 1995. *Shallow Infiltration Processes at Yucca Mountain, Nevada - Neutron Logging Data 1984-93.* USGS Water-Resources Investigations Report 95-4035. Denver, Colorado: U.S. Geological Survey. MOL.19960924.0577.

FLI96 Flint, A. L., J. A. Hevesi, and L. E. Flint. 1996. *Draft Conceptual and Numerical Model of Infiltration for the Yucca Mountain Area, Nevada,* in cooperation with the Nevada Operations Office, U.S. Department of Energy, U.S. Geological Survey, U.S. Department of the Interior, Denver, Colorado. [MOL.19970409.0087]

FLI98 Flint, L.E. 1998. *Characterization of Hydrogeologic Units Using Matrix Properties, Yucca Mountain, Nevada.* Water-Resources Investigations Report USGS-WRIR-97-4243. Denver, Colorado: U.S. Geological Survey. ACC:MOL.19980429.0512. TIC:236515.

FRE79 Freeze, R.A. and Cherry, J.A. 1979. *Groundwater.* Englewood Cliffs, New Jersey: Prentice-Hall. TIC 217571.

FRI94 Fridrich, C.J., W.W. Dudley, Jr., and J.S. Stuckless. 1994. *Hydrogeologic Analysis of the Saturated-Zone Ground Water System, under Yucca Mountain, Nevada,* Journal of Hydrology, 154:133-168.

GAB95 Gable, C.W.; Cherry, T.A.; Trease, H.E.; and Zyvoloski, G.A. 1995. *Geomesh Grid Generation*. Yucca Mountain Project Milestone 4074 Letter Report LA-UR-95-4143. Los Alamos, New Mexico: Los Alamos National Laboratory. MOL.19960315.0299.

GAB96 Gable, C.W., H. Trease, and T. Cheny. 1996. Geological Applications of Automatic Grid Generation Tools for Finite Elements Applied to Porous Flow Modeling. In *Numerical Grid Generation in Computational Fluid Dynamics and Related Fields*, edited by B.K. Soni, J.F. Thompson, H. Hausser, and P.R. Eiseman, Engineering Research Center. Mississippi State University Press.

GEL96 Geldon, A.L. 1996. *Results and Interpretation of Preliminary Aquifer Test in Boreholes UE-25c #1, UE-25c #2, and UE-25c #3, Yucca Mountain, Nye County, Nevada*. USGS Water-Resources Investigations Report 94-4177. Denver, Colorado: U.S. Geological Survey.

GEL97 Geldon, A.L.; Umari, A.M.A.; Fahy, M.F.; Earle, J.D.; Gemmell, J.M.; and Damell, J. 1997. *Results of Hydraulic and Conservative Tracer Tests in Miocene Tuffaceous Rocks at the C-Hole Complex, 1995 to 1997, Yucca Mountain, Nye County, Nevada.* Level 3 Milestone Report SP23PM3. Denver, Colorado: U.S. Geological Survey. MOL.19980122.0412.

GEL98 Gelhar, Lynn W. 1998. *Report on U.S. Technical Review Board Winter Meeting*, January 20-21, 1998, Amargosa Valley, Nevada.

GEO97 Geomatrix Consultants, Inc. and TRW. May 1997. *Unsaturated Zone Flow Model Expert Elicitation Project*, Las Vegas, Nevada, May.

GEO98 Geomatrix and TRW (Geomatrix Consultants, Inc., and TRW Environmental Safety Systems Inc.). 1998. *Saturated Zone Flow and Transport Expert Elicitation Project*, San Francisco, California, and Las Vegas, Nevada. [MOL.19980825.0008]

GRA97 Graves, R.P.; Tucci, P.; and O'Brien, G.M. 1997. *Analysis of Water-Level Data in the Yucca Mountain Area, Nevada, 1985-95.* USGS Water-Resources Investigations Report 95-4256. Denver, Colorado: U.S. Geological Survey. MOL.19980219.0851.

GRI80 Grisak, G.E., and J.F. Pickens. 1980. Solute Transport Through Fractured Media: 1. The Effect of Matrix Diffusion. *Water Resources Research* 16(4):719-730.

HEV92 Hevesi, J.A., J.D. Istok, and A.L. Flint. 1992. "Precipitation Estimation in Mountainous Terrain Using Multivariate Geostatistics, Part I, Structural Analysis," *Journal of Applied Meteorology* 31(7). pp. 661-676.

HEV94 Hevesi, J.A.; Flint, A.L.; and Flint, L.E. 1994. Verification of a One-Dimensional Model for Predicting Shallow Infiltration at Yucca Mountain." *High Level Radioacctive Waste Management, Proceedings of the Fifth Annual International, Las Vegas, Nevada, May 22-26, 1994*, 4, 2323-2332. La Grange Park, Illinois: American Nuclear Society, Inc.; New York, New York; American Society of Civil Engineers. 238118.

HIL80 Hillel, D., "Introduction to Soil Physics," New York, NY, Academic Press, 1980.

HIL92 Hill, M.C. 1992. *A Computer Program (MODFLOWP) for Estimating Parameters of a Transient, Three-Dimensional, Ground Water Flow Model Using Nonlinear Regression*. USGS-OFR-91-484. Denver, Colorado: U.S. Geological Survey. TIC 232369.

HOR33 Horton, R.E. 1933. The Role of Infiltration in the Hydrologic Cycle. *Transactions, American Geophysical Union, 14th Annual Meeting, June 1933.* 14, 446-460. Washington, D.C.: American Geophysical Union. 237958.

KAR90 Karasaki, K., M. Landsfeld, and K. Grossenbacher. 1990. Building a Conceptual Model at the UE25-C Hole Complex. In *Volume 2, Proceedings of International Topical Meeting: High Level Radioactive Waste Management, Las Vegas, Nevada.* American Society of Civil Engineers and American Nuclear Society.

KIL91 Kilroy, K.C. 1991. *Ground Water Conditions in Amargosa Desert, Nevada-California, 1952-87*. USGS Water-Resources Investigations Report 89-4101. Denver, Colorado: U.S. Geological Survey. TIC 209975.

LAN96 Los Alamos National Laboratory, *Summary Report of* Chlorine-36 *Studies: Systematic Sampling for Chlorine-36 in the Exploratory Studies Facility,* Level 4 Milestone Report 3783D, March 1996.

LBL96 Lawrence Berkeley Laboratory. 1996. *Development And Calibration Of The Three-Dimensional Site Scale Unsaturated Zone Model Of Yucca Mountina, Nevada*, Berkeley, California.

LEC97 LeCain, G.D. 1997. *Air-Injection Testing in Vertical Boreholes in Welded and Nonwelded Tuff, Yucca Mountain, Nevada.* Water-Resources Investigations Report 96-4262. Denver, Colorado: U.S. Geological Survey. ACC:MOL.19980310.0148. TIC: 233455.

LUC96 Luckey, R.R.; Tucci, P.; Faunt, C.; Ervin, E.M.; Steinkampf, W.C.; D'Agnese, F.A.; and Patterson, G.L. 1996. *Status of Understanding of the Saturated-Zone Ground Water Flow System at Yucca Mountain, Nevada, as of 1995.* USGS Water-Resources Investigations Report 96-4077, p. 17. Denver, Colorado: U.S. Geological Survey. TIC: 227084.

MAL85 Maldonado, F. 1985. *Geologic Map of the Jackass Flats Area, Nye County, Nevada,* USGS Miscellaneous Series Investigations Map I-1519, Reston, VA, U.S. Geological Survey.

MAL91 Maloszewski, P., and A. Zuber. 1991. Influence of Matrix Diffusion and Exchange Reactions on Radiocargbon Ages in Fissured Carbonate Aquifers. *Water Resources Research* 27(8):1937-1945.

MAT96 Mattson, S.R. and Clayton, R.W., 1996. *Yucca Mountain Project Stratigraphic Compendium,* Document Identifier B00000000-01717-5700-00004 Rev. 2. MOL.19970113.0088, Civilian Radioactive Waste Management System Management and Operating Contractor, Las Vegas, Nevada.

MCD88 McDonald, M.G. and Harbaugh, A.W. 1988. *A Modular Three Dimensional Finite-Difference Ground Water Flow Model.* USGS Techniques of Water-Resources Investigations, Book 6, Chapter A1. Denver, Colorado: U.S. Geological Survey. TIC 224714.

MON84 Montazer, P. and Wilson, W.E. 1984. *Conceptual Hydrologic Model of Flow in the Unsaturated Zone, Yucca Mountain, Nevada.* Water-Resources Investigation Report. 84-4345. Denver, Colorado: U.S. Geological Survey. ACC:NNA.19870519.0109.

NER80 Neretnicks, I. 1980. Diffusion in the Rock Matrix: An Important Factor in Radionuclide Migration? *Journal of Geophysical Research* 85(B8):4379-4397.

NER82 Neretnicks, I, T. Eriksen, and P. Tahtinen. 1982. Tracer Movement in a Single Fissure in Granitic Rock: Some Experimental Results and Their Interpretation. *Water Resources Research* 18:849-858.

NIT97 Nitao, J.J. 1997. *Preliminary Bounds for the Drift-Scale Distribution of Percolation and Seepage at the Repository Level Under Pre-Emplacement Conditions,* Deliverable No, SPLB1M4, Level 4, Livermore, CA, Lawrence Livermore National Laboratory.

NRC92 U.S. Nuclear Regulatory Commission. 1992. "Initial Demonstration of the NRC's Capability to Conduct a Performance Assessment for a High-Level Waste Repository," NUREG-1327, Washington, D.C.

NRC95 U.S. Nuclear Regulatory Commission. 1995. "Interim NRR Procedure for Environmental Reviews," Office of Nuclear Materials Safety and Safeguards, Washington, D.C. [243843]

NRC96 U.S. Nuclear Regulatory Commission. March 27, 1996. *Presentation to the Advisory Committee on Nuclear Waste Concerning Duration of the Regulatory Period*, T. McCartin.

NRC97a U.S. Nuclear Regulatory Commission. June 1997. *Issue Resolution Status Report on Methods to Evaluate Climate Change and Associated Effects at Yucca Mountain (Key Technical Issue: Unsaturated and Saturated Zone Flow Under Isothermal Conditions).*

NRC97b U.S. Nuclear Regulatory Commission. September 1997. *Issue Resolution Status Report Key Technical Issue: Unsaturated and Saturated Flow Under Isothermal Conditions*. Revision 0. Washington, D.C.: NRC.ACC:MOL.19980219.0572. (Section 4.3)

NRC98 U.S. Nuclear Regulatory Commission. November 1998. *Issue Resolution Status Report, Key Technical Issue: Total System Performance Assessment and Integration, Revision 1*, Division of Waste Management, Office of Nuclear Material Safety and Safeguards.

NWT98 U.S. Nuclear Waste Technical Review Board. 1998. *Report to the U.S. Congress and the U.S. Secretary of Energy*, Arlington, VA, U.S. Nuclear Waste Technical Review Board.

OBR97 O'Brien, G.M. 1997. *Analysis of Aquifer Tests Conducted in Boreholes USW WT-10, UE-25 WT#12, and USW SD-7, 1995-96, Yucca Mountain, Nevada.* USGS Water-Resources Investigations Report 96-4293. Denver, Colorado: U.S. Geological Survey. MOL.19980219.0822.

OST94 Osterkamp, W.R.; Lane, L.J.; Savard, C.S. 1994. *Recharge Estimates Using a Geomorphic/Distributed-Parameter Simulation Approach, Amargosa River Basin.* Water Resources Bulletin, 30, n. 3, 493-507. Washington, D.C.: American Geophysical Union. TIC 237428.

PAC96 Paces, J. B., et al. August 24, 1996. "Synthesis of Ground Water Discharge Deposits Near Yucca Mountain," Report 3GQH671M, U.S. Geological Survey, Final Version, 75 pp.

PET84 Peters, R., E. Klavetter, I. Hall, S. Blair, P. Heller, and G. Gee. 1984. *Fracture and Matrix Hydrologic Characteristics of Tuffaceous Materials from Yucca Mountain, Nye County, Nevada*, SAND84-1471, Albuquerque, NM, Sandia National Laboratories.

PRU87 Pruess, K. 1987. *TOUGH Users Guide*. NUREG-CR-4645. Also prepared as LBL-20700 (Berkeley, California: Lawrence Berkeley National Laboratory) and SAND-86-7104 (Albuquerque, New Mexico: Sandia National Laboratories). Washington, D.C.: Division of Waste Management, Office of Nuclear Materials Safety and Safeguards, U.S. Nuclear Regulatory Commission. TIC 217275.

PRU91 Pruess, K. 1991. *TOUGH2 - A General-Purpose Numerical Simulator for Multiphase Fluid and Heat Flow*. LBL-29400. Berkeley, California: Lawrence Berkeley National Laboratory. TIC 213489.

PRU93 Prudic, D.E.; Harrill, J.R.; and Burbey, T.J. 1993. *Conceptual Evaluation of Regional Ground Water Flow in the Carbonate-Rock Province of the Great Basin, Nevada, Utah, and Adjacent States*. USGS-OFR-90-560. Denver, Colorado: U.S. Geological Survey. MOL.19950105.0016.

RAS86 Rasmuson, A., and I. Neretnicks. 1986. Radionuclide Transport in Fast Channels in Crystalline Rock. *Water Resources Research* 22(8):1247-1256.

RAU97 Rautman, C.A. and McKenna, S.A. 1997. *Three-Dimensional Hydrological and Thermal Property Models of Yucca Mountain, Nevada*. SAND97-1730. Albuquerque, New Mexico: Sandia National Laboratories. MOL.19980311.0317.

REE94 Reeves, M. 1994. Review and Selection of Unsaturated Flow Models. Intera document B00000000-01 425-2200-00001.

REI97 Reimus, P.W., and J.H. Turin. 1997. *Results, Analyses, and Interpretation of Reactive Tracer Tests in the Lower Bullfrog Tuff at the C-Wells, Yucca Mountain, Nevada*, Yucca Mountain Site Characterization Project Milestone Report SP2370M4, Los Alamos, NM, Los Alamos National Laboratory.

RIC84 Rice, W.A. 1984. *Preliminary Two-Dimensional Regional Hydrologic Model of the Nevada Test Site and Vicinity*. SAND83-7466. Albuquerque, New Mexico: Sandia National Laboratories. NNA.19900810.0286.

ROB96 Robinson, B.A., A.V.Wolfsberg, H.S. Viswanathan, C.W. Gable, G.A. Zyvoloski, and H.J. Turin. 1996. *Site-Scale Unsaturated Zone Flow and Transport Model-Modeling of Flow; Radionuclide Migration, and Environmental Isotope Distributions at Yucca Mountain.*

ROB97 Robinson, B.A., A.V. Wolfsberg, H.S. Viswanathan, G.S. Bussod, C.W. Gable, and A. Meijer. 1997. *The Site-Scale Unsaturated Zone Transport Model of Yucca Mountain,* YMP Milestone Number SP25BM3, Level 4, Los Alamos, NM, Los Alamos National Laboratory

ROU99 Rousseau, J.P.; Kwicklis, E.M.; and Gillies, D.C. (eds) 1999. *Hydrogeology of the Unsaturated Zone, North Ramp Area of the Exploratory Studies Facility, Yucca Mountain, Nevada.* Milestone Report 3GUP667M. Water-Resources Investigations Report 98-4050. Denver, Colorado: U.S. Geological Survey. ACC:MOL.19990419.0335. TIC: 243099.

SAS88 Sass, J.H.; Lachenbruch, A.H.; Dudley, Jr., W.W.; Priest, S.S.; and Munroe, R.J. 1988. *Temperature, Thermal Conductivity, and Heat Flow near Yucca Mountain, Nevada - Some Tectonic and Hydrologic Implications.* USGS-OFR 87-649. Denver, Colorado: U.S. Geological Survey. GS950408318523.001; TIC 203195.

SIN87 Sinton, P.O. 1987. *Three-Dimensional, Steady-State, Finite-Difference Model of the Ground Water Flow System in the Death Valley Ground Water Basin, Nevada-California.* Master's thesis. Golden, Colorado: Colorado School of Mines. TIC 236959.

STO96 Stothoff, S.A., H.M. Castellaw, and A.C. Bagtzoglou. July 3, 1996. "Simulating the Spatial Distribution of Infiltration at Yucca Mountain, Nevada," San Antonio, TX, Center for Nuclear Waste Regulatory Analyses, sent under cover letter from E. Pearcy (CNWRA) to N. Coleman (NRC).

STR96 Straume, T.,et. al. 1996. "The Feasibility of Using I-129 to Reconstruct I-131 Deposition from the Chernobyl Reactor Accident," *Health Physics*, 71(5):733-740.

SUD81 Sudicky, E.A., and E.O. Frind. 1981. "Carbon-14 Dating of Groundwater in Confined Aquifers: Implication of Aquitard Diffusion," *Water Resources Research,* 17(4):1060-1064.

SUD85 Sudicky, E.A., R.W. Gillham, and E.O. Frind. 1985. Experimental Investigation of Solute Transport in Stratified Porous Media: 1. The Nonreactive Case. *Water Resources Research* 21(7):1035-1041.

SZA94 Szabo, B. J., et al. 1994. "Paleoclimatic Inferences from a 120,000-Yr Calcite Record of Water-Table Fluctuation in Brown's Room of Devils Hole, Nevada," Quaternary Research, Vol. 41, pp. 59-69.

SZY89 Szymanski, J.S. 1989. *Conceptual Considerations of the Yucca Mountain Groundwater System with Special Emphasis on the Adequacy of this System to Accommodate a High-Level Nuclear Waste Repository.* DOE Internal report, 3 vols. Las Vegas, Nevada: U.S. Department of Energy, Yucca Mountain Project Office. TIC 207760; TIC 207761; TIC 230942.

THO96 Thomas, J.M.; Welch, A.H.; and Dettinger, M.D. 1996. *Geochemistry and Isotope Hydrology of Representative Aquifers in the Great Basin Region of Nevada, Utah, and Adjacent States.* USGS Professional Paper 1409-C. Denver, Colorado: U.S. Geological Survey. TIC 235070.

TID97 Tidwell, V., L. Meigs, T. Christian-Frear, C. Boney. 1997. Visualizing, Quantifying, and Modeling Matrix Diffusion in Heterogenous Rock Slabs, *Eos Transactions: Proceedings of the 1997 American Geophysical Union Fall Meeting*, American Geophysical Union.

TRE96 Trease, H., D. George, C.W. Gable, J. Fowler, A. Kuprat, and A. Khamyaseh. 1996. The X3D Grid Generation System. In *Numerical Grid Generation in Computational Fluid Dynamics and Related Fields*, edited by B.K. Soni, J.F. Thompson, H. Hausser, and P.R. Eiseman, Engineering Research Center. Mississippi State University Press.

TRI96 Triay, I.R., A. Meijer, J.L. Conca, K.S. Kung, R.S. Rundberg, and E.A. Strietelmeier. 1996. *Summary and Synthesis Report on Radionuclide Retardation for the Yucca Mountain Site Characterization Project*, Milestone 3784, Los Alamos NM, Los Alamos National Laboratory.

TRI97 Triay, I.R., et.al. 1997. Summary Report Geochemistry/Transport Laboratory Tests. Los Alamos National Laboratory YMP milestone SP23QM3.

TRW97 TRW Environmental Safety Systems Inc. 1997. *Retrievability Strategy Report,* B00000000-01717-5705-00061, Revision 00, Las Vegas, Nevada. (*7.0 mb*) [MOL.19970813.0110]

TUC95 Tucci, P. and Burkhardt, D.J. 1995. *Potentiometric-Surface Map, 1993, Yucca Mountain and Vicinity, Nevada.* USGS Water-Resources Investigations Report 95-4149. Denver, Colorado: U.S. Geological Survey. MOL.19960924.0517.

USG84 U.S. Geological Survey. 1984. *Conceptual Hydrologic Model of Flow in the Unsaturated Zone, Yucca Mountain, Nevada,* Water Resources Investigations Report 84-4345.

WAD82 Waddell, R.K. 1982. *Two-Dimensional, Steady-State Model of Ground Water Flow, Nevada Test Site and Vicinity, Nevada-California.* USGS Water-Resources Investigations Report 82-4085. Denver, Colorado: U.S. Geological Survey. TIC 203212.

WAD84 Waddell, R.K.; Robison, J.H.; and Blankennagel, R.K. 1984. *Hydrology of Yucca Mountain and Vicinity, Nevada-California - Investigative Results Through Mid-1983.* USGS Water-Resources Investigations Report 84-4267. Denver, Colorado: U.S. Geological Survey. TIC 203219.

WAD97 Waddell, R.K. 1997. Speech presented at YMP Saturated Zone Expert Elicitation, Denver, CO, July, 1997.

WAN98 Wang, J.S.Y., R.C. Trautz, P.J. Cook, S. Finsterle, A.L. James, J. Birkholzer, and C.F. Ahlers. 1998. *Testing and Modeling of Seepage into Drift, Input of Exploratory Study Facility Seepage Test Results to Unsaturated Zone Models*, Yucca Mountain Project Milestone SP33PLM4, Berkeley, CA, Lawrence Berkeley National Laboratory.

WAT94 Watermark Computing. 1994. *PEST Model-Independent Parameter Estimation: User's Manual.* Oxley, Australia: Watermark Computing. MOL.19961202.0179.

WHI85 Whitfield, M.S., Jr., E.P. Eshom, W. Thordarson, and D.H. Schaefer. 1985. *Geohydrolgy of Rocks Penetrated by Test Well USW H-4, Yucca Mountain, Nye County, Nevada*, USGS Water-Resources Investigations Report 85-4030, 1985, 33 p.

WHI98 Whipple, C., R. Budnitz, R. Ewing, D. Moeller, J. Payer, and P. Witherspoon. 1998. *Third Interim Report, Total System Performance Assessment Peer Review Panel*, prepared for Civilian Radioactive Waste Management and Operating Contractor, Las Vegas, NV. June 25, 1998.

WIL94 Wilson, M. L., J. H. Gauthier, R. W. Bamard, G. E. Barr, H. A. Dockery, E. Dunn, R. R. Eaton, D. C. Guerin, N. Lu, M. J. Martinez, R. Nilson, C. A. Rautman, T. H. Robey, B. Ross, E. E. Ryder, A. R. Schenker, S. A. Shannon, L. H. Skinner, W. G. Halsey, J. D. Gansemer, L. C. Lewis, A. D. Lamont, I. R. Triay, A. Meijer, and D. E. Morris. 1994. *Total-System Performance Assessment for Yucca Mountain – SNL Second Iteration (TSPA-1993), Volume 2,* Sandia National Laboratories, Albuquerque, New Mexico. [NNA.19940112.0123]

WIN72 Winograd, I. J. and Friedman, I. 1972. "Deuterium as a Tracer of Regional Ground Water Flow, Southern Great Basin, Nevada-California." *Geological Society of America Bulletin, 83*, n. 12, 3691-3708. Boulder, Colorado: Geological Society of America. TIC 217734.

WIN75 Winograd, I.J. and Thordarson, W. 1975. *Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site.* USGS Professional Paper 712-C. Denver, Colorado: U.S. Geological Survey. TIC 206787.

WIN92 Winograd, I.J.; Coplen, T.B; Landwehr, J.M.; Riggs, A.C.; Ludwig, K.R.; Szabo, B.J; and Revesz, K.M. 1992. "Continuous 500,000-Year Climate Record from Vein Calcite in Devils Hole, Nevada." *Science, 258,* 255-260. Washington, D.C.: American Association for the Advancement of Science. TIC 237563.

WIN97 Winograd, I.J.; Landwehr, J.M.; Ludwig, K.R.; Coplen, T.B.; and Riggs, A.C. 1997. "Duration and Structure of the Last Four Interglacials." *Quaternary Research, 48,* 141-154. New York, New York: Academic Press. TIC 236777.

WIT92 Wittwer, C.S.; Bodvarsson, G.S.; Chornack, M.P.; Flint, A.L.; Flint, L.E.; Lewis, B.D.; Spengler, R.W.; and Rautman, C.A. 1992. "Design of a 3-D Site-Scale Model for the Unsaturated Zone at Yucca Mountain, Nevada." *High Level Radioactive Waste Management, Proceedings of the Third Annual International Conference, Las Vegas, Nevada, April 12-16, 1992,* 263-271. La Grange Park, Illinois: American Nuclear Society. GS911208312293.001; TIC 225904; TIC 224134.

YAN96 Yang, I.C.; Rattray, G.W.; and Yu, P. 1996. *Interpretation of Chemical and Isotopic Data from Boreholes in the Unsaturated Zone at Yucca Mountain, Nevada.* USGS Water-Resources Investigations Report 96-4058. Denver, Colorado: U.S. Geological Survey. MOL.19970715.0408.

ZEL96 Zelinski, W.P. and Clayton, R.W. 1996. *A 3D Geologic Framework and Integrated Site Model of Yucca Mountain: Version ISM1.0.* Revision 2. Las Vegas, Nevada: Author. DTN: MO9607ISM10MOD.001. MOL.19970122.0053.

ZYV83 Zyvoloski, G.A. 1983. "Finite Element Methods for Geothermal Reservoir Simulation." *International Journal for Numerical and Analytical Methods in Geomechanics, 7,* 75-86. New York, New York: John Wiley and Sons, Inc. TIC 224068.

ZYV86 Zyvoloski, G.A. 1986. "Incomplete Factorization for Finite Element Methods." *International Journal for Numerical Methods in Engineering, 23,* 1101-1109. New York, New York: John Wiley and Sons, Inc. TIC 237569.

ZYV90 Zyvoloski, G.A. and Dash, Z.V. 1990. *Software Verification Report FEHMN Version 1.0.* TWS-EES-5/5-90-3. Los Alamos, New Mexico: Los Alamos National Laboratory. NNA.19910806.0018.

ZYV95 Zyvoloski, G.A.; Robinson, B.A.; Dash, Z.V.; and Trease, L.L. 1995. *Models and Methods Summary for the FEHMN Application.* LA-UR-94-3787. Los Alamos, New Mexico: Los Alamos National Laboratory. TIC 222337.

ZYV97 Zyvoloski, G.A., B.A. Robinson, K.H. Birdsell, C.W. Gable, J. Czarnecki, K.M. Bower, and C. Faunt. 1997. *Saturated Zone Radionuclide Transport Model,* Civilian Radioactive Waste Management System Management and Operating Contractor: Milestone Report SP25CM3A, Los Alamos, NM, Los Alamos National Laboratory.