STATE OF NEVADA COMMENTS
ON THE U.S. DEPARTMENT OF ENERGY'S
DRAFT 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

Volume 1

Prepared by
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EVALUATION OF POTENTIAL ECONOMIC IMPACTS OF 40 CFR PART 197:

PUBLIC HEALTH AND ENVIRONMENTAL RADIATION PROTECTION STANDARDS FOR YUCCA MOUNTAIN, NEVADA

June 2001

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LIST OF ACRONYMS

BWR	Boiling Water Reactor
CAM	Corrosion Allowance Material
CRM	Corrosion Resistant Material
CSNF	Commercial Spent Nuclear Fuel
DEIS	Draft Environmental Impact Statement
DOE	Department of Energy
EDA	Enhanced Design Alternative
EnPA	Energy Policy Act
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
GWS	Ground Water Protection Standard
HIS	Human-Intrusion Protection Standard
HLW	High-Level Waste
ICRP	International Commission on Radiation Protection
IPS	Individual-Protection Standard
MTHM	Metric Tonnes of Heavy Metal
MTU	Metric Tonnes of Uranium
NAS	National Academy of Sciences
NRC	Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWPAA	Nuclear Waste Policy Amendments Act
NWTRB	Nuclear Waste Technical Review Board
PWR	Pressurized Water Reactor
RA	Reasonable Assurance
RE	Reasonable Expectation
RMEI	Reasonably Maximally Exposed Individual
SCP	Site Characterization Plan
SDWA	Safe Drinking Water Act
SR	Site Recommendation
SZ	Saturated Zone
TSPA	Total System Performance Assessment
UZ	Unsaturated Zone
VA	Viability Assessment
WIPP	Waste Isolation Pilot Plant

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EXECUTIVE SUMMARY

This Economic Impact Assessment (EIA) demonstrates that DOE's strategy for development and design of a possible repository at Yucca Mountain has evolved so that the EPA's 40 CFR Part 197 standards will have no impact on costs of the repository or the repository development program. It also shows that the EPA's generic 40 CFR Part 191 standards, as well as the 40 CFR Part 197 site-specific standards, did not influence evolution of the DOE program or the repository design.

The EIA analysis uses three major, converging perspectives to support the conclusion that the EPA standard for Yucca Mountain does not impose additional costs on the DOE program:

- An historical perspective in Chapter 3 traces the evolution of the repository design from principal reliance for safety performance on natural features to principal reliance on engineered features and the factors that influenced it. This discussion concludes that the inversion of performance roles of the natural and engineered features of the disposal system has evolved as a result of site characterization findings, guidance from external reviews such as those of the Nuclear Waste Technical Review Board, and evolution of strategy for dealing with uncertainties. **This discussion demonstrates that evolution of the repository design has been independent of the EPA standards, the major components of which have remained essentially unchanged since the 1985 promulgation of the generic 40 CFR Part 191 standards for geologic disposal.**

- A performance assessment perspective in Chapter 4 traces the evolution of strategy to achieve performance, the evolution of identification and characterization of factors that contribute to performance, and the approach to identifying and reducing uncertainties that are important to demonstration of compliance with standards. **The discussion includes DOE estimates of performance for the current repository design which show that, under nominal conditions, there will be no radionuclide releases and no potential for radiation doses for more than 10,000 years after repository closure.**

  The new repository design was not developed to respond to any provisions of the EPA standard, but rather to reduce or eliminate uncertainties in the very conservative performance assessments of the previous design. Relative to the "reasonable expectation" approach to implementation that is included in the standard (described in more detail in this document), the previous assessments of the older design are considered to illustrate the impact of reasonable expectation on repository design and performance assessments.

- An information-needs perspective assesses the data and analyses needed to address the IPS, GWS, and HIS components of the EPA standard, with emphasis on whether resources beyond those needed to address the individual-protection standard, which is fundamental to radiation protection, are needed to address the GWS and HIS standards. **This EIA demonstrates that the data and analysis requirements for assessing compliance with the ground water protection and human-intrusion standards are the same as those required for assessing compliance with the fundamental and essential individual-protection standard. The ground water protection standard and the human-intrusion standard, therefore, impose no incremental cost impacts.**

Comparative Impacts of Alternative Dose Limits for the Individual-Protection Standard

A contentious issue in developing the individual-protection standard has been comparative impacts of alternative dose limits, e.g., 15 mrem/yr versus 25 mrem/yr. Figure ES-1, which shows the performance projections for the newest repository design (EDA II), under conditions of expected performance, provides an important perspective on the dose limit issue. Doses in the period less than 10,000 years are entirely the result of a very low probability (the mean annual probability is $1.6x10^{-8}$) potential igneous disruption of the disposal facility. A very small downward shift in estimates of probability would eliminate this scenario from consideration altogether. In addition, the consequences associated with potential releases from igneous activity appears to be treated in an extremely conservative manner. Alternative assumptions are possible that would eliminate releases associated with igneous activity entirely, even in the unlikely event that such activity occurs.

The nominal scenario represents an assessment of the function of the repository when only gradual degradation processes occur. This scenario does not lead to any releases in the first 10,000 years, despite a significant level of conservatism built into the model. The current model of the current repository design shows lower consequences at longer times than did earlier iterations of the TSPA. Significantly, even these earlier iterations (e.g. TSPA-VA), which contained extremely conservative assumptions about juvenile failures of waste containers, were able to comfortably comply with either of the alternative individual-protection standards.

As seen in Figure ES-1, the EDA II repository design demonstrates performance such that projected doses are significantly less than either the 15 mrem/yr or the 25 mrem/yr dose limit. Furthermore, for nominal behavior of the repository, there are no projected doses during the first 10,000 years. It is therefore evident that selection of a 15 mrem/yr dose limit rather than a 25mrem/yr limit will not impose any additional cost impacts on the repository. This is a highly significant finding in that the 15 mrem/yr CEDE dose limit is consistent with the recommendations of the National Academy of Sciences and regulatory precedents.

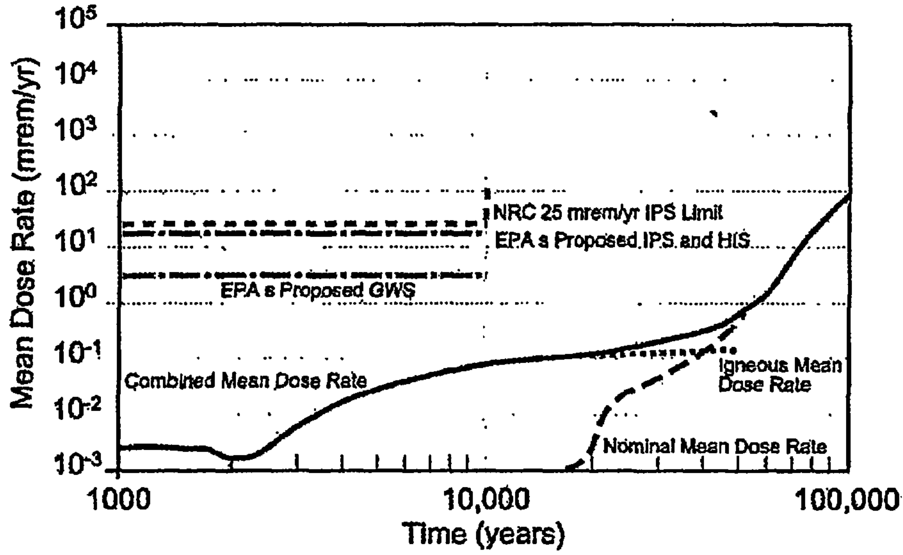

Figure ES-1. Comparison of Proposed Radiation Protection Standards with Expected Values of TSPA-SR Calculations for a Repository at Yucca Mountain for Nominal and Igneous Scenarios.

Conclusions

The information presented in this EIA has demonstrated that the design of a repository for disposal of radioactive wastes at Yucca Mountain has evolved without having been affected by the EPA standards. The standards have been demonstrated to have no impact on repository program costs, and nominal performance for the current repository design would result in no radiation doses for more than 10,000 years. Additionally, the difference between a 25 mrem/yr dose standard and a 15 mrem/yr standard is insignificant to program costs and performance evaluations.

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1.0 EVOLUTION OF REGULATORY REQUIREMENTS

This chapter describes the basis for this rulemaking and provides a brief history of EPA's regulatory authority and prior rulemaking actions concerning disposal of radioactive wastes. It demonstrates that this rulemaking is derived from provisions of the Energy Policy Act of 1992. Standards for individual protection and human intrusion are based on recommendations made by the National Academy of Sciences, and ground water protection standards are based on the Safe Drinking Water Act and regulatory precedents.

1.1 EPA Proposed Action and Authority

The U.S. Environmental Protection Agency (EPA), pursuant to Section 801 of the Energy Policy Act of 1992 (EnPA) is proposing a rule, 40 CFR Part 197, which contains standards for the protection of the public from releases of radioactive materials stored or disposed of in a repository at the Yucca Mountain site in Nevada. This document was prepared to evaluate the economic impact of this rule.

The proposed rule contains three principal component standards: Individual-Protection Standard (IPS), Human-Intrusion Standard (HIS), and Ground Water Protection Standards (GWS). Details of the evolution of the rule and these proposed standards are described in Section 3 of this document.

1.2 Role of this Document

This document describes, in detail, the basis for, and results of, the assessment of economic impacts of the proposed standards on the costs of storage and disposal of radioactive wastes at Yucca Mountain.

The document traces the history of evolution of the Yucca Mountain repository design, from the early use of a small, thin-walled canister, and repository features that were expected to dominate safety performance reflecting ground water travel times of tens of thousands of years (circa 1988), to the current design, in which engineered features (consisting of drip shields and large, multi-walled waste packages) dominate performance, and are expected to maintain radionuclides in isolation for at least 10,000 years (TRW00). The document also discusses the evolution of performance assessments and the inversion of roles of engineered and natural barriers, the EPA's "Reasonable Expectation" approach to performance projections and compliance decisions, and the overall impact of the proposed standards on Yucca Mountain costs.

This document will demonstrate that the repository design evolved not in response to the expected provisions of the standard, but in response to improved understanding of the natural and engineered barrier interactions and performance expectations, as a result of 12 years of site characterization, performance assessment and design activities performed by the DOE. The uncertainties identified by DOE's efforts over this period could be addressed by either developing enhanced engineering design alternatives to reduce or eliminate the uncertainties, or by investing time and resources in more extensive characterization and testing studies. DOE has leaned toward enhanced engineering, at least in part because inherently some uncertainties about the characteristics and behavior of the natural system may not be amenable to unequivocal reduction or elimination even with extensive field and laboratory testing.

1.3 40 CFR Part 197

The remainder of this chapter describes the evolution of the proposed 40 CFR Part 197 regulation and the rationale underlying its development. 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. The EPA is proposing in the 40 CFR Part 197 site-specific environmental standards to protect public health from releases from radioactive materials disposed of or stored in the potential repository to be constructed at Yucca Mountain in Nevada.[1] These standards provide the basic framework to control the long-term storage and disposal of radioactive wastes at Yucca Mountain.

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.

Emphasis in this document is on the major components of the Yucca Mountain standard, namely the Individual-Protection Standard (IPS), the Human-Intrusion Standard (HIS), and the Ground Water Protection Standard (GWS). In reviewing the development of the current standard attention will be devoted primarily to these components.

[1] No decision has been made regarding the acceptability of Yucca Mountain for storage or disposal. In this document, the characterization of the Yucca Mountain repository as "potential" is often omitted but always intended.

1.4 Legislative History

EPA has the authority to set generally applicable environmental standards for radioactive releases under the Atomic Energy Act (AEA) of 1954, as amended (AEA54), and the EPA Reorganization Plan No. 3 of 1970 (NIX70). The basic authority under the AEA, as transferred to the EPA by Reorganization Plan No 3, includes the mandate of:

- *...establishing generally applicable environmental standards for the protection of the general environment from radioactive materials. As used herein, standards mean limits on radiation exposures or levels, or concentrations or quantities of radioactive material, in the general environment outside the boundaries of locations under the control of persons possessing or using radioactive materials (AEA54).*

In 1982, the Nuclear Waste Policy Act (NWPA) (Public Law 97-425) established formal procedures regarding the evaluation and selection of sites for geologic repositories, including procedures for the interaction of state and Federal Governments. The Act assigned the U.S. Department of Energy (DOE) the responsibility of siting, building, and operating an underground geologic repository for the disposal of these wastes, established provisions for the selection of at least two independent repository sites, and limited the quantity of wastes to be disposed of in the initial repository to 70,000 metric tons of heavy metal (MTHM).[2] The NWPA also reiterated the existing responsibilities of the Federal agencies involved in the national program (see AEA authority above) and provided a timetable for several key milestones to be met by the Federal agencies. The NWPA also directed that EPA, pursuant to its authorities under other provisions of law, was required to:

- *by rule, promulgate generally applicable standards for the protection of the general environment from off-site releases from radioactive material in repositories (NWP83).*

The basic authority for EPA to establish environmental standards for the repository effort originates from these sources.

In September 1985, EPA published 40 CFR Part 191, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes" (EPA85). These standards were generic and intended to apply to all sites for the deep geologic disposal of high-level radioactive waste. In 1987, the U.S. Court of Appeals for the

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[2] This is a measure of the uranium content of the spent nuclear fuel to be emplaced in the repository.

First Circuit responded to a legal challenge by remanding Subpart B of the 1985 standards (the disposal standards) to the Agency for further consideration. This regulation, which is of considerable importance to the development of 40 CFR Part 197, will be discussed further in the next section.

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 only the Yucca Mountain site as the location for the first high-level waste and spent nuclear fuel repository (NWP87). An important program change instituted by the amendments act was establishment of the Nuclear Waste Technical Review Board (NWTRB). The NWTRB was charged with providing independent technical and scientific review of the OCRWM program. It consists of experts in various disciplines (about 10, but limited to 22) and has a small support staff. Members of the NWTRB are appointed by the President of the United States. The opinions and recommendations of the NWTRB have played a significant role in the development of the repository design, as will be pointed out in other sections of this document.

The NWPAA, while dramatically changing the scope and focus of the repository effort, did not affect or alter EPA's role, i.e., to develop the environmental standard for deep geological disposal.

In October 1992, the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA, Public Law 102-579) was enacted. While reinstating certain sections of the Agency's 1985 disposal standards, the Act exempted the Yucca Mountain site from these generic disposal standards (WIP92). In its stead, the Energy Policy Act (EnPA) of 1992 was enacted (Public Law 102-482), which established EPA's authority to develop standards for environmental releases specific to Yucca Mountain.

Section 801 of the EnPA directed EPA to promulgate standards to ensure protection of public health from releases of radioactive material from a deep geologic repository to be built at Yucca Mountain (EnP92). EPA must set standards to ensure protection of the health 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. These EPA standards will apply only to the Yucca Mountain site and are to be developed 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* (EnP92).

1.5 40 CFR Part 191

The 1985 EPA standards for the management and disposal of spent nuclear fuel and high-level and transuranic waste were divided into two main sections, Subparts A and B (EPA85). Subpart A, which addressed the management and storage of waste, limited radiation exposure to any member of the general public to 25 millirem (mrem) to the whole body and 75 mrem to any critical organ for disposal facilities operated by the Department of Energy, but not regulated by the NRC or an Agreement State. For facilities regulated by the NRC or an Agreement State, the standards endorsed the annual dose limits given in the environmental standards for the uranium fuel cycle (40 CFR Part 190): 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any critical organ (EPA77). The 25 mrem dose limit was based on a dosimetry system dating from the 1977 International Commission on Radiation Protection recommendations (ICR77), which are now outdated. The ICRP dose limit has since been revised to be consistent with current dosimetry, so that the 15 mrem/yr CEDE dose limit in the proposed 40 CFR Part 197 rule is essentially the same as the 25 mrem/yr limit for the 1977 dosimetry.

Subpart B imposed limits associated with the release of radioactive materials into the environment following closure of the repository. The key provisions of Subpart B (EPA85) were:

- Limits on cumulative releases of radioactive materials into the environment during the 10,000 years following disposal (§191.13)

- Assurance requirements to compensate for uncertainties in achieving the desired level of protection (§191.14)

- Individual exposure limits based on the consumption of ground water and any other potential exposure pathways for 1,000 years after disposal (§191.15)

- Ground water protection requirements in terms of allowable radionuclide concentrations and associated doses for 1,000 years after disposal (§191.16)

- Consideration of inadvertent human intrusion into the repository (Appendix B)

Under §191.15 and §191.16 of Subpart B, the annual dose to any member of the general public was limited to 25 mrem to the whole body and 75 mrem to any critical organ (under the outdated dosimetry system). The ground water concentration for beta or gamma emitters was limited to the equivalent yearly whole body or organ dose of 4 mrem. The allowable water concentration for alpha emitters (including radium-226 and radium-228, but excluding radon) was 15 picocuries/liter (pCi/L). For radium-226 and radium-228 alone, the concentration limit was 5 pCi/L. Appendix A of the standards provided acceptable radionuclide-specific cumulative release limits.

In March 1986, five environmental groups led by the Natural Resources Defense Council and four States filed petitions for a review of 40 CFR Part 191 (USC87). These suits were consolidated and argued in the U.S. Court of Appeals for the First Circuit in Boston. The main challenges concerned:

- Violation of the Safe Drinking Water Act (SDWA) underground injection section
- Inadequate notice and comment opportunity on the ground water protection requirements
- Arbitrary standards, not supported in the record, or not adequately explained

In July 1987, the Court rendered its opinion and noted three findings against the Agency and two favorable judgments. The Court's action resulted in the remand of Subpart B, the disposal standards. The Court began by looking at the definition of "underground injection." In the view of the Court, the method envisioned by DOE for disposal of radioactive waste in underground repositories would "...likely constitute an underground injection under the SDWA."

Under the SDWA, the Agency is required to assure that underground sources of drinking water will not be endangered by any underground injection. With regard to such potential endangerment, the Court supported part, but not all, of the Agency's approach. Inside the controlled area, the Court ruled that Congress—through the EPA—had allowed endangerment of ground water. However, the Court accepted EPA's approach of using the geological formation as part of the containment. This aspect of the Court's opinion is important in that it recognizes that a portion of the area around the footprint of the geologic repository could be considered to be an integral part of the repository system and could be dedicated to that use. This area was designated as a controlled area in the rule and was limited to an area of 100 sq. km.

Outside the controlled area, the Court found that §191.15 would allow endangerment of drinking water supplies. In the context of the SDWA, "endangerment" was considered when doses higher than those allowed by the Primary Drinking Water Regulations could occur. In §191.15, an annual dose of 25 mrem to the whole body and 75 mrem to any critical organ from all pathways is permitted, whereas existing EPA regulations promulgated under the SDWA allowed an annual dose of 4 mrem from drinking water. Although the Court recognized that an exposure level less than 4 mrem could result from the ground water pathway, it rejected this possibility because the Agency stated that radioactivity could eventually be released into the ground water system near the repository and that substantially higher doses could result. Therefore, the Court decided that a large fraction of the 25 mrem limit could be received through the ground water exposure pathway. Accordingly, the Court found that the Part 191 standards should either have been consistent with the SDWA or the Agency should have justified the adoption of a different standard.

The Court stated that the Agency was not necessarily incorrect in promulgating the proposed standards. However, it noted that the Agency never acknowledged the interrelationship of the SDWA and the Part 191 standards nor did it present a reasonable explanation for the divergence between them. The Court also supported the petitioner's argument that the Agency had not properly explained the selection of the 1,000-year limit for individual-protection requirements (§191.15). The Court indicated that the 1,000-year criterion was not inherently flawed, but rather that the administrative record and the Agency's explanations did not adequately support this choice. The criterion was remanded for reconsideration, and the Agency was directed to provide a more thorough explanation for its basis.

Finally, the Court found that the Agency did not provide sufficient opportunity for notice and comment on §191.16 (Ground Water Protection Requirements), which was added to Subpart B after the standards were proposed. This section was remanded for a second round of notice and comment. There were, however, no rulings about §191.16 issued on technical grounds.

In August 1987, the Department of Justice petitioned the First Circuit Court to reinstate all of 40 CFR Part 191 except for §191.15 and §191.16, which were originally found defective. The Natural Resources Defense Council filed an opposing opinion. The Court then issued an Amended Decree that reinstated Subpart A, but continued the remand of Subpart B.

In 1992, the WIPP LWA reinstated Subpart B of 40 CFR Part 191, except §191.15 and §191.16, and required the Administrator to issue final disposal standards no later than six months after enactment. On December 20, 1993, EPA issued amendments to 40 CFR Part 191 which eliminated §191.16 of the original rule; altered the individual-protection requirements; and added Subpart C on ground water protection (EPA93).

The revised Part 191 standard finalized in 1993 retained the waste containment and assurance requirements in the original 1985 standard. However, an important change was made for the individual-protection requirements: the protection dose limit was recalculated according to the newer Committed Effective Dose Equivalent (CEDE) methodology. This approach gave a dose limit of 15 mrem/yr. This new methodology considers the weighted relative importance of organ doses and the accumulation of dose potential over time. The original dose limit of 25 mrem/yr in the old methodology is equivalent to the 15 mrem/yr limit in the new system.

The revised Part 191 standard finalized in 1993 also moved the guidance on the treatment of human intrusion into a new Appendix C dealing with implementation of the rule's numerical standards. This guidance was subsequently supplanted by recommendations from the National Academy of Sciences in their report on the technical basis for Yucca Mountain standards (NAS95; see discussion below). With regard to the ground water protection standards, the revised Part 191 rule retained the requirements for specific radionuclides that were in the 1985 standards, but the compliance period was changed from 1,000 to 10,000 years to be consistent with the individual-protection requirement.

The WIPP LWA also exempted Yucca Mountain from the generic disposal standards set forth under 40 CFR Part 191, Subpart B. Pursuant to specific provisions in the EnPA, EPA was charged with setting site-specific environmental radiation standards for Yucca Mountain. The 40 CFR Part 197 standard is responsive to this mandate.

1.6 The National Academy of Sciences Recommendations

In the EnPA, the Congress directed 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* (EnP92).

The NAS recommendations in these three areas had direct bearing on the approach used by EPA in developing its proposed site-specific IPS, HIS, and GWS Yucca Mountain standards.
To address these questions, the Academy assembled a committee of 15 members 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 Nuclear Regulatory Commission (NRC), the Department of Energy (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 (NAS95). In this report, the committee offered the Agency several general recommendations as to the approach EPA should take in developing 40 CFR Part 197. Specifically, the NAS recommended (NAS95, p.2):

- *The use of a standard that sets a limit on the risk to individuals of adverse health effects from releases from the repository. 40 CFR Part 191 contains an individual-dose standard, and it continues to rely on a containment requirement that limits the releases of radionuclides to the accessible environment. The stated goal of the containment requirement was to limit the number of health effects to the global population to 1,000 incremental fatalities over 10,000 years. We do not recommend that a release limit be adopted.*

- *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.) The standard in 40 CFR Part 191 applies for a period of 10,000 years. Based on performance assessment calculations provided to us, it appears that peak risks might occur tens or hundreds of thousands of years or even farther into the future.*

- *Against a risk-based calculation of the adverse effect of human intrusion into the repository. Under 40 CFR Part 191, an assessment must be made* *of the frequency and consequences of human intrusion for purposes of demonstrating compliance with containment requirements. In contrast, we conclude that it is not possible to assess the frequency of intrusion far into the future. We do recommend that the consequences of an intrusion be calculated to assess the resilience of the repository to intrusion.*

The NAS committee also recommended that policy issues be resolved through a rulemaking process that allows opportunity for wide-ranging input from all interested parties (NAS95).

The committee also addressed each of the specific questions posed to it by the Congress in the EnPA. With regard to the first issue, protecting human health, the NAS committee recommended (NAS95, pp. 4-7):

- *...the use of a standard that sets a limit on the risk to individuals of adverse health effects from releases from the repository.*
- *...the critical-group approach be used in the Yucca Mountain standards.*
- *...compliance assessment be conducted for the time when the greatest risk occurs, within the limits imposed by long-term stability of the geologic environment.*

The NAS also concluded that 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. A necessarily important component in the development of a standard for Yucca Mountain is the means of assessing compliance. The NAS committee concluded as follows (NAS95, p. 9):

- *...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 10^6 years. The Committee further concluded that 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.*
- *...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.

With respect to the second and third questions posed by the Congress in Section 801 of the EnPA, the NAS Committee concluded (NAS95, p. 11):

- *...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 to 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.*

1.7 40 CFR Part 197 - Environmental Radiation Protection Standards for Yucca Mountain, Nevada

Three key elements of the 40 CFR Part 197 standard are the individual-protection standard (§197.20), the human-intrusion standard (§197.25), and the ground water protection standards (§197.35). These are discussed below and compared with the 40 CFR 191 generic disposal standards and the NAS recommendations. The basis for certain site-specific aspects of the regulation are also presented.

In developing a site-specific standard for the Yucca Mountain site, the generic requirements in Part 191 serve as a starting point for the process. The generic requirements in Part 191 were examined in terms of whether their components are relevant to the Yucca Mountain geologic setting; if they are determined to be relevant, the next issue is how they can be framed appropriately for that setting.

In contrast to the individual, human intrusion, and ground water protection standards, Part 191 also contained a containment requirement that was not carried into the Yucca Mountain standard. The containment requirement in Part 191 was intended to address a situation where releases from a poorly performing geologic repository could enter into large surface water bodies, such as rivers, lakes, or the ocean, where the contamination would be greatly diluted and the dose distributed to a potentially large population. The containment requirement was intended to limit such situations. For the Yucca Mountain setting, this scenario is not plausible since no large surface water bodies exist in the arid desert environment in the site vicinity. The text below discusses how the individual, human intrusion, and ground water protection standards were framed for the Yucca Mountain setting.

1.7.1 Individual-Protection Standard

An individual-protection standard is a relevant and fundamental regulatory requirement for any repository setting and therefore must be incorporated into any site-specific standard.

The individual-protection standard in Part 197 requires DOE to demonstrate

- *...using performance assessment, that there is a reasonable expectation that for 10,000 years following disposal the reasonably maximally exposed individual receives no more than an annual committed dose equivalent of 150 microsieverts (15 mrem) from releases from the undisturbed Yucca Mountain disposal system. The DOE's analysis must include all potential pathways of radionuclide transport and exposure* (EPA99).

By way of comparison, the individual-protection standard in the 40 CFR Part 191 generic disposal standard also specifies, at §191.15, an annual committed effective dose equivalent (CEDE) of 15 mrem. The use of an individual-protection standard rather than a release limit is consistent with recommendations of the NAS as discussed in 1.3 above. Further, the NAS noted that a risk range of 10^{-5} to 10^{-6} per year was a reasonable starting point for EPA's rule making (NAS95, p. 5). Thus selection of a CEDE of 15 mrem for 40 CFR Part 197, which is equivalent to an annual risk of $7x10^{-6}$, is also consistent with the NAS recommendations.

Total release limits in the generic Part 191 regulation were developed to protect the general population from repository releases via all pathways. The NAS concluded that protecting public health by establishing an individual-protection exposure limit is also an adequate means of assuring the general population is protected. For the Yucca Mountain site, the overwhelmingly dominant exposure pathway involves releases into the ground water system beneath the repository, followed by transport of contaminants to downgradient individual receptors. An all-pathways standard for an individual would therefore include the most important exposure pathways.

1.7.2 Human-Intrusion Standard

Inadvertent intrusion is an unanticipated event that could have consequences ranging from minor to highly significant depending on the geologic setting. An HIS was included in the generic Part 191 standard because of this potential range of consequences, and to enable the consequences to be examined for any specific repository site. For the Yucca Mountain setting, site characterization work has shown that potable water is the only recognized potential resource at and near the repository location. Recognizing the relatively low probability of intrusion into the repository for resource exploration, the NAS recommended that human intrusion be considered only as a stylized test of repository resiliency, separate and distinct from the evaluations of expected repository performance. The NAS did not find that consideration of human intrusion was inappropriate for the Yucca Mountain site. They made recommendations on framing the stylized scenario which were the basis for EPA's standard.

As discussed in Section 1.3 above, the NAS Committee on the Technical Bases for Yucca Mountain Standards concluded that active institutional controls would not be a reliable long-term deterrent to human intrusion into a repository. Consistent with this finding, EPA has proposed two alternative approaches for consideration as the human-intrusion standard under 40 CFR Part 197. Under Alternative 1 for §197.25, DOE would be required to demonstrate that

- *...there is a reasonable expectation that for 10,000 years following disposal the reasonably maximally exposed individual receives no more than an annual committed effective dose equivalent of 150 microsieverts (15 mrem) as a result of human intrusion. The DOE's analysis of human intrusion must include all potential environmental pathways of radionuclide transport and exposure* (EPA99).

Under this alternative NRC would determine the range of time during which intrusion occurs based on EPA guidance provided in §197.26.
Under Alternative 2 the DOE would be required to determine:

- *...the earliest time after disposal that the waste would degrade sufficiently that a human intrusion ... could occur without recognition by the drillers* (EPA99).

In the final rule, DOE must project the time at which waste packages have degraded sufficiently that penetration of a waste package by a drilling intrusion could occur without being noticed by the drillers. A connection between the repository and the underlying saturated zone below the repository is established by the intruding borehole penetration, and doses from the single breached waste package are to be projected in the same manner as for the individual protection standard compliance calculations. The same dose limit is applied, as used for the individual protection standard, but the calculation is a separate performance scenario independently calculated and evaluated against the 15 millirem/yr limit. If exposures occur before the end of the regulatory period, the calculations assessments are evaluated against the 15 millirem/yr limit. If exposures occur after the regulatory period, the assessments are included in the repository Environmental Impact Statement.

In each case a single vertical borehole is assumed to penetrate the degraded waste package and continue down to the saturated zone. Similar to 40 CFR Part 191, intrusion is limited to inadvertent exploratory drilling for resources. However, the frequency of intrusion is different in the two regulations. The Appendix C Guidance to the generic disposal standards specifies that the drilling not exceed 30 boreholes per square kilometer per 10,000 years for repositories near sedimentary rocks and 3 boreholes per square kilometer per 10,000 years for repositories in other geologic formations. This Appendix C Guidance was refined for the Waste Isolation Pilot Plant in 40 CFR Part 194 (Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations). In §194.33 drilling frequency is based on the frequency of drilling for resources for the past 100 years within a particular geographic area (i.e., the Delaware Basin) surrounding the WIPP Site. This requirement is appropriate for an area where extensive drilling for a variety of resources had occurred. Since the Yucca Mountain area has not been subject to extensive exploration drilling, the Agency chose the approach very similar to that recommended by the NAS, namely a "stylized intrusion scenario consisting of one borehole of a specified diameter drilled from the surface through a canister of waste to the underlying aquifer" (NAS95, p. 111).

1.7.3 Ground Water Protection Standards

Ground water protection standards were included in the generic Part 191 standards and in the WIPP certification effort. Inclusion of ground water protection standards in the Yucca Mountain standard can be considered relevant for several reasons. The repository site is located in the unsaturated zone (UZ) directly above potable water sources; any contaminant releases into the UZ will move downward into these aquifers, which supply water to the population downgradient of the site. Also, protection of ground waters is well established national policy. From a purely technical perspective, the NAS chose not to consider the question of ground water standards, noting that an all-pathways exposure limit would include doses from ground water use. However, it is Agency policy, as well as national policy, to protect ground water resources.

Throughout the NAS report the text acknowledged that EPA may elect to take approaches other than a narrow interpretation of the committee's recommendations for reasons other than specified in the report. In this way, the broader role of the Agency in applying policy factors as well as technical rationale was acknowledged.

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 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 MCLs, 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. If the revised MCLs are promulgated prior to finalizing the 40 CFR Part 197 regulation, then these revised values will be included in Table 1. Otherwise, the MCLs will remain unchanged for the Yucca Mountain licensing process.

The generic disposal standards at 40 CFR Part 191 also incorporate the 40 CFR 141 Subpart B ground water protection requirements. EPA believes that it is prudent and appropriate to impose requirements for waste disposal that are protective of water resources for future generations, without imposing a burden of water treatment and cleanup on those future generations.

In the Yucca Mountain standard, DOE is required under §197.30 to provide, in its license application to NRC,

- *...a reasonable expectation that, for 10,000 years, of undisturbed performance after disposal, releases of radionuclides from radioactive materials in the Yucca Mountain disposal system will not cause the level of radioactivity in the representative volume of ground water at the point of compliance to exceed the limits in Table 1...(EPA99).*

Table 1 limits combined Ra-226 and Ra-228 to five picocuries per liter (pCi/l) including natural background and gross alpha activity (including Ra-226 but excluding radon and uranium) to 15 pCi/l including natural background. Combined beta and photon emitting radionuclides are limited to levels where the annual dose (excluding natural background) to the whole body or any organ will not exceed 40 microsieverts (4 mrem). These limits are the same as the maximum contaminant levels (MCLs) established by the Agency under the Safe Drinking Water Act (SWDA).

1.7.4 Site Specific Regulatory Requirements

While many elements of the 40 CFR Part 197 rule are either similar to other EPA regulations such as 40 CFR 191 and 40 CFR Part 141 or based on recommendations of the NAS, certain elements are based on site-specific considerations. These include the definition of the reasonably maximally exposed individual (RMEI), the location of the point of compliance, and the representative volume of water for measuring compliance with the ground water protection standard. Each of these site specific elements are discussed below.

Reasonably Maximally Exposed Individual (RMEI)

For DOE to determine whether the Yucca Mountain disposal system complies with the individual-protection standard, they must calculate the dose to an individual or group of individuals and compare that dose with the requirements contained in §197.20 (i.e., a maximum annual CEDE of 15 mrem). The regulation must specify those characteristics, habits, age, life-style, etc. which describe the individual or group of individuals. For this purpose EPA has chosen to use, as the basis for comparison with individual-protection standard, the dose received by the reasonably maximally exposed individual.

The RMEI is defined in §197.21 as a hypothetical person who

- *(a) lives in the accessible environment above the point of the highest concentration of radionuclides in the plume of contamination;*
  (b) Has a diet and living style representative of the people who are now residing in the Town of Amargosa Valley, Nevada. The DOE must use the most accurate projections available, which might be based upon surveys of the people residing in the Town of Amargosa Valley, Nevada, to determine their current diets and living styles and use the mean values of these factors in the assessments conducted for §§ 197.20 and 197.25; and
  (c) Drinks two liters of water per day from wells drilled into the ground water at the location where the RMEI lives.

The NAS recommended that the risk to the average member of the critical group be used as the basis of comparison with the risk limit of the standard. The NAS Committee proposed two alternatives – a probabilistic critical group approach and a subsistence farmer critical group. After considering these possibilities, the Agency decided to use the RMEI concept which is consistent with other EPA programs and is believed by the Agency to provide a level of protection substantially equivalent to that provided by the critical group concept for small populations. The RMEI concept involves estimating high-end doses which are in excess of the 90^{th} percentile of the range of doses for the exposed population. The goal is to calculate doses which are not the most extreme but are well above the average for the exposed population.

EPA considered four possible scenarios to define the RMEI including (EPA99):

- A subsistence farmer residing 30 to 40 km downgradient at a location where the water table is near the surface, who obtains all food and water from contaminated sources

- A commercial farmer subject to the same exposure pathways as the subsistence farmer.

- A community located near the repository site that obtains its water for domestic use from an underground source of drinking water.

- A rural-residential RMEI exposed to the same pathways as the subsistence farmer. However, the rural-residential RMEI does personal gardening but does not work as a full-time farmer.

The fourth scenario was chosen as the basis for developing the specific requirements under §197.21. This scenario is believed to be representative of most of the current residents of the Amargosa Valley.

Representative Volume of Ground Water

In accord with Agency policy of protecting ground water resources, the Representative Volume (RV) concept was developed in response to consideration of the actual resource to be protected at the site. The RV is based on current land uses involving ground water, i.e , the resource to be protected, and the fundamental assumption is that future lifestyles and water uses will be the same as those of the present. This assumption is necessary to avoid making judgments based on speculation. The RV is intended to be a volume of water used annually that provides the basis for calculating radionuclide concentrations resulting from repository releases. Resulting concentrations would be compared to Maximum Contaminant Levels established in the Safe Drinking Water Act.

The representative volume is the volume of water needed to supply the demands of a defined RMEI that could exist in the future at the point of compliance for the ground water protection standards (see discussion below for details on point of compliance). To meet such demands, the water must contain less than 10,000 milligrams of total dissolved solids per liter (i.e., potable).

The proposed Part 197 standards proposed a number of possible RVs based on current land uses south of Yucca Mountain. One proposed alternative was 1,285 acre-feet/yr. This RV is the sum of the water requirements for alfalfa farming and domestic use. It is based on a small farming community of 25 people with 255 acres of alfalfa under cultivation (the average current size of these farms in the area) which is the current economic base for the Amargosa Valley. Alfalfa farming requires about 5 acre-feet of water per acre (255 acres x 5 acre-feet per acre = 1,275 acre-feet for irrigation). The average annual water demand for a non-farming family of four with a garden is 10 acre-feet. This is also the lower bound for the amount of water used through 15 connections from public water supply serving at least 25 people (as defined in the SWDA). The representative volume is, therefore, the sum of the water requirements for alfalfa farming and domestic use.

Another alternative RV proposed is 120 acre-feet/yr. This value corresponds to the water use for a small municipal community of approximately 150 individuals who use the water for domestic and municipal purposes.

For the final rule, a representative volume of 3,000 acre-ft/yr was defined. This representative volume, as described in the preamble to the final rule, represents a composite of the water demands for downgradient users of the ground water resource. The composite water use estimate includes current use for alfalfa cultivation (the largest consumer of water for agricultural purposes), and projected increases for population and commercial/industrial uses in the Lathrop Wells area northward to the boundary of the Nevada Test Site.

Section 197.31 describes the RV and includes specific concepts concerning how the RV could be incorporated into the radionuclide transport modeling that will be included in analyses to support demonstration of compliance during the licensing process.

Point of Compliance

In the proposed rule, two mechanisms were proposed for compliance determinations, specifically to identify where ground-water contamination and individual radiation exposures are to be projected for comparison against the limits contained in the standard. One alternative was a controlled area concept, similar in intent to the concept as originally used in Part 191. The controlled area denotes a bounded geographic area within which the standards would not be applied. The standard's limits would be applied at the boundary of the controlled area, which serves as the beginning of the defined "accessible environment". The land within the boundary of the controlled area is considered part of the natural barrier of the disposal system, and as such is dedicated to the sole purpose of isolating the radioactive wastes from the accessible environment. The second proposed alternative was the use of a compliance point, which serves the same purpose as the border of the controlled area - it identifies the point at which ground water contaminant concentrations and individual exposures are calculated for comparison against the standard's limits. The point of compliance is to be located at a specific distance from the repository and over the point at which calculated releases from the repository are projected to be at their highest levels in the ground water beneath this point.

In the proposed rule EPA has included four compliance measure alternatives for consideration, two of which incorporated a controlled area and two of which incorporated a compliance point. These alternatives include downgradient distances of 5, 18, 20, and 30 km. At the present time there is no one residing 5 km downgradient[3] from the repository, since it is within the boundaries of the Nevada Test Site (NTS); there are about 10 people residing between 18 km (the NTS boundary) and 20 km downgradient, and hundreds of persons around 30 km downgradient. Future population increases are expected at the 20- and 30-km downgradient locations (EPA99). In addition, the depth to ground water decreases from about 300 meters near the repository location to about 50 to15 meters within that portion of the Town of Amargosa where most of the population reside and commercial agriculture is the basis for the local economy.

In the final rule, the Agency has incorporated a controlled area concept as a compliance mechanism, as defined in Section 197.12 of the final rule. The controlled area concept comports more directly with the direction of the EnPA, which explicitly mentions the "accessible environment" and refers to its definition from Part 191 which incorporates the controlled area concept. The controlled area concept also more clearly delineates the extent of the natural barrier around the repository than the simpler point of compliance approach. Neither the point of compliance, or the controlled area, approach imposes any significant cost impacts on the repository development program, because the site characterization efforts to define the magnitude and direction of potential releases are the same for either approach.

[3] This is the same compliance point as specified in 40 CFR Part 191, the generic disposal standard.

2.0 OVERVIEW OF RADIOACTIVE WASTE DISPOSAL AT YUCCA MOUNTAIN

This chapter briefly describes the Yucca Mountain site and the wastes that would be stored and disposed there if the site is approved for disposal. A summary of current estimates of repository program costs, which total approximately $57.6 billion, is included.

2.1 Yucca Mountain as a Disposal Site

The Nuclear Waste Policy Amendments Act of 1987 (which amended the Nuclear Waste Policy Act (NWPA) of 1982) designated the Yucca Mountain site in Nevada as the only location to be evaluated as a possible place for disposal of spent nuclear fuel and high-level radioactive wastes. The Yucca Mountain site is located about 90 miles north of Las Vegas, Nevada, and is situated on the boundary of the Nevada Test Site. The climate is semi-arid, and the location was originally selected as a candidate location for disposal because it was expected that there would be limited potential for water to enter the repository and then to transport radionuclides to distant locations.

2.2 Sources and Characteristics of Radioactive Wastes to Be Disposed

A repository at Yucca Mountain would dispose of spent fuel from nuclear power reactors and high-level wastes from reprocessing of spent fuel. The sources of spent fuel would be commercial nuclear power reactors, naval reactors, and reactors used in DOE and research programs. High-level wastes are the result of defense operations in the states of Washington, Idaho, and South Carolina where fuel from production reactors was processed to obtain the uranium and plutonium used in nuclear weapons. They will consist of solidified fission product waste separated from the recovered uranium and plutonium.

The NWPA limited the amount of wastes to be disposed at Yucca Mountain to 70,000 metric tons equivalent of uranium (MTU). The DOE has interpreted this to correspond to disposal of 63,000 metric tonnes of spent fuel and the equivalent of 7,000 MTU of high-level wastes. The 70,000 MTU limit remains in force today, but is subject to change by future Congressional action.

The wastes would come to Yucca Mountain for disposal from commercial nuclear power sites and DOE operations sites throughout the country, as shown in Figure 2-1. At present, the spent

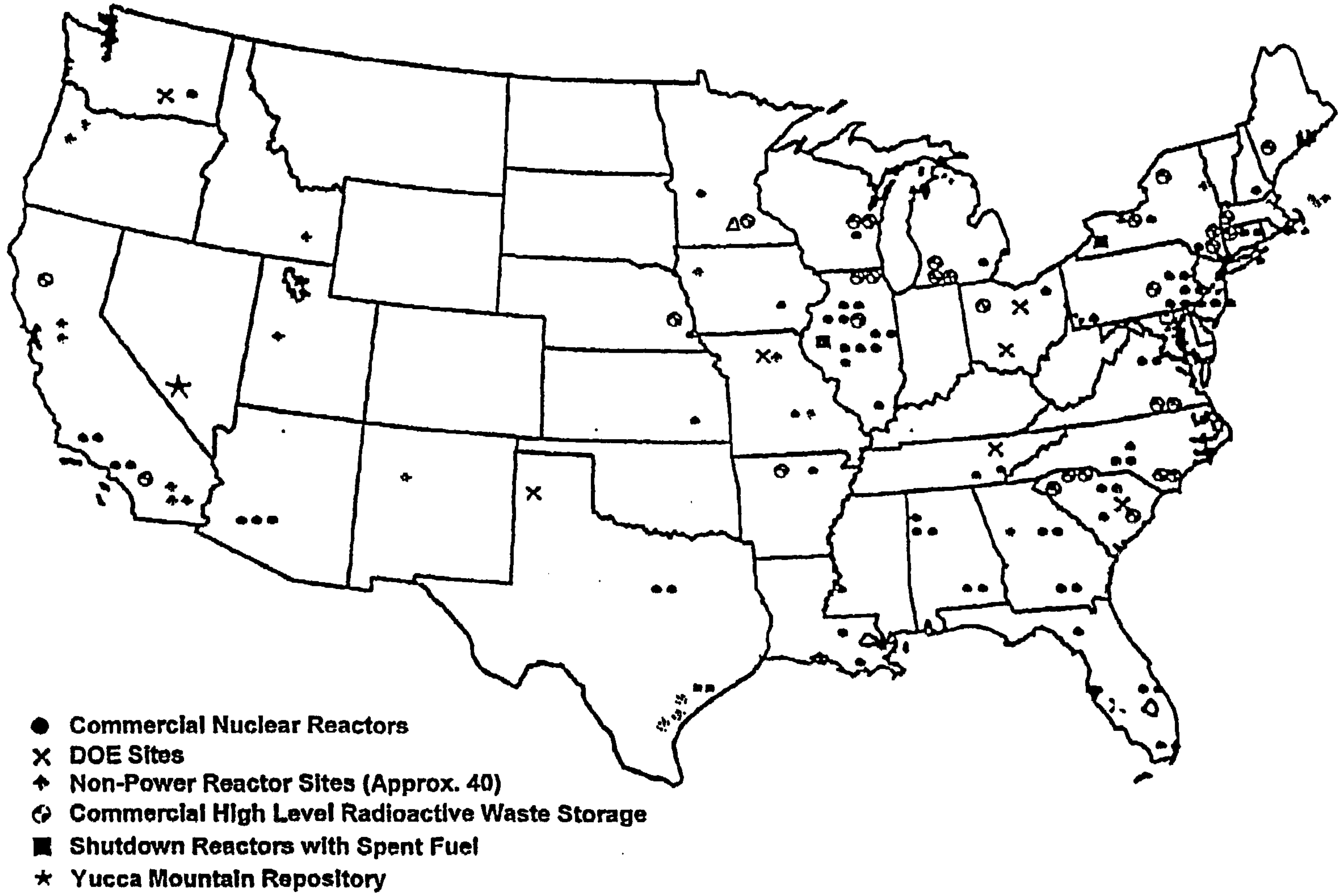


Figure 2-1. Sources of Radioactive Wastes for the Yucca Mountain Repository

fuel from commercial power reactors is primarily stored at the sites where the fuel was used in the reactors. The amount currently in storage totals about 40,000 MTU. Such spent fuel continues to be discharged from the commercial reactors at a total annual rate of about 2,200 MTU. If all reactors operate to the end of their current licenses, the total amount of spent nuclear fuel discharged will be about 87,000 MTU.

The DOE spent fuel, which comes primarily from research and test reactors, and spent fuel from naval nuclear reactors, is presently stored at various DOE sites. The current total amount of this spent fuel is less than 3,000 MTU, and the amount will not increase significantly.

High-level wastes were generated by defense production operations at DOE's Savannah River, Idaho, and Hanford, Washington sites. In the as-generated form, these wastes are liquid and have a total amount of tens of millions of gallons. The wastes will be solidified, and the amount sent to Yucca Mountain, in terms of number of cans of waste to be disposed, will depend on the solidification process used. The draft Environmental Impact Statement for the proposed repository at Yucca Mountain, issued by DOE in August 1999, estimated that the 7,000 MTU of HLW would be contained in about 14,000 waste canisters (DOE99).

2.3 Overview of the Repository for Disposal

The basic concepts for disposal of highly radioactive wastes into geological formations were set forth by the National Academy of Sciences in the 1950's and have been embodied in repository design concepts and regulatory concepts ever since then. The wastes are to be emplaced in deep geological formations which isolate them from the human environment, and a system of engineered and natural barriers is to be used in combination to maintain the wastes in isolation and to prevent release of radionuclides. The Yucca Mountain site, and other sites that had been under consideration, would use a combination of engineered and natural barriers appropriate to the site to maintain the wastes in isolation and to demonstrate compliance with regulatory standards for radionulides that were released from the repository.

At Yucca Mountain, the repository would be excavated in the unsaturated zone, i.e., in a geologic formation in which the pores and fractures in the geologic medium are not filled with water. The Yucca Mountain site, in comparison with other candidate sites, was unique in having capability for this type of emplacement. It was expected that the lack of ability for water to reach the wastes and transport them to the environment would dominate the safety performance of the repository and enable easy demonstration of compliance with regulatory standards.

2.4 DOE Estimate of the Repository Program Cost

DOE documented estimated repository program costs in the Viability Assessment (VA) documents (DOE98). The principal cost elements were identified as follows:

Historical costs -	$ 5.9 billion
Costs to complete work to the License Application -	1.1
Respository costs from licensing to closure -	18.7
Total for the repository program -	$ 25.7 billion

Estimates of costs for design options (options to the VA design) were provided in Volume 5 of the VA document. One of the options considered was use of drip shields and backfill, as is now planned for the current design, EDA II (see Section 3.6). The estimated cost of this option was $0.8 billion. However, this estimate did not consider the long-term total cost of these modifications.

DOE has released an updated "Total System Life Cycle Cost" (TSLCC) estimate (DOE01a), which gives a total cost for the repository of $57.6 billion, which includes historic costs. This higher cost includes cost elements not included in the VA estimate, and is a more accurate estimate of total program costs.

3.0 EVOLUTION OF THE YUCCA MOUNTAIN REPOSITORY DESIGN

This chapter describes the evolution of design concepts for a repository at Yucca Mountain that has occurred as a result of site characterization findings, performance assessment results, external reviews, and strategy for dealing with uncertainties. The discussion demonstrates that EPA's standards have not affected the design evolution.

This section describes how the design of a repository for the Yucca Mountain site has evolved since the Site Characterization Plan (SCP; DOE88) was published in 1988. The SCP reference design concept involved vertical emplacement of small, thin-walled canisters, with a design lifetime on the order of 300-1,000 years, into the floor of tunnels excavated in Yucca Mountain. The current design concept calls for horizontal emplacement of large, double-walled waste packages, with a design lifetime of more than 100,000 years (TRW00), into drifts excavated in Yucca Mountain with a tunnel boring machine.

The design evolution has been driven principally by acquisition of site characterization data which showed that the performance of the natural features of the repository system during the regulatory period would be less effective than anticipated when the SCP was issued and data were sparse. It was originally expected that water would flow very slowly, and in limited amounts, through the unsaturated geohydrologic regime, that radionuclides released from the repository and transported by water would be trapped on rock surfaces and pores along the flowpath, and that water would travel relatively slowly through the saturated zone. In contrast to this expectation, site characterization data have demonstrated that water from precipitation infiltrates into the mountain at rates much higher than originally expected; that there are paths for rapid transport of water from the surface to the repository horizon and possibly to greater depths; and that flow in the saturated regime is expected to occur primarily in fractures and with limited dilution of radionuclide concentrations. Potential for radiation doses during the regulatory period is dominated by soluble radionuclides that are mobile and move with the water. The natural features will constrain transport of radionuclides that are insoluble and sorbed onto rock surfaces.

The design evolution also was guided by results of a series of analyses of expected repository performance known as Total System Performance Assessments (TSPA); by DOE/NRC technical exchanges and NRC documents which indicate NRC expectations for licensing reviews; and by external reviews of program documents and status by parties such as the Nuclear Waste Technical Review Board (NWTRB), the NRC staff, and the TSPA Peer Review Panel. A series of formal Expert Elicitations on key performance topics such as waste package degradation also played a significant role in design evolution.

Several stages of design evolution can be identified and associated with the SCP and a subsequent series of TSPA reports. The SCP in 1988 was followed by a series of TSPA evaluations in 1991, 1993, 1995, 1998, and 2000. These evaluations were aimed at providing guidance for site characterization activities and priorities and at exploring the effects of engineered design options on performance. In the 1996-1997 time frame, site characterization data and results of expert elicitations became available and provided the basis for the TSPA evaluations included in the Yucca mountain Viability Assessment (i.e., the TSPA-VA), which was issued in 1998 in response to a mandate by the U.S. Congress. The TSPA-VA was the first performance evaluation for a potential repository design at Yucca Mountain. This assessment has been replaced by the TSPA for Site Recommendation (TSPA-SR), which focuses on the latest repository design. This design was developed as a consequence of findings of the TSPA-VA, as described here.

External and DOE-internal reviews of the TSPA-VA revealed that there were highly significant uncertainties and technical issues associated with the repository design that were the basis for the TSPA-VA. In response to the critiques and suggestions, DOE subsequently developed and adopted the Enhanced Design Alternative (EDA) concept, in which several improved repository designs were evaluated. The selected alternative, known as EDA II, subsequently became the design basis for the most recent TSPA iteration, known as the TSPA for Site Recommendation (TSPA-SR).

Discussion of the design and associated TSPA evolution process is provided below. The current design concept, EDA II, is described in Section 3.4. Discussion of TSPA methodology and results is provided in Section 4. The discussion here shows how the repository design was shaped by the evolving understanding of the site's natural features and the uncertainties involved in projecting repository performance.

3.1 The 1988 Site Characterization Plan

The Nuclear Waste Policy Act of 1982 (NWPA) required each candidate repository site to prepare a comprehensive site characterization plan describing how information would be obtained to determine the site's suitability for disposal of highly radioactive wastes. After enactment of the Nuclear Waste Policy Amendments Act of 1987, which designated Yucca Mountain as the only candidate site to move forward with evaluation of suitability for disposal, DOE issued the SCP for the site in 1988. The document received comprehensive, in-depth review by NRC staff, whose comments, based on the Commission's 10 CFR Part 60 regulations for high-level waste disposal, helped shape the path of site characterization and design.

At the time of publication of the SCP, the site characterization data base was highly limited. Expectations of repository performance were based largely on assumptions concerning site features and characteristics. The plans for site characterization activities were designed to obtain data sufficient to assess compliance with existing regulatory standards in the 40 CFR Part 191 and 10 CFR Part 60 regulations. Repository development was subsequently driven by NRC requirements.

3.1.1 Regulatory Framework for the SCP

Under provisions of the NWPA (NWP83), the EPA is to promulgate, for high-level radioactive waste disposal, generally applicable environmental standards for protection of the environment and human health. The NRC is to promulgate regulations to implement the EPA standards and to review the License Application from DOE in order to evaluate compliance with the standards. The EPA regulations were promulgated in 1985 and codified at 40 CFR Part 191; the implementing NRC regulations were codified at 10 CFR Part 60. When the SCP was published in 1988, Part B of the EPA regulations had been remanded by a Federal District court to the Agency for reconsideration. Part B specifies limits on cumulative, long-term radioactivity release from a repository, and also characterizes use of performance assessment to evaluate releases. Although Part B of the 40 CFR Part 191 regulations was being reconsidered by the Agency at the time the SCP was issued, DOE treated the Part B requirements as an operative part of the regulatory framework. Implementation was guided by the Issues Hierarchy (DOE86), which had at the top of the hierarchy, as the overarching issues, the NRC's 10 CFR Part 60 subsystem performance requirements.

The NRC's implementing 10 CFR Part 60 regulations, in addition to adopting the EPA requirements, set performance objectives for specific parts of the repository system. These subsystem performance requirements included:

- Containment of waste within the waste packages must be "substantially complete" for a period of 300 to 1,000 years

- The rate of radionuclide release (with certain exceptions) from the Engineered Barrier System (EBS) following the containment period must not exceed one part in 100,000 per year of the inventory at 1,000 years following repository closure

- The pre-waste-emplacement ground water travel time along "the fastest path of likely radionuclide travel" from the disturbed zone to the accessible environment must be at least 1,000 years. The boundary of the accessible environment was defined by the EPA regulations to be located 5 km from the boundary of the repository and covering no more than 100 km^2 in area.

These subsystem performance requirements drove the repository system design, e.g., selection of a waste canister design with an expected lifetime of 300-1,000 years. As previously noted, the natural features of the repository system (low and slow water flow; radionuclide holdup) were expected to be the dominant contributors to safety performance.

3.1.2 Principal SCP Repository Design and Natural System Features

The SCP repository design was based on emplacement of 70,000 MTHM of spent fuel and high-level waste in an array of vertical boreholes drilled into the floor of drifts in the Topopah Spring Member of the Paintbrush Tuff Formation. (The 70,000 MTHM limit was set in the NWPA and remains unchanged.) The areal power density for the repository was set at 57 kW/acre, and the reference design was based on emplacement of 10-year-old spent fuel.

The SCP repository layout is shown in Figure 3-1 (DOE88a). Three main drifts traverse the length of the repository and the emplacement panels are accessed by side drifts from the mains. Entrance into the repository is through ramps located at the North end.

As previously noted, the site characterization data base was quite sparse when the SCP was issued. It was expected that the water that could infiltrate the mountain and cause corrosion, waste form dissolution, and radionuclide release was "...limited to very small amounts" (DOE88). Based on annual precipitation of 15 cm, only about 0.1-0.5 mm/yr was expected to percolate from the surface to the deep rock units where the repository would be located. Travel times to the boundary of the accessible environment were expected to be on the order of tens of

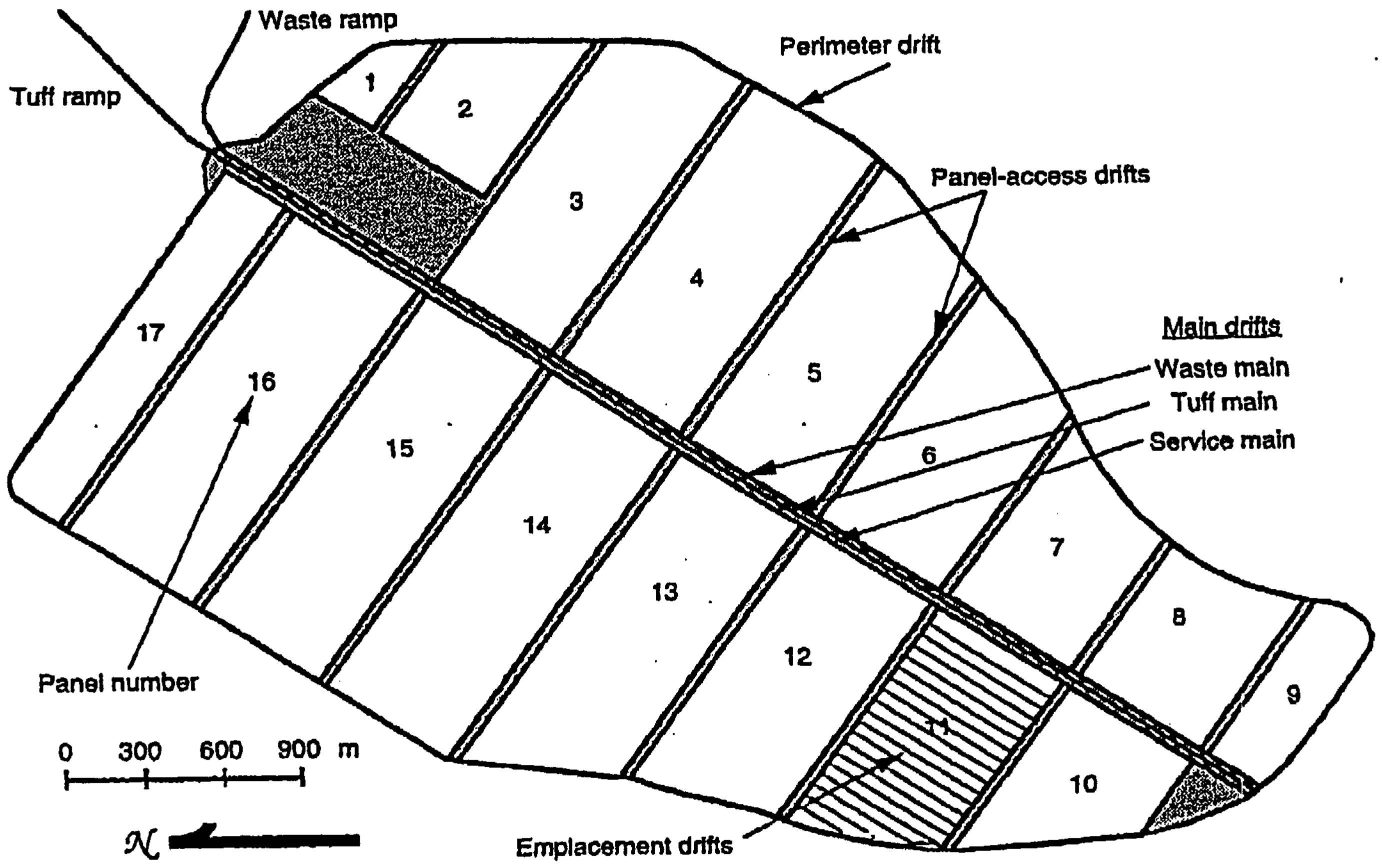


Figure 3-1. Layout of the Site Characterization Plan Repository

thousands of years because flow through the unsaturated zone was expected to occur in the rock matrix.

Characterization of Yucca Mountain for the repository project began in 1978. It involved extensive drilling of boreholes and measurement of hydrologic properties such as hydraulic conductivity and transmissivity. Because of the complexity of the geohydrologic regime, the data base at the time the SCP was issued was still characterized as "...scanty and incomplete". The basic model for the unsaturated zone was one of flow dominated by the partially saturated matrix. The saturated zone model was based on Darcian flow and a dual-porosity (fractures and matrix) concept.

The available models and data were used to estimate hydrologic parameters important to repository performance. The average annual precipitation was estimated to be about 150 mm/yr.

Because of the thickness and heterogeneity of the unsaturated zone above the repository horizon, temporal and spatial variations of infiltration were not expected to be the same at depth as at the surface.

Various estimates of the infiltration rate were made; all of them showed low rates. One estimate found that the infiltration rate at the repository horizon would be no more than 0.2 mm/yr, and the surface rate would be no more than 0.5 mm/yr. Another study estimated that the net infiltration rate would range from about 0.5 to no more than 4.5 mm/yr. Yet another study estimated the range at 0.015 to no more than 4.5 mm/yr. Modeling studies after the SCP was published generally used infiltration rates of 1.0 mm/yr or less. As discussed below, these types of values prevailed as a basis for unsaturated zone performance until the 1996-1997 time frame.

Because of the 10 CFR Part 60 subsystem performance requirements, estimates were made of ground water velocities and travel times. The SCP quotes findings by Sinnock et al. that the unsaturated zone travel time, for an infiltration rate of 0.5 mm/yr, would be a minimum of 9,345 years, a mean of 43,265 years, and a maximum of 80,095 years. If the infiltration rate was doubled to 1 mm/yr, the minimum travel time was decreased to 3,700 years, "...still greater than the amount of time required to satisfy the [regulations]". It was stated that "...the modeling effort has attempted to use the best available data , and it is believed the results obtained are realistic." As indicated by this statement, at the time the SCP was developed (and for a considerable period of time thereafter) the travel time through the UZ was believed to be sufficient to meet the 10,000-year requirement in the EPA standard.

Estimates of travel time in the saturated zone, which were based on Darcian flow and travel paths parallel to the hydraulic gradient and nearly horizontal, showed travel times of 30 years in the 3-km path in tuffacious beds of the Calico Hills formation and 140 years in the 2-km path for the Topopah Springs member, for a total of 170 years to the 5-km boundary of the Accessible Environment. It was noted that other factors such as dispersion, the existence of faults or impermeable zones, or vertical movement of water could affect the saturated zone travel times. It was also noted that "...at this time it is uncertain whether some or all of this mechanisms exist along the travel path". However, page 3-220 of the SCP states that more realistic data give an SZ travel time to the 5-km Accessible Environment boundary of 1,700 years (SCP88). In contrast, recent SZ travel time estimates presented to the NWTRB (EDD01) estimated travel times to a distance of 20 km downgradient to be between 640 years (median parameter values) to 900 years (mean parameter values). A "refined conceptual approach," equivalent to the SCP estimate using more realistic data at that time, gave a travel time of 1300 years to the 20 km distance.

The SCP concluded that "...based on an upper-bound flux of 0.5 mm/yr, ground water travel time within the unsaturated zone from the proposed repository to the water table is estimated to range from about 9,000 to 80,000 yr," and "... the minimum ground water travel time from the edge of the repository to the accessible environment [5 km] under present conditions is approximately 9,200 years, well in excess of the 1,000 year limits required by 10 CFR Part 60.113(a)(2)."

With these expectations of high performance for the natural features of the repository system, the engineered barrier system could be the minimum required to meet regulatory requirements, as discussed below.

3.1.3 The SCP Engineered Barrier System

In accord with NRC's subsystem performance requirements, the waste package for the SCP design consisted of Type 304L stainless steel containers 4.76 m long and 0.66 m in diameter, with a wall thickness of 0.95 cm. Most of the commercial spent fuel was expected to be consolidated, but disposal of intact assemblies was planned for fuel assemblies with damaged rods. The HLW containers were similar to those for spent fuel but shorter.

The containers were to be backfilled with argon and welded shut. Fully loaded waste packages would weigh 2.7 to 6.4 metric tons, would have a power output of about 3.3 kW at the time of emplacement, and would have a surface gamma dose rate of about 50,000 rads per hour.

The waste packages were to be emplaced in 76-cm diameter holes bored into the floor of drifts in the underground workings. The boreholes were to be metal-lined and had a metal support plate at the bottom on which the waste package rested. A metal plug would be placed on the top of the emplaced package, the upper portion of the borehole would be filled with crushed tuff, and a metal cover would be placed on the floor of the drift. Eventually, the drifts would be backfilled with crushed tuff.

An important concept included in the SCP design was use of heat emitted by the waste packages to drive water in the rocks away from the emplacement cavities, thereby effectively drying out the repository host rock. The concept was seen to make a good repository setting (the unsaturated zone in a semi-arid environment), even better by delaying the eventual contact of water with the waste containers. The technical difficulties in characterizing performance under high thermal load conditions were recognized in the SCP and was preserved as a significant technical issue in commentary, in 1999, on the Total System Performance Assessment for the Viability Assessment from external parties such as the TSPA Peer Review Panel (PRP99). This uncertainty played a significant role in DOE's decision to adopt the highly engineered EDA II repository design (described in Section 3.4 of this document).

The engineered barrier system (EBS) design, including the waste package design, was intended to comply with the subsystem performance requirements of 10 CFR Part 60, including ability for retrieval after 50 years. The package was intended to provide substantially complete containment of waste for a period of not less than 300 years, but no more than 1,000 years would be required. Thereafter the package was to limit the rate of radionuclide release from the EBS as required by the NRC subsystem performance objectives. With the anticipated high performance of the natural system barriers, the relatively modest performance expectation for the engineered barrier system was expected to be sufficient to meet the assumed (from 40 CFR Part 191) standard for cumulative releases.

The evolution of performance assessments, and the associated changing repository design, are described in the following sections, along with the progressively improved understanding of the natural barrier characteristics.

3.2 Design Options in the Total System Performance Assessments of 1991, 1993, and 1995

As previously noted, the TSPA evaluations reported in 1991, 1993, and 1995 were intended to guide site characterization activities and priorities, and to explore the effect of design alternatives on repository system performance. DOE carefully noted that none of the design concepts was intended to represent an actual repository design, and none of the results were intended to be a test of compliance with regulatory standards. However, to have a basis for assessing study results, outputs of the evaluations were compared to the total system performance standards in Subpart B of EPA's 40 CFR 191 regulations that had been adopted by NRC's 10 CFR Part 60 regulations.

Throughout this period, results of the site characterization work and other data acquisition programs were, as they became available, incorporated into the studies and used to improve the performance assessment models. Because the Part 191 EPA regulations set limits on radionuclide releases to the Accessible Environment boundary at 5 km, the site characterization work was focused on and near the repository footprint. The surface-based data acquisition program included activities such as drilling numerous boreholes, geologic mapping of trenches, characterization of surface expression of faults, and daily acquisition of meteorological data. Excavation of the Exploratory Studies Facility (ESF), primarily during 1995 and 1996, enabled data acquisition activities at the repository horizon to proceed in accord with excavation progress and in parallel with the surface-based studies.

Highlights of the 1991, 1993, and 1995 TSPA analyses are presented below with focus on design options considered. As can be seen, the options considered ranged from the simple waste canisters in the SCP reference design to precursors of the VA design and the current design, EDA II. During the time period through 1995, clear evidence of limitations on the performance of the natural features of the repository was not yet available; the shift of emphasis to large, highly-robust packages was driven by logistics considerations (far fewer packages to handle), the decision to excavate the repository using a tunnel boring machine, and growing indications that very conservative assumptions and analyses would be expected by the licensing authority during licensing reviews.

3.2.1 TSPA-1991

The TSPA-1991 studies were the initial attempt to demonstrate TSPA concepts and methodology. The design concept for TSPA-1991 was that of the SCP: PWR fuel with an average burnup of 33,000 MWd/MTHM and BWR fuel with an average burnup of 27,500 MWd/MTHM would be consolidated into vertically emplaced stainless steel waste packages. The waste package performance evaluations were based on several assumptions not supported by detailed modeling studies. The waste package was expected to be initially dry due to heating produced by radioactive decay; this dry period would last from 300 to 1,300 years. After wetting, the container was expected to have a lifetime range of 9,500 years "to reflect the great uncertainty in container performance" (BER92). A total of 33,300 containers was included in the repository design.

3.2.2 TSPA-1993

Two separate but parallel performance assessments were conducted in 1993 - one by the DOE M&O Contractor (DOE94) and one by Sandia National Laboratories (Wil94). These parallel assessments are designated as the "M&O Approach" and the "SNL Approach" in the following discussion. The EBS designs used in these assessments resemble the design used in the TSPA-VA and the newer EDA II design, and represent the first attempt to examine designs that were developed to reflect anticipated repository conditions at Yucca Mountain.

3.2.2.1 M&O Version of TSPA-93

The M&O's TSPA-93 studies considered three areal power loadings -- 28.5, 57 and 114 kW/acre. Waste packages using a thick, outer corrosion allowance material (CAM) and a thinner, corrosion resistant material (CRM) as the inner package wall were horizontally emplaced in drifts in the Topopah Spring Member of the Paintbrush Formation. The commercial reactor spent fuel loading was 63,000 MTHM contained in thirty-year old fuel with an average burnup of 36,437 MWd/MTHM (DOE94, p. 2-3). In addition, 7,000 MTHM in HLW from the defense programs was included. The commercial spent fuel was contained in 6,468 waste packages and the defense HLW was contained in 3,829 waste packages (DOE95, p. 8-15). (Note that this design concept reduced the number of waste packages required for commercial spent fuel by about a factor of 5 in comparison with the SCP design.)

The waste packages were comprised of an outer, mild steel corrosion allowance material and an inner, nickel-base corrosion resistant material, Alloy 825. Three thicknesses were considered for the outer layer: 10, 20, and 45 cm. The inner layer was either 0.95 or 3.5 cm thick. The packages were assumed to be placed horizontally on crushed tuff on the floor of the drifts.

The M&O TSPA-93 assumed an ambient percolation flux with an exponential distribution and an expected value of 0.5 mm/y. Two-thirds of the flux values were less than the expected value and one-third were greater. These low flux values reflected SCP expectations; results of site characterization studies had not yet had an impact.

Radionuclide sorption and decay were included in modeling of the unsaturated zone (UZ) but diffusion was not. Six layers were used to represent stratigraphy in the UZ below the repository. Nine vertical columns were modeled to represent UZ variability in thickness and stratigraphy over the repository area. Temperature profiles, Darcy fluxes, and liquid saturations, were developed for each stratigraphic layer for each thermal load as function of time. These determined dry out extent and duration in the near field. No far-field thermal perturbation was assumed.

Climate change was incorporated by assuming that the infiltration rate would vary from 1 to 5 times the base value with an average value of 2.5. Transition to a full glacial climate would occur linearly over 100,000 years then return to baseline over the next 100,000 years. This cycle was repeated over the one million year simulation time frame.

Retardation factors, developed for each nuclide for each stratigraphic unit, were similar to those used in TSPA-1991. Sorption and decay were included in saturated zone (SZ) modeling but not diffusion. The SZ flux was assumed to have average value of 2 m/yr with a wide range from 4.7 x 10^{-6} m/yr to 390 m/yr. Only the longitudinal component of dispersion was considered in modeling of SZ radionuclide transport. A single porosity medium was assumed for the SZ.

3.2.2.2 SNL Version of TSPA-93

The SNL TSPA-93 studies considered both vertical (in borehole) and horizontal (in-drift) emplacement of waste packages and areal thermal loadings of 57 and 114 kW/acre. Alternative waste package designs were also considered. Details are presented in Table 3-1 (WIL94).

Table 3-1. *Repository Designs Evaluated by SNL in TSPA-1993*

Emplacement Mode	Thermal Loading (kW/acre)	Container Description	Waste Capacity (MTU/ container)	Heated Area (km^2)	Heated Area (acres)	Spacing (m)
Vertical In-borehole	57	Thin-wall, corrosion resistant high-Ni alloy	2	4.61	1,139	5.6
Vertical In-borehole	114	Thin-wall, corrosion resistant high-Ni alloy	2	3.14[a]	777[a]	2.8
Horizontal In-drift	57	Mild-steel CAM over thin-wall high-Ni CRM	8	4.63	1,144	23.2
Horizontal In-drift	114	Mild-steel CAM over thin-wall high-Ni CRM	8	2.33	575	11.6

a - 2.33 km^2 (577 acres) for spent fuel and 0.81 km^2 (200 acres) for HLW.

The waste package for vertical, in-borehole emplacement was a thin-wall cylinder of a high-nickel alloy such as Alloy 825. The waste package had a outside diameter of 0.71 m, a wall thickness of 0.95 cm and a length of 4.76 m. The package could handle about 2 metric tons of spent fuel (e.g. 3 PWR and 4 BWR fuel assemblies) and weighed about 5 metric tons when loaded. The waste package for horizontal, in-drift emplacement was substantially larger with the ability to contain 21 PWR or 40 BWR fuel assemblies. The waste package was comprised of an Alloy 825 inner barrier 0.95 cm thick surrounded by an outer barrier of mild steel 10 cm thick. The two barriers were separated by a 0.6 cm gap. This waste package was 4.91 m long, had an outside diameter of 1.75 m and weighed more than 50 metric tons when loaded with spent fuel. This multiwall container was too massive to permit it to be tilted and moved for vertical emplacement and retrieval. Additional details on the two types of waste packages are summarized in Table 3-2.

3.2.3 TSPA-1995

At the time TSPA-1995 was prepared, the regulatory framework was still in a state of flux. The National Academy of Sciences Committee on Technical Bases for Yucca Mountain Standards issued its report in August 1995 (NAS95), but EPA had not promulgated the environmental regulations specific to Yucca Mountain. Given this situation, DOE chose in TSPA-95 to

Table 3-2. Spent Fuel Waste Package Inventory for TSPA-1993

Reactor Type	Amount of Waste (MTU)	Percentage of Total Spent Fuel	Weighted Average Age (Years)	Weighted Average Burnup (MWd/MTU)	Hybrid Waste Packages	Single Type Waste Packages
Borehole Emplacement						
BWR	22,248	35.3	26.3	31,550	28,057	1,215
PWR	40,749	64.7	25.5	40,461		2,750
Totals	62,996	100	--	--	32,022	
In-Drift Emplacement						
BWR	22,183	35.3	26.4	31,533	--	3,109
PWR	40,646	64.7	25.5	40,433	--	4,531
Totals	62,829	100	--	--	--	7,640

For vertical borehole emplacement, an additional 13,957 canisters would be required for vitrified HLW.

evaluate cumulative releases of radioactivity to the accessible environment based on cumulative normalized release limits included in Table 1 of 40 CFR Part 191 and maximum doses to individuals using ground water from a well in the tuff aquifer at the boundary of the accessible environment. In each case, the boundary of the accessible environment was assumed to be five kilometers down the saturated zone hydraulic gradient from the edge of the repository (DOE95). Evaluations were also made against subsystem requirements in 10 CFR Part 60.

Repository design concepts investigated in TSPA-95 were based on 63,000 MTU of spent nuclear fuel and 7,000 MTU of defense HLW emplaced in horizontal waste packages (the same as TSPA-93). Two areal mass loading were considered – 25 MTU/acre and 83 MTU/acre. Both backfill and no-backfill options were analyzed as repository closure strategies. The use of backfill was expected to act as a capillary barrier to water and as a thermal management tool. Its use would increase waste package temperatures; evaluations of the temperature impacts of the backfill were included in the studies.

Commercial spent fuel was assumed to be 30 years old with a weighted average burnup of 36,666 Mwd/MTU. The same number of waste packages were assumed as in the TSPA-93 analyses performed by the M&O contractor (DOE95, p. 8-15).

"Low" (ca. 0.02 mm/y) and "high" (ca. 1.2 mm/y) infiltration rates were considered. These rates are in the range expected under the SCP; results of site characterization studies which showed that infiltration rates are actually in the range 1-10 mm/yr, and currently average about 8 mm/yr, were not yet available for TSPA-95.

The waste package design concept for TSPA-95 was similar to that considered in TSPA-93; i.e., it consisted of a outer mild steel corrosion-allowance material (CAM) over an inner corrosion-resistant material (CAM) of Alloy 825. The waste container for either 21 PWR assemblies or 44 BWR assemblies was about 5.7 m long and about 1.8 m in diameter. The CAM thickness was 100 mm while the CRM thickness was 20 mm. A 21 PWR waste package would weigh about 66 tons and produce an average of 10 kW of heat at the time of emplacement. The waste package was assumed to rest on a gravel invert covering the bottom of a circular cross-section drift with a diameter of 5m.

In summary, the TSPA exercises and reports of 1991, 1993, and 1995 served several important purposes in the evolution of the Yucca Mountain repository design. In brief, TSPA-91 provided a baseline by introducing the TSPA concept and applying it to the SCP design. The subsequent TSPA-93 and TSPA-95 efforts explored the potential ranges of contributions of engineered and natural barriers to repository system performance. Key factors considered included the following:

- In the 1993-1995 time frame, DOE knew, as a result of enactment of the Energy Policy Act of 1992, that revised dose standards and requirements for demonstration of compliance would be forthcoming, so alternative dose standards and receptor locations were considered. Consequently, EBS designs more reflective of changing site characterization information were beginning to be assessed.

- As stated in TSPA-95, the SCP conceptual engineered design "... has been revised to take into account the possibility of alternative areal mass loads, as well as the decision to use a tunnel boring machine for the excavation of the emplacement drifts." In addition, the large multi-purpose canister design was adopted. These design considerations led to investigation of the performance characteristics of large, horizontally emplaced waste packages with alternative design details, such as the type and thickness of wall materials.

- Site characterization data were being incorporated into the TSPA-95 models and information base as they became available, but it was becoming increasingly apparent that there was a high degree of inherent variability in natural system parameters, that performance of the natural barriers might not meet expectations expressed in the SCP, and that performance of the natural barriers might be difficult to demonstrate with confidence in licensing reviews.

- As a result of a limited data base (limited in part by the fact that the high variability of natural features would require an extensive data base for reliable characterization), potential bounds of the performance of the natural features were explored, using models not well founded. For example, TSPA-95 recognized that the principal contribution of the saturated zone to performance would be dilution, and the TSPA-95 developed and used models which predicted overall SZ dilution factors, for an infiltration rate of 1.25 mm/yr, of 4,500 at 5 km and 31,000 at 30 km. Subsequent expert elicitations confined the expected SZ dilution factor range to 1 - 100.

Collectively, these exploratory studies and their results laid the foundation for the Viability Assessment reference design and the TSPA-VA performance evaluations discussed below.

3.3 Design Features for the Viability Assessment - 1998

The Energy and Water Development Appropriations Act of 1997 specified that DOE prepare a viability assessment of the Yucca Mountain repository, thereby providing a status report on the project and identifying critical issues that must be addressed before the Secretary of Energy can make a recommendation concerning suitability of the Yucca Mountain site for disposal. The Viability Assessment report, which included a Total System Performance Assessment - Viability Assessment (TSPA-VA), was published in December 1998 (DOE98). Although the EPA standards had not been developed, DOE based its analyses on annual radiation doses to the individual members of the general public. DOE assumed a radiation dose limit of 25 mrem/yr. Releases from the ground water to the biosphere were evaluated at a point 20 km downgradient from the repository. Multiple exposure pathways were included in calculating doses to humans. Time histories to one million years were considered.

As previously noted, DOE considers that the TSPA-VA evaluations are the first that address a potential repository at the site. The major features of the repository design were similar to those in TSPA-95. However, in response to recommendations from the expert elicitation on waste package degradation, the waste package inner wall was Alloy 22 to provide enhanced corrosion resistance. The drifts were assumed to be concrete lined. Backfill was not included in the reference design but was examined as a design option. Use of ceramic coatings and drip shields were also briefly investigated as options.

The areal mass loading in the reference design was 85 MTU per acre with an initial heat output of about 100 kW/acre. This is based only on 63,000 MTU of commercial spent fuel which will be emplaced in about 7,650 waste packages (DOE98, p. 3-30). According to the Draft Environmental Impact Statement (DEIS) (DOE99), the 7,000 MTU of DOE spent fuel and HLW waste also to be emplaced in the repository will require a total of about 22,000 waste packages.

UZ flow modeling for the TSPA-VA included climate, infiltration, mountain-scale flow and seepage into emplacement drifts. Climates modeled included the present day dry climate with an average annual rainfall of 170 mm/y, a long-term average climate with a rainfall of 300 mm/y and a superpluvial climate with an average rainfall of 450 mm/y. About 90% of the one million-year modeling period is spent under long-term average climate conditions.

The net infiltration rate in the TSPA-VA was assumed to be about 8 mm/yr (DOE98, p. 3-10) for the current dry climate. This value is substantially higher than the value of about 1 mm/yr used in TSPA-93 and TSPA-95, and it reflects the results of site characterization studies. The increased flow includes rapid travel through fast-path fractures which was not apparent from the earlier equivalent continuum models where fracture and matrix flows were closely coupled. The TSPA-VA used a dual permeability model to represent the full range of possible fracture-matrix coupling possibilities. Specifically, UZ transport was modeled using a three-dimensional, dual permeability finite element code (FEHM).

As noted above, Alloy 825 in the TSPA-95 was replaced with Alloy 22 (a highly corrosion-resistant nickel alloy) for the CRM in the VA waste packages. The drifts were lined with concrete. The waste packages were placed on carbon steel supports which in turn rest on a concrete invert to create level floors in the drifts. A typical 21 PWR waste package was 4.89 m long (without lifting extensions) and 1.65 m in diameter. The inner barrier of Alloy 22 was 2 cm thick while the outer barrier of A516 carbon steel was 10 cm thick (DOE98a).

The TSPA -VA was the first performance assessment in which the importance of fuel element cladding as a long-term barrier to radionuclide release was considered.

The TSPA-VA base case assumed that one waste package would fail by some unspecified juvenile failure mechanism at 1,000 years after repository closure (DOE98a). The probabilistic base case assumed 0 to 10 waste package failures at 1,000 years based on a log-uniform distribution.

The base-case expected-value TSPA-VA evaluations projected dose rates to the average individual withdrawing water from a well 20 km downgradient from the repository (based on conservative scenarios and modeling) as follows (DOE98, Figure 4-12):

- 0.04 mrem/yr at 10,000 years
- 5 mrem/yr at 100,000 years
- 50 mrem/yr at one million years

Results of more elaborate probability-weighted dose assessments (DOE98, Figure 4-26) show mean and median values for the peak dose at 10,000 years of 0.1 and 0.002 mrem/yr, respectively. Hence, all applicable dose values were found to be well below the proposed 15 mrem/yr individual protection limit. As discussed in Section 4, these results were developed using highly conservative, and in some cases unrealistically conservative, assumptions concerning performance factors and models for framing the performance scenarios analyzed.

The analyses found that the most important radionuclides contributing to individual dose for the first 10,000 years are Tc-99 and I-129; for the first 100,000 years they are Tc-99 and Np-237, and for one million years they are Np-237 and Pu-242.

The most important factors contributing to uncertainty in the peak dose rate over the first 10,000 years (in decreasing order of importance) were determined to be the fraction of waste packages contacted by seepage water, the mean corrosion rate of the waste package Alloy 22 inner barrier (a contributing uncertainty is the effect on corrosion rates of carbonate dominated ground waters resulting from contact with the drift lining), the number of juvenile waste package failures, and the saturated zone dilution factor (DOE98, Figure 4-34). These uncertainties were to be addressed by the design alternatives examined and selected for the new repository design (EDA II) as described below.

The TSPA-VA assessment results showed that calculated doses within 10,000 years were dominated by very conservative release assumptions. These assumptions, in turn, were associated with arbitrary and non-mechanistic assumed juvenile failures of the waste packages.

As a consequence, subsequent attention focused on improved approaches for evaluating such juvenile failures.

3.4 Enhanced Design Alternatives - 1999

As stated in the VA documentation, the design concept used for the VA and the TSPA-VA evaluations was intended to be a step in design evolution to the design that will eventually be used for the license application. Even though the site characterization data indicating infiltration rates that were much higher than previously expected were available for the VA, other data (e.g., concerning corrosion of waste package materials) were still limited, and the VA made extensive use of the results of seven expert elicitations that had been conducted during 1996 and 1997.

Subsequent to publication of the VA, DOE began to develop an improved repository design. The basis for the design development effort was a group of Enhanced Design Alternatives (EDA). Six EDA designs were evaluated and the EDA II design (described below) was recommended by the M&O contractor to DOE as the preferred approach. This recommendation was accepted by DOE management in September 1999. Design features for the EDA II design are discussed in Section 3.4.2.

In parallel with DOE's EDA design development effort, substantive action to revise the regulatory frame work was occurring for the first time since the original NRC and EPA regulations for Yucca Mountain were promulgated in the 1980's. On February 22, 1999, the NRC published their proposed 10 CFR Part 63 regulations which set a dose limit of 25 mrem/yr and eliminated the subsystem performance objectives included in 10 CFR Part 60. In August 1999, EPA issued for comment the proposed 40 CFR Part 197 environmental protection standards for Yucca Mountain (EPA99). These standards would require DOE to demonstrate a reasonable expectation for 10,000 years after disposal that the annual committed effective dose equivalent to the reasonably maximally exposed individual is no more than 15 mrem (CEDE). The draft standard also imposed ground water protection requirements. The EPA's proposed rule had not been published at the time the EDAs were being evaluated, but the individual dose standard is the same as that incorporated in the generic standard (40 CFR Part 191) an used in the WIPP certification process.

3.4.1 Basis for the Current Design

Reviews of the repository design concept and performance assessment results for the Viability Assessment by parties such as the Nuclear Waste Technical Review Board, the NRC, and the Performance Assessment Peer Review Panel determined that some of the engineered features of the VA repository contributed significantly to uncertainty in the Total System Performance Assessment (TSPA) results. Major design factors contributing to performance uncertainty included:

- The high areal mass (thermal) loading, 85 MTU/acre, and resulting high temperatures in the rocks surrounding the repository caused significant uncertainties concerning thermal, hydrological, chemical, and mechanical coupling effects. It also caused uncertainties concerning the behavior of rock structure and ground water surrounding the drifts during repository temperature variations with time.

- The use of concrete lining in the drifts caused concerns about the effect of materials in the concrete on the chemical constituents in ground water that contacts waste packages and the effect of those constituents on the corrosiveness of the water.

- The use of carbon steel as the Corrosion Allowance Material and the outer wall of the waste packages, and use of Alloy 22 as the Corrosion Resistant Material and the inner wall of the waste packages, caused concern that the carbon steel could create potential for crevice corrosion of the Alloy 22, thereby increasing the rate of penetration of the Alloy 22 by about a factor of 25 and consequently greatly reducing the waste package lifetime.

- The waste packages were not protected from the potential that ground water at the repository horizon could, at times relatively soon after emplacement, drip onto the packages and thereby produce aqueous corrosion, enter the package interior, contact the waste form, leach out radionuclides, and transport the radionuclides to the environment.

The DOE's development and selection of an improved repository design was directed at being responsive to these concerns.

3.4.2 Selection of the Repository Design for the Site Recommendation

DOE used the License Application Design Selection (LADS) process to select the engineered design for the Site Recommendation. Six Enhanced Design Alternatives (EDA) were defined and comparatively evaluated. They were identified as EDA options I, II, IIIa, IIIb, IV, and V. Options IIIa and IIIb differed in the choice of waste package materials but were otherwise the same.

In defining the EDA options, specific design features were used to address the important performance uncertainties. All EDA options use a drip shield of corrosion-resistant material to divert water from the waste packages and to control the waste package environment; all EDA options also use a corrosion-resistant material as the outer wall of the waste package and limit the use of cementitious material in the repository. The options differ in their use of high or low thermal loading, emplacement configurations and waste package energy densities, and backfill.

Use of evaluation criteria and a comparison methodology produced the results of analyses of the EDA options shown in Table 3-3. These results produced a recommendation by the DOE's Management & Operations contractor that the EDA II option be selected for the Site Recommendation (SR). DOE endorsed the contractor's recommendation in September 1999, and this design is now being used as the basis for development of the SR.

3.4.3 Comparison of the EDA II and Viability Assessment Designs

The principal EDA II and VA engineered design features are compared in Table 3-4. DOE estimated that the net present value for development, construction, operation, and closure of the VA repository would be about $10.1 billion; the estimated net present value for the EDA II repository is about $11.0 billion (Table 3-3). The cost difference for the two designs is minimized by the assumption that the drip shields and backfill for the EDA II design would be installed at the time of repository closure, i.e., 50 years or more after the end of emplacement operations.

The EDA II and VA designs are compared qualitatively with respect to the performance uncertainties discussed in Section 3.4.1 in Table 3-5. As shown in this table, the EDA II design, in comparison with the VA design, has a significantly reduced areal mass loading, no concrete liner, a waste package design which has the corrosion resistant material on the outside rather than

Table 3-3. Principal Results of EDA Analysis
(Source: K.J. Coppersmith, TRB99a)

Performance Categories		EDA I	EDA II	EDAs IIIa/IIIb	EDA IV	EDA V
Performance Factors	Margin	2,500	3,550	1,500	180,000	1,250
	Time to 25mrem	290,000 years	310,000 years	290,000/310,000 years	100,000 years	300,000 years
	Peak Annual Dose	85 mrem	85 mrem	215/100 mrem	1,200 mrem	200 mrem
Licensing Probability/Safety Factors	Rock Temperatures	Always below 96°C	>96°C several m's into drift for hundreds of yrs.	>96°C across most of repository	>96°C across most of repository	>96°C across essentially all of repository
	Waste Package Corrosion	Does not enter aggressive corrosion range	Does not enter aggressive corrosion range	Some WPs in aggressive corrosion range for 1,000s of years	Humid air corrosion of WPs begins as early as 100 years	Some WPs in aggressive corrosion range >10,000 years
Construction, Operations, and Maintenance Factors	Number of Waste Packages	15,903	10,039	10,213	10,213	10,039
	Length of Emplacement Drifts	132 km	54 km	55 km	60 km	54 km
	Key Construction, Operations, and Maintenance Issues	Operational impacts of more packages and longer drifts: blending	Blending; emplacement of backfill	Fabrication of dual corrosion-resistant material package in IIIb	Fabrication, welding, and handling thick WPs; empl. of backfill	Blending
Flexibility Factors	Emplacement area for 70,000 MTHM	1,400 acres	1,050 acres	740 acres	740 acres	420 acres
	Ability to Change to Lower Temperature	N/A	Requires longer ventilation	Requires changes in drift spacing	High temp. integral to WP performance	Requires changes in drift spacing
	Ability to Change to Higher Temperature	Requires development of larger packages and coupled models for PA	Requires development of coupled models for PA	N/A	N/A	N/A
Cost	Repository Life Cycle Cost	$25.1 billion	$20.6 billion	$20.1 billion/ $21.3 billion	$21.7 billion	$20.0 billion
	Net Present Value	$13.4 billion	$11.0 billion	$10.7 billion/ $11.4 billion	$11.3 billion	$10.8 billion

Table 3-4. EDA II/VA Design Comparison (Source: M.C. Tynan, TRB99a)

Design Characteristics	EDA II	Viability Assessment Design
Areal Mass Loading	60 MTU/acre	85 MTU/acre
Drift Spacing	81 m	28 m
Drift Diameter	5.5m	5.5 m
Total Length of Emplacement Drifts	54 km	107 km
Ground Support	Steel	Concrete lining
Invert	Steel with sand or gravel ballast	Concrete
Number of Waste Packages	10,039	10,500
Waste Package Material	2 cm Alloy 22 over 5 cm stainless steel 316L	10 cm carbon steel over 2 cm Alloy 22
Maximum Waste Package Capacity	21 PWR assemblies	21 PWR assemblies
Peak Waste Package Power (blending)	20% above average PWR waste package power	95% above average PWR waste package power
Drip Shield	2 cm Ti-7	none
Backfill	Yes	none
Preclosure Period	50 years *	50 years
Preclosure Ventilation Rate	2 to 10 cubic m/s	0.1 cubic m/s

Table 3-5. Impact of EDA II Design Features on Performance Uncertainties

Design Feature	VA Repository	EDA II Repository	EDA II Impact
Areal Mass Loading	85 MTU/acre	60 MTU/acre	Reduce thermal coupling issues
Drift Spacing	28 meters	81 meters	No temperature rise above boiling point in rock between drifts; reduces overall performance uncertainty
Drift Liner and Invert Material	Concrete	Steel	Eliminate effect of concrete constituents on water chemistry; reduce corrosion rates and radionuclide release rates; increases package lifetime
Waste Package Materials	10 cm carbon steel over 2 cm Alloy 22	2 cm Alloy 22 over 5 cm 316L stainless	Eliminate crevice corrosion potential; reduce Alloy 22 corrosion rate by factor of 25 or more; increases package life
Peak Waste Package Power	95% Above Average	20% Above Average by Blending Assemblies	Reduce thermal gradients; less driving force for water movement and degradation processes
Drip Shield	None	2 cm Titanium 7	Protect waste packages; defer contact by water and eliminate juvenile failure potential
Backfill	None	Yes	Divert water from waste packages; protect against rockfall

on the inside, and use of drip shields and backfill to help reduce and defer contact of water with the waste packages. Each of these design features is responsive to concerns for performance uncertainties in the VA design; each helps to mitigate performance uncertainties and to improve expected repository system performance with respect to timing and quantities of radionuclide release. Improvement is obtained either by delaying penetration of the waste package walls or by changing the expected physical/chemical conditions to reduce the amount of radionuclides that could be transported out of the EBS by migrating ground water that moves through the repository.

3.5 Evolution of the Comparative Contributions of Engineered and Natural Barriers to Repository System Performance

As previously noted, the evolution of repository design and performance has been characterized by greatly augmented contribution of engineered barriers to performance and greatly diminished contributions of the natural barriers. The natural barriers of principal significance are the rate of infiltration of water into the mountain; the water percolation flux at the repository horizon; the rate of seepage of water into the drifts and onto the waste packages; travel times in the unsaturated and saturated zones; radionuclide holdup on rock formations as a result of sorption; and dilution of radionuclide concentrations as a result of dispersion and mixing of contaminated and uncontaminated water. Acquisition of data to characterize these performance factors has been underway since inception of the Yucca Mountain project, is continuing today, and will continue through the post-emplacement performance confirmation period if a repository is built at the site.

The diminished role of natural barriers in repository performance expectations occurred relatively abruptly in the 1996-1997 time frame, and was first made evident in the TSPA-VA evaluations (which, as previously noted, were the first TSPA evaluations for a potential "actual" repository at the site). In comparison with the prior TSPA studies, the TSPA-VA evaluations used greatly increased infiltration values and greatly reduced dilution factors for the saturated zone. For example, the SCP and all TSPA studies prior to the TSPA-VA assumed infiltration rates on the order of one mm/yr or less; in contrast, the TSPA-VA used a current-climate average infiltration rate of 7.7 mm/yr and a long-term climate average infiltration rate of 42 mm/yr. Models and analyses in TSPA-95 projected overall dilution factors for the saturated zone on the order of 1,000 to 100,000; TSPA-VA used a dilution factor range of 1-100 with a median value of 10.

These changes were brought about principally by the following:

- In 1996, Flint et al. (FLI96) reported analysis of accumulated site characterization data which demonstrated that the infiltration rate is on the order of 1-10 mm/yr and is highly variable over the area of the repository footprint

- In 1997, D'Agnese et. al reported a regional scale model of the Death Valley hydrologic regime in Nevada and California (DAG97)

- In 1997, an Expert Elicitation on unsaturated zone flow was conducted; based on available data, the experts estimated the mean infiltration rates to range from 3.9 mm/yr to 12.7 mm/yr (DOE97)

- Data showing that Cl-36 from nuclear weapon tests had traveled to the repository horizon in 50 years or less were interpreted to show that there are fast paths for flow through the unsaturated zone, the infiltration rate had to be at least about 2 mm/yr, and the fast flow apparently took place in the fracture zones (Fab98).

- An improved model for flow and transport in the unsaturated zone, based on integration of hydrologic, mineralogic, structural, hydrochemical and geochemical site characterization data, was reported and made available in 1997 for the TSPA-VA (BOD97)

- An Expert Elicitation on flow and radionuclide transport in the saturated zone was conducted (GEO98). The experts rejected the models used in TSPA-95 which showed very large dilution factors, and they emphasized the limitations of processes that would cause dilution of contaminant concentrations. The experts also took note of the extreme lack of data to characterize the geohydrologic regime in the saturated zone beyond the 5-km boundary of the accessible environment (the result of prior focus on the requirements of the EPA's 40 CFR Part 191 regulations). The experts expressed their belief that radionuclide transport would be by movement in vertically thin plumes through flow tubes beneath the repository; they also recommended that the overall dilution factor be constrained to the range of 1 to 100, with a median value of 10.

The results of these activities and findings were incorporated into the basis for the models and performance parameter values used in the TSPA-VA. For example, the Expert Elicitation recommendations concerning dilution in the saturated zone were adopted directly, and a new one-dimensional stream tube model for radionuclide transport in the saturated zone was developed in response to the experts' opinions concerning flow in the saturated zone.

Overall, the models and assumptions adopted for the TSPA-VA analyses resulted in essentially no contribution to performance from transit and holdup in the unsaturated zone, and dilution of radionuclide concentrations during transit of the saturated zone to a location 20 km from the repository occurred by only a factor of 10 in the base case. Dilution during pumping by the dose receptor was assumed not to occur.

Despite minimization of the role of natural barriers in the TSPA-VA analyses, the TSPA Peer Review Panel (PRP99) stated, "The current treatment of saturated zone (SZ) flow and transport at Yucca Mountain is far from satisfactory." The Panel noted three main areas of weakness in the TSPA-VA treatment:

- The lack of data for some important parameters
- The incomplete nature of site characterization
- Continuing questions regarding the adequacy of the numerical models

The basic remedy for these weaknesses, which could permit increased and justified reliance on performance of the natural barriers, is to significantly expand the data base of site characteristics and by so doing increase understanding of the functioning of the natural barrier. To do so would, however, be costly and time-consuming, and may not be necessary given the extreme reliance on engineered barriers that has been developed to reduce the importance of uncertainties in natural barrier performance (see the description of the current repository design in Section 3.4.2). Indeed, in 1996 the Nuclear Waste Technical Review Board noted that "...there are no data to support a realistic estimate of dilution...[and it is not clear] whether further characterization can provide the data for reducing the uncertainty...further studies of the saturated zone beyond those now planned or under way... may not be cost-effective" (TRB96). These considerations indicate that the DOE move to a more highly engineered repository design was directed by a realization of the limitations of further characterization efforts on the complex flow system in and around the site, and the recommendations of external parties to move in the direction of enhanced design to lower the uncertainties.

At present, Nye County, in cooperation with DOE, is conducting a drilling and testing program using boreholes drilled approximately along a radius 20 km from the proposed repository location. These data will expand knowledge of the characteristics of the saturated zone in the valley-fill alluvium. Data available to date indicate that the geologic formations are highly complex, and that flow may occur principally in channels within the alluvium (NYE00). The results of these and other tests planned by DOE may serve only to confirm that significant contributions to performance from features of the saturated zone are not to be expected.

In contrast to the situation for the saturated zone, ongoing experiments in the unsaturated zone at the repository horizon may provide a basis for increased reliance on, or confidence in, performance of natural features in the unsaturated zone in future TSPA evaluations. Experiments concerning seepage into drifts (which has been consistently shown by TSPA evaluations to be one of the most important performance parameters) are showing that seepage is highly limited, and no natural seepage into drifts excavated to date has yet occurred. A world-wide investigation of natural analogs has also shown that seepage dripping into underground openings like those that would be characteristic of the repository is highly limited or non-existent because of capillary forces (TRB00a). The most recent report on the seepage work (TRB00b) indicated that the current seepage model matches the limited available data reasonably well, and that the model predicts a seepage threshold of 200 mm/yr for the rock formations at the repository horizon.

Seepage was incorporated into TSPA modeling for the first time in the TSPA-VA. The TSPA Peer Review Panel found the modeling approach to be "...both novel and informative" (PRP99). The modeling approach assumed steady-state flow in a fracture continuum, in which seepage starts where conditions exist for the drift surface to become fully saturated. The percolation flux threshold was estimated to be in the range 2-3 mm/yr, i.e., approximately the same as the current infiltration rate.

As noted above, experiments to date are indicating that the seepage threshold is actually on the order of 200 mm/yr. (This value corresponds to the high end of the values used in the TSPA-VA for the superpluvial glacial period in the VA climate model.) Available data are, however, limited, and the threshold will be highly sensitive to geometric and wetting conditions on the drift wall. In addition, seepage patterns and rates may change as a result of thermomechanical and thermochemical effects, and rock fall as a result of seismic events. The Peer Review Panel recommended further testing, which is currently underway (TRB00b).

DOE has recently adopted a technique termed "neutralization analysis" to characterize the contribution of individual performance factors to overall repository system performance (TRW00). The technique is being applied to the EDA II design; its use, and the relative roles of the engineered and natural barriers for the EDA II design, are discussed in Section 4.6. In general, the natural barriers play even less of a role in the current EDA II repository design than in the VA design because of further augmentation of engineered barriers in the EDA II design.

3.6 Summary of Factors Affecting Evolution of the Repository Design

As described above, the evolution of the design of the Yucca Mountain repository and its engineered barrier system has been an iterative process occurring, to date, over an eleven-year period from 1988, when the SCP was issued, until 1999, when the EDA II design was selected to be the basis for the Site Recommendation scheduled to be made in 2001. The evolutionary process has been driven principally by the following factors:

- Findings, from site characterization data, that performance of the natural barrier system will be significantly less than was expected when the SCP was issued. Specifically, infiltration rates are much higher than had been expected, water travel times in the UZ are faster than had been expected, and dilution of radionuclide concentrations will be much less than had been modeled as recently as 1995.

- Findings, from TSPA evaluations of design options and natural barrier performance models, that the SCP engineered barrier design concepts resulted in a high degree of uncertainty of ability to achieve compliance with EPA's 40 CFR Part 191 total system release standards and NRC's 10 CFR Part 60 subsystem performance requirements.

- As a result of DOE/NRC Technical Exchanges, development of NRC's Issue Resolution Status Reports, and external reviews, development of understanding of the rigor, depth, and limits on uncertainty that must be addressed in order to prepare a safety case adequate for licensing reviews.

- Results of external reviews such as those by the NWTRB, the TSPA Review Panel, and NRC staff, and understanding of the sources and magnitudes of uncertainties and technical issues in data, performance models, and performance assumptions that are significant to the adequacy and defensibility of the safety case.

In summary, the engineered design of the repository has evolved as a result of progress along a learning curve involving understanding of what the engineered and natural barriers can and cannot do in the Yucca Mountain setting, understanding of the essential elements of a safety case that is adequate for licensing reviews, and understanding of the needs for design approaches and data to bring uncertainties to acceptable levels. Identification of "acceptable levels" of uncertainties is related to EPA's concept of "reasonable expectation" and NRC's concept of "reasonable assurance", discussed in Section 5. The EPA standards have included, since promulgation of 40 CFR Part 191 in 1985, and through revised Part 191 in 1993, Part 194, and proposed Part 197, individual-protection standards of 15 mrem/yr CEDE (or equivalent), human-intrusion standards of 15 mrem/yr CEDE (or equivalent), and ground water protection standards derived from the Safe Drinking Water Act.

It is noteworthy that the design evolution has not been driven by EPA's 40 CFR Part 191 standards concerning radionuclide releases or by anticipated EPA dose standards. Examination of the DOE performance evaluations to date show that there are many alternative means to reduce uncertainties in performance projections, even with limited contributions of natural barriers to repository system performance. What is necessary is to build a solid foundation, through use of data, reasonable performance models, and reasonable assumptions, to demonstrate that the safety case is a reasonable and appropriate representation of expected repository performance.

3.7 EDA II Design and the TSPA-SR

As discussed in Section 3.6, DOE has evolved the repository design over a number of years from one emphasizing the natural barriers of the site to one with much greater reliance on engineered barriers. Among the reasons for this shift in emphasis was an increasing realization that collecting data to resolve residual uncertainties in the behavior of the natural system would be more costly than to develop and use engineered barriers that would eliminate the concern over those uncertainties. Following the Enhanced Design Alternatives program in 1999 (Section 3.4), the program focused on the EDA II design as the basis for the next iteration of the TSPA, known at the TSPA for Site Recommendation (TSPA-SR).

The TSPA-SR is intended as an update and improvement of the TSPA for Viability Assessment (TSPA-VA) (DOE98a), and as technical support for the Site Recommendation. Changes made to the TSPA models were intended to address criticisms of the TSPA-VA modeling approaches, to evaluate the system with more elaborate and soundly based modeling approaches. In addition, greater emphasis was placed on quantification of uncertainties that were not addressed in the TSPA-VA. In particular, in TSPA-SR greater emphasis was placed on the potential for igneous disruption of the repository, on waste package degradation mechanisms potentially leading to early failures, and on potential human intrusion events. Considerably more attention was focused on evaluating the robustness of model assumptions and the influence of various engineered barriers than had been done previously.

The TSPA-SR supports the mandated site recommendation process in Sections 112 and 114 of the Nuclear Waste Policy Act (NWP83, NWP87). The site recommendation is an advanced stage of development of a recommendation by the Secretary of Energy to the President regarding the suitability of the proposed site for development. Since it is an integral part of the legal process for determination of the suitability of the repository to proceed toward a key decision step, the intent is for the TSPA-SR to be a strongly defensible analysis, and to form the foundation for the TSPA to be used in a license application.

3.7.1 New Approaches in the TSPA-SR

The primary scenarios evaluated in TSPA-SR are (1) a nominal scenario, (2) an igneous scenario, and (3) a human intrusion scenario. In addition, assessments were conducted that evaluate the robustness of the analysis to extreme assumptions regarding system behavior, such as very early failure of engineered barriers. These assessments were conducted as part of a series of analyses intended to investigate "barrier neutralization," "uncertainty importance," sensitivity, and robustness of the TSPA. As such, they are regarded as parallel and supporting lines of argument in the Repository Safety Strategy, but are not central to TSPA-SR conclusions regarding regulatory compliance.

3.7.1.1 The Nominal Scenario

The "nominal scenario" is intended to represent the "sequence of anticipated conditions" (TRW00a). This is contrasted with "discrete, unanticipated events that disrupt the nominal case system (TRW00a)." That is, the sequence of external events and processes influencing the system in the nominal scenario represent only gradual degradation processes, with discrete, rapid degradation processes characterized as "disruptive events." The intent of the TSPA is both to show "how the system is thought to behave, but also to provide information on how much uncertainty is associated with each total system performance assessment component..." (TRW00a). To that end, **the analyses in the nominal scenario are intentionally biased toward conservatism in assumptions and choices of parameters** . Consequently, despite using scenarios that represent "anticipated conditions," the expected values of the consequences of the nominal scenario should not be interpreted as the expected consequences of the repository. Instead, the "expected values" are a mathematical expression of a conservative representation of reality. This approach is generally acknowledged to be an appropriate approach to developing defensible TSPA analyses for repositories. Nevertheless, while a conservative approach to defining performance scenarios is typically used in TSPAs, proper interpretation of the results and subsequent decision making must be done with an understanding of the nature and extent of the conservatism embedded in the TSPA results. These points are key to understanding the TSPA-SR results in the context of reasonable expectation (described in Section 5) of compliance.

There appears to be consensus among DOE and EPRI commentators that the assumptions in the nominal case of the TSPA-SR are defensible and conservative, and in some cases very conservative. EPRI (EPR00) provided a long list of "departures from reality" in assumptions in the TSPA-SR. Essentially all potentially non-conservative assumptions listed were offset by an associated conservative assumption. However, there were numerous conservative assumptions that were not offset by any balancing approach. Among the most important conservative assumptions in the TSPA-SR are (EPR00):

- The model for hydrogen absorption on the titanium drip shield can be considered very conservative since it assumes that all the hydrogen absorbed during general corrosion will remain in the residual wall thickness and is available to induce hydrogen-induced cracking (HIC). This constitutes a very conservative assumption for the materials in the EDA II design. Without hydrogen absorption, dripshield lifetimes would be extended to greater than 30,000 years (EPR00). The primary effect of modifying this assumption would be to displace the dose curve out further in time, lowering doses calculated in the first 100,000 years by perhaps two orders of magnitude.

- The model for crevice propagation, if it were to initiate, is conservative. The crevice propagation is assumed to progress in a conservative non-mechanistic manner that may allow moisture ingress into the waste package. However, EPRI (EPR00), in comparing the potential effects of crevice corrosion on the failure time of the waste packages, found that it had only moderate effects (about 1,000-2,000 years) on the failure time.

- The initiation of stress corrosion cracking in the annealed final closure weld is a conservative assumption. EPRI argued that the material properties and the stress-state the waste package will experience imply that the probability of initiation of stress corrosion cracking is negligible, approaching zero. Eliminating this mechanism from the model may delay the onset of releases for several ten of thousands of years (EPR00, Figure 5-17).

- The cladding is assumed to be in an extremely aggressive environment, representing severe conditions for corrosion (DOE01). It is assumed that fluoride enters the waste package and comes in contact with only the cladding. The model does not account for buffering the fluoride by the basket internals. Accounting for this buffering would tend to provide a competitive mechanism for reaction of the fluoride, in turn providing a much less aggressive environment for the cladding. In addition, for fluoride to enter the waste package, significant water would need to flow through the crack, diluting the concentration of the fluoride and lessening the impact. It is unclear whether these concentrations might be decreased enough to eliminate fluoride corrosion initiation entirely. If fluoride effects are eliminated, one would expect the onset of releases to be significantly delayed, since the reaction of cladding with fluoride is the primary initiation reaction in the DOE model. The TSPA-SR also assumes that the fluoride contacts the cladding in a limited area, which is argued by EPRI (EPR00) to be extremely conservative. In presenting an alternative model for cladding corrosion, in which corrosion was treated as general in nature (not specifically driven by contact with fluoride), EPRI calculated the median time to cladding failure as between 25,000 and 70,000 years, for dripping and dry conditions, respectively. This results contrasts with the barrier sensitivity analysis presented by DOE01 (DOE01, Figure 4-214), which shows little difference between the base case analysis and one in which virtually no credit is given for cladding corrosion.

In addition, it is noted that the flow model at the repository level includes an assumption that seepage initiates when a percolation threshold of 10 mm/yr is reached. Research on this effect suggests that a threshold value of 200 mm/yr is needed to overcome capillary effects (TRB00b). Notably, the only extant measurements associated with the threshold value indicate 200 mm/yr in the middle nonlithophysal unit of the Topopah Spring Tuff (DOE01, pg 4-92). This value is treated as an extreme end of a probability distribution in the TSPA-SR. Consequently, this assumption represents a significant level of conservatism, and particularly overestimates the effects of wet-climate states. Applying a higher threshold value would imply that the emplacement drifts would experience dry conditions for a considerably longer time.

A key change to the TSPA-SR compared with the earlier TSPA-VA was the treatment of manufacturing defects in the waste package. In the TSPA-VA, an assumed number of defects were assumed to lead to almost instantaneous releases from the repository. These early failures dominated the dose consequences in the period less than 10,000 years. However, these assumed early failures were somewhat arbitrary and not based on any known mechanism. For the TSPA-SR, the initiation of early failures was evaluated based on established engineering approaches for evaluating the likelihood of manufacturing defects, which are subsequently not identified during inspections. This approach, which is far more reasonable than the TSPA-VA approach, is nonetheless coupled with conservative models and parameters for corrosion initiation and propagation. The resulting approach, while still conservative, has shown the early failures used in the TSPA-VA to be non-mechanistic and implausible (DOE01).

Despite the apparent level of conservatism of the nominal scenario, there are no significant doses to the RMEI in the time period over which the performance objectives apply. The conservatism of the nominal scenario leads to releases and subsequent doses to the RMEI during the period 10,000 to 100,000 years. Less conservative assumptions could well delay the releases until after 100,000 years.

3.7.1.2 Igneous Scenarios

The igneous scenario is subdivided into two scenarios: eruption and intrusion. The eruption scenario refers to penetration of the repository, leading to total disruption of waste packages and drip shields encountered by the magma, bringing waste to the surface. Doses result from ash eruption, with downwind transport, redistribution of ash at the surface, and subsequent human exposures. The intrusion scenario refers to penetration of the repository by magma, leading to total disruption of waste packages and drip shields encountered by the magma, but without further movement of radionuclides. However, since the engineered barriers are assumed to be totally destroyed, this scenario functions as equivalent to assessing juvenile failures of waste packages. Releases for the magma intrusion scenarios are via releases to ground water from the disrupted waste packages.

DOE01 has described the process by which the probability of occurrence of the igneous scenarios was derived. A panel of ten experts representing a wide range of expertise was assembled to interpret the volcanic hazard. The panel evaluated existing data, tested alternative models and hypotheses, and produced an integrated assessment of the volcanic hazard. The use of this procedure may have elicited slightly overstated probability of occurrence. The panel was concerned that some past basaltic activity in the area may have been eroded or buried by younger sediments. Consequently, the panel formally recognized this possibility by including these undetected volcanos into their estimates of the number that have occurred. DOE00a stated that most common multiplier for hidden events was 1.1 to 1.2 of the known volcanic events, despite the fact that there is no known episode of magmatic intrusion in the Yucca Mountain region that has not been accompanied by a surface expression.

The mean estimated annual frequency of intersection of the repository by a dike is 1.6×10^{-8}. The 5^{th} and 95^{th} percentiles of the annual probability are 7.6×10^{-10} and 5.0×10^{-8}, respectively. Shifting even selected probability values by 10-20 percent is unlikely to reduce the mean annual probability below the scenario cutoff value of 10^{-8}. Furthermore, DOE00a cites a series of estimates for the probability of intersection of the proposed repository at Yucca Mountain published during 1982-1999. These values cluster between $1\text{-}3 \times 10^{-8}$, with a few values as high as 10^{-7} for very conservative assumptions, and other values as low as 10^{-10} for less conservative assumptions. Regardless, a series of investigators have suggested that a probability in slight above 10^{-8} is credible. Hence, while the probability may be slightly overstated by the TSPA-SR analysis, it is unlikely that the igneous scenario can be eliminated solely by arguments related to the probability of occurrence.

By contrast, the consequence analysis conducted for the TSPA-SR appears to be very strongly biased toward conservatism. All eruptions are assumed to be violent strombolian for their entire duration. The justification for this assumption is that this is a conservative approach, and that it is consistent with the capabilities of an existing NRC computer code, ASHPLUME. EPRI (EPR00) strongly criticized this assumption, and concluded that strombolian eruptions are both rare in extensional environments like Yucca Mountain, and are not consistent with existing basaltic deposits associated with past events in the region. EPRI (EPR00) suggested that the Pu'u O'o eruption of Kilauea Volcano, Hawaii would be a better model for the type of eruption that may occur in the Yucca Mountain region. This type of eruption would have much less severe consequences than would a violent strombolian eruption. NRC (NRC99a) notes that such "...low-energy, low-dispersivity eruptions have limited potential to disperse HLW to critical group locations."

In the TSPA-SR it is assumed that the magma destroys all waste packages and drips shields that it contacts, making the full inventory of those packages available for transport. The justification for this assumption is that it is conservative, and that other assumptions would be difficult to support (TRW00a). The TSPA-SR is based on a very high temperature (1200 C) in the dike. It has been noted (EPR00) that literature information is available that would indicate that dikes of similar size to the drifts would solidify in 10 to 20 days, and that the expected contact temperature between the magma and the containers would be substantially (as much as 40 percent) lower than the value used by DOE. Taking these effects into account would drastically reduce release rates associated with this scenario, since the containers would likely survive intact at lower temperatures. EPRI (EPR00) also notes the existence of natural analogues for this effect, in which cars, telephone poles, and other objects in the magma path are embedded in the magma rather than consumed by it. In the supporting documentation for the TSPA-SR, DOE (DOE00) acknowledges these temperature effects, conducts modeling of the thermal interactions of waste packages and magma, and presents a conceptual model in which the waste packages are primarily intact after interactions with magma. This conceptual model was not used in the TSPA-SR.

These two assumptions (waste package destruction and type of eruption), if modified, have the potential by themselves to lead to minimal or zero releases from the waste packages in the case of igneous activity.

A number of additional assumptions in the TSPA-SR igneous models are also conservative (EPR00), but would tend to have less profound impacts on the results:

- Effects associated with magma viscosity and velocity are conservative. It is assumed that sufficient magma enters the emplacement drift to contact between 6 to 18 waste packages and move them around, contributing to waste package failure. Assumptions of less violent behavior would tend to decrease releases directly in proportion to the number of damaged containers.

- The assumed waste form particle size after disruption is conservative. When the waste form is exposed to the erupting magma it is assumed that the spent fuel is pulverized into very fine particles. The shearing forces involved in magma eruption are unlikely to be able to cause enough grinding of the ceramic fuel to pulverize the majority of the fuel into a fine powder. This is conservative for the eruption scenario because a fine powder is more easily dispersed over long distances. This assumption is inconsistent with the conceptual model of dike-waste package interactions presented by DOE00. In that report, waste packages were described as being substantially intact following interactions with a dike. If the waste is not pulverized during the eruption, the eruption scenario, which relies entirely on an airborne pathway, would likely be inconsequential.

- The fuel particles are assumed to be on or near the top of all of the magma and eruptive material as it falls back to earth. This assumption is conservative since the majority of the dose from the eruptive scenario is via the inhalation pathway. Waste buried deeper within the fallen ash is less likely to be resuspended by the wind. The particle size assumption discussed above would make this assumption even more conservative.

- The wind is conservatively assumed to always blow toward Amargosa Valley, thereby ensuring the ash fall lands on the greatest local population. The SCP Chapter 5 (DOE88a) shows that no more than about 15 percent of the surface winds are from the north, and at higher elevations winds are generally from the east or southeast. Consequently, this assumption likely represents a conservatism of on the order of a factor of 2-3 in the probability-weighted dose.

- A magma conduit is always assumed to be centered on a drift. This will tend to be conservative since a conduit not centered on a drift should intersect less waste containers. Based on the ratio of the area of the drifts to the area of the repository, this assumption is likely to be conservative by less than an order of magnitude.

- The major faults on either side of the repository have the potential to divert any magma around the repository. This has been conservatively ignored. The effect of accounting for such diversion around the repository would be to lower the probability of its occurrence. Given that the mean probability of occurrence of the scenario is only marginally above the value that should be considered in the TSPA, altering this assumption may eliminate the igneous scenario from further consideration.

3.7.1.3 Human Intrusion Scenario

The human-intrusion scenario is a hypothetical analysis of the potential effects of a drilling event at the site. In this analysis, a stylized drill hole is assumed to penetrate a waste package and continue to the saturated zone. The scenario therefore serves both to disrupt a waste package prematurely, and to provide a reasonably enhanced pathway to the saturated zone.
DOE developed the human intrusion scenario for the TSPA-SR to be consistent with existing guidance in the draft 40 CFR 197 (EPA99), the proposed version of 10 CFR 63 (NRC99), and the proposed version of 10 CFR 963 (DOE99a). The implementation of the regulatory requirements was conducted in the TSPA-SR as shown in Table 3-6 (TRW00a). The central feature for treatment of these requirements was to be consistent with the more conservative of the proposed requirements from the draft regulations. Most notably, the intrusion is assumed to occur at 100 years, consistent with the proposed NRC requirement (NRC99). Intrusion at later times, when (consistent with EPA99) a waste package might reasonably be more degraded to allow an unrecognized drilling penetration, was treated as a sensitivity case study.

As illustrated in Table 3-6, similarities between the proposed 40 CFR Part 197 and the proposed 10 CFR 63 consist of

- the intrusion event is a single borehole that penetrates a waste container and continues to the saturated zone,

Table 3-6 Implementation of regulatory requirements in the TSPA-SR for regulatory requirements (Table adapted from TRW00a). Key differences between the NRC and EPA assumptions are indicated as underlined text.

NRC Base Assumptions (from Proposed 10 CFR Part 63)	EPA Additional and/or Conflicting Assumptions (from Proposed 40 CFR Part 197)	Conceptualization for TSPA-SR
Assumed intrusion is a drilling event.	Assumed intrusion is an acute and inadvertent drilling event.	Inadvertent drilling event.
Drilling result is a single, nearly vertical borehole that penetrates a waste package and extends down to the SZ.	Borehole penetrates a degraded waste package, and extends to the SZ.	Single vertical borehole from surface through a single waste package to the SZ.
Intrusion occurs 100 years after closure	Intrusion time should take into account the earliest time after disposal that a waste package could degrade sufficiently that current drilling techniques could lead to waste package penetration without recognition by the drillers.	Intrusion occurs at 100 years (a 10,000 year intrusion time is examined in a sensitivity simulation).
Borehole properties (diameter, drilling fluids) are based on current practices for resource exploration.	Borehole results from exploratory drilling for groundwater. Borehole properties are consistent with current practices.	Borehole diameter consistent with an exploration groundwater well.
Borehole is not adequately sealed to prevent infiltrating water.	Natural degradation processes gradually modify the borehole, the result is no more severe than the creation of a groundwater flow path from the crest of Yucca Mountain through the potential repository and to the water table.	Infiltration and transport through the borehole assumes a degraded, uncased borehole, with properties similar to a fault pathway.
Hazards to the drillers or to the public from material brought to the surface by the assumed intrusion should not be considered.	Only consider releases through the borehole to the SZ; consider releases occur gradually through air and water pathways, not suddenly as with direct removal.	Groundwater is only pathway considered.
A separate consequence analysis is required, identical to the performance assessment, except for the occurrence of the specified human intrusion scenario.	Unlikely natural processes and events are not included, but analysis could include disturbances by other processes or events that are likely to occur. Separate consequence-only analysis.	Intrusion borehole is applied to nominal case; effects of volcanism are not included.
Peak dose is not to exceed 25 mrem/yr. in the first 10,000 years.	Peak dose is not to exceed 15 mrem/yr. In the first 10,000 years.	Does not affect simulations.

- doses to the driller are not considered,
- doses are evaluated only for gradual processes occurring at the repository, and
- borehole properties are consistent with current technical practices.

The primary differences between the two proposed regulations are

- different dose criteria (15 vs. 25 mrem/yr), and
- the time of intrusion (100 years vs. a credible time for unrecognized penetration).

The DOE approach presented in Table 3-6 was to be consistent with the proposed regulations where they are consistent, and to consider both proposed regulations where they differ.

The approaches used in TSPA-SR for evaluating these conditions are shown in Table 3-7. The analyses are based on a representation of an exploratory drilling intrusion, which leads to disruption of a waste package and an enhanced pathway through the unsaturated zone. The saturated zone and biosphere analysis are the same as in the nominal scenario.

3.7.2 Results of the TSPA-SR

The results of the TSPA-SR show the following characteristics. The results are composed of the combination of the nominal scenario and two igneous scenarios. The dose curves from these scenarios are weighted by their probabilities so they can be combined, as shown in Figure 3-2. These curves are then intended to be compared with proposed dose criteria, which are also shown in Figure 3-2. Human intrusion is treated as a separate scenario, which is not combined with the results from the nominal and igneous scenarios.

The nominal scenario produces nil dose values during the compliance period (<10,000 years). The only significant doses associated with the nominal scenario occur in the post-compliance period (>10,000 years). This is the result of complete containment of the waste by the design-basis engineered barrier system during the first 10,000 years.

TRW (TRW00a) states that doses in the first 2000 years after closure are dominated by the eruption scenario. From 2000 years until after 10,000 years, the doses are dominated by igneous intrusion followed by releases to ground water from the magma-disrupted waste packages. After

Table 3-7 Technical Assumptions Implemented in the Human Intrusion Scenario in TSPA-SR (Table excerpted from TRW00a).

Issue	Key Component Affected	TSPA-SR Implementation
Borehole diameter	Infiltration Borehole Transport	Typical water well borehole has a diameter of 20.3 cm (8 in.)
Infiltration into borehole	Infiltration	Assumed infiltration rate distribution is based on modeled infiltration in the Yucca Mountain region for the glacial transition climate. Values at the high end of the distribution inherently include the possibility of surface water collection basin focusing.
Seepage into penetrated waste package	Infiltration Waste Mobilization	Volumetric flux is equivalent to infiltration rate times borehole area. Volume of drilling fluid is ignored.
Type of waste package penetrated	Waste Mobilization	Sampled from CSNF and co-disposed waste packages. Co-disposed packages contain both DSNF and HLW glass.
Thermal and geochemical conditions in waste package	Waste Mobilization	Assume temperature and in-package chemistry as calculated in nominal scenario. This assumes Well J-13 water and ignores any chemical effects of the drilling fluid.
Waste form degradation	Waste Mobilization	Waste in penetrated package is assumed to have perforated cladding from drilling disturbance.
Solubilization of radionuclides in water	Waste Mobilization	Infiltrating water can mix with waste in entire waste package. Solubility is based on temperature and in-package chemistry as in nominal scenario.
Borehole flow and transport properties	Infiltration Borehole Transport	Volumetric flux consistent with seepage into the waste package. Transport properties consistent with a UZ fault pathway.
Borehole location	Infiltration SZ Transport	Random over the footprint of the potential repository. Uncertainty in location is captured in infiltration rate and location that radionuclides enter the SZ.
Borehole length	Borehole Transport	Borehole length from the potential repository to SZ conservatively assumes water level consistent with glacial transition climate.
SZ	SZ Transport	Assume SZ flow and transport properties identical to nominal scenario.
Biosphere processes	Biosphere	Assume exposure pathways and receptor characteristics identical to nominal scenario.

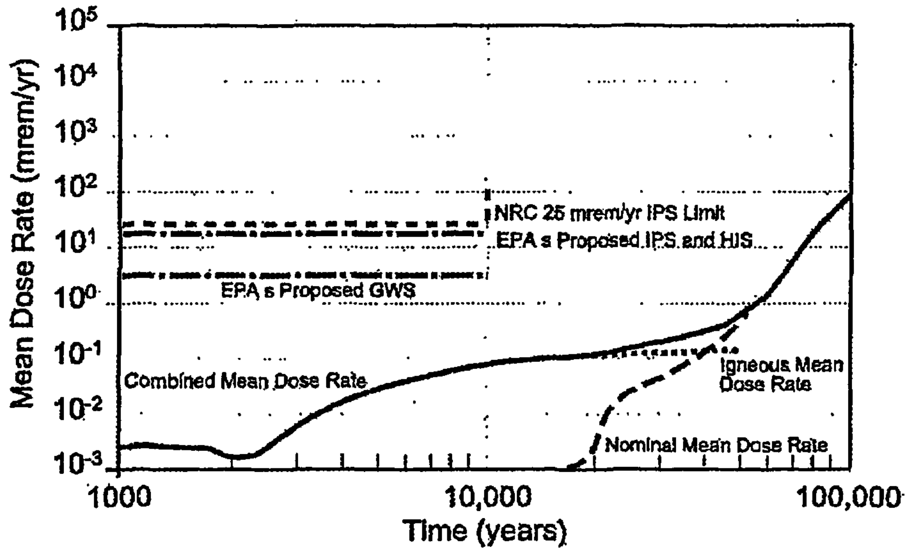


Figure 3-2 Comparison of Proposed Radiation Protection Standards with Expected Values of TSPA-SR Calculations for a Repository at Yucca Mountain for Nominal and Igneous Scenarios (Figure adapted from TRW00a).

10,000 years, the doses curves are a more complicated function of the probability weighted doses from each of the three scenarios (nominal, eruption, and intrusion).

In all cases the mean dose rate from the combined scenarios is substantially less than the regulatory standards over 10,000 years. In addition, analyses presented in the TSPA-SR (TRW00a) show that none of the TSPA realizations exceeded any of the proposed regulatory criteria during the 10,000-year compliance period. As discussed in Section 3.7.1 above, the results within 10,000 years are likely to be extremely conservative because of the conservative treatment of igneous activity. Modified assumptions for repository behavior during interaction with magma have the potential to eliminate all calculated doses in the first 10,000 years.

It is interesting to contrast these results with earlier TSPA results presented in the TSPA-VA (DOE98). In the TSPA-VA, doses in the period less than 10,000 years were dominated by artificially introduced juvenile failures of the waste containers from manufacturing defects. These early doses have been eliminated in the TSPA-SR through a combination of an improved waste package design, and improved, more realistic modeling of juvenile failures associated with the new design. However, in the assessments of doses within 10,000 years these juvenile failures from manufacturing defects have been replaced in the TSPA-SR by juvenile failures associated with the igneous scenarios, with their associated assumptions about early complete destruction of the waste containers, and very conservative assumptions for eruption characteristics.

Mean dose-rate results from the human-intrusion scenario are presented in Figure 3-3. As discussed in Section 3.7.1, the base case represents a conservative assumption of intrusion at 100 years, in keeping with NRC guidance (NRC99). Mean dose-rate results from a sensitivity case are also shown on the figure, in which the intrusion occurs at 10,000 years in keeping with EPA guidance (EPA99). The mean dose rate is not significantly higher at 100 years than at 10,000 years. The mean dose rate is well below proposed regulatory standards at all times.

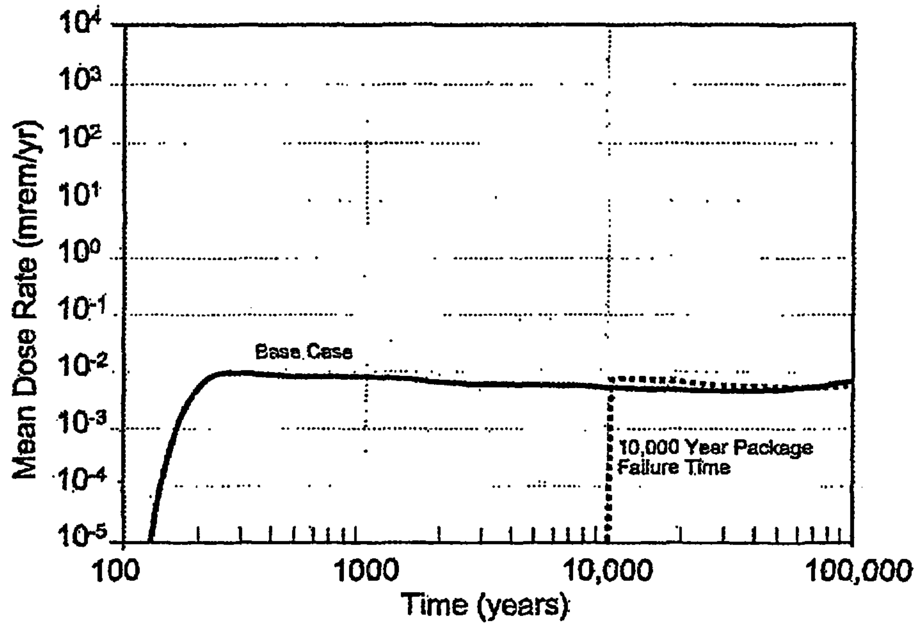


Figure 3-3 Expected Values of TSPA-SR Calculations for a Repository at Yucca Mountain for the Inadvertent Human Intrusion Scenario (Figure adapted from TRW00a).

3.8 DOE's Current Program Costs

The cost figures in Table 3-7 reflect DOE's most recent estimates (DOE01a) for both historical costs for the repository program to the year 2000, and projected costs through the closure and decommissioning phases. These cost estimates are adjusted to a common basis of constant dollars at year 2000. Table 3-7 retains DOE's cost estimates that were presented in the Viability Assessment documents (DOE 98) for site characterization work, since comparable detail for these expenditures were not given in the newest cost estimates.

Cost figures indicate that the combined cost of the EDA II design waste package and drip shield fabrication is estimated at $13.2 Billion. Emplacement costs for the waste package and drip shields is estimated at an additional $8.2 Billion (DOE01a, pg3-10), giving a total cost of implementing this component of the EDA II design of $21.4 Billion. This sum is considerably higher than the cost of planned additional site characterization investigations and reflects DOE's choice to use enhanced engineering to reduce or eliminate uncertainties in the behavior of the natural barrier.

As discussed in Chapters 4 and 5 of this document, overly conservative assumptions included in performance assessment scenarios produce dose projections that will be considerably higher, by orders of magnitude, than what should be expected for more realistic assessments. Typically, performance assessment analyses are deliberately framed with conservative assumptions. This is done to provide a measure of confidence that the assessments represent a conservative, and perhaps "worst case" analysis so that the acceptability of the disposal system's projected performance can be evaluated with a greater public acceptance and a fundamentally conservative performance case for the licensing process. Counterbalancing this conservative assessment bias must be a recognition that excessive conservatism in framing performance scenarios can lead to design choices which may be significantly more "robust" than necessary to provide a reasonable expectation of satisfactory performance. Greatly increased costs can result if the conservative bias in framing performance scenarios is taken to excess. Chapters 4 and 5 of this document discuss the evolution of DOE's performance assessment approaches for the Yucca Mountain repository, and the conservatism incorporated in them, as well as the contrast between these performance scenario assumptions and the "reasonable expectation" approach inherent in the Agency's standard.

Table 3-7. Estimates of Costs for the Yucca Mountain Program[4]

1. Historical Total, Mined Repository FY 1983-2000 (DOE01a TSLCC, pg. 1-2):			$8.2 B
2. Complete Work to License Application (DOE01a TSLCC, pg. 1-3):			0.8
3. Details of Completion Work, FY 1999-2002 (DOE98, Vol.4, Table 6-2)			
Site Investigations (total)		$189.2 million	
Nye County	$15.6 million		
SZ data analysis	3.4		
SZ modeling	2.2		
Repository Design		296.5	
Performance Assessment		63.6	
Finalize analyses	8.3	-	
EIS		64.1	
Site Recommendation		2.9	
Licensing		76.6	
Field Operations		106.1	
Other Support		277.3	
Financial Assistance		61.8	
		1138.1	
4. Repository (2003-2119) (DOE01a, pg. 3-8)			36.3
Licensing (2003-2006)		$1.3 billion	
Pre-Emplacement Construction (2006-2010)		4.4	
Emplacement Operations (2010-2041)		19.7	
Monitoring (2041-2110)		6.0	
Closure and Decommissioning (2110-2119)		4.0	
		36.3	
5. Design Options to the VA Repository			13.2
Drip Shields and Backfill Fabrication (DOE01a, pg. 13-2)			
6. Total Program Cost (2001-2119) (DOE01a, pg. 3-8), billions:			$36.3
7. Total Repository Cost (DOE01, pg. 1-2) $49.3 B + Historical Costs $8.2 B			$57.6B

At present, as shown in Table 6-2 of Volume 4 of the VA report, the planned costs associated with the SZ for work up to the License Application are as follows:

[4] Costs from the Total System Life Cycle Cost Estimate (DOE01a) are in constant year 2000 dollars.

4.0 EVOLUTION OF PERFORMANCE ASSESSMENT AND BARRIER ROLES

This chapter summarizes and evaluates the repository system performance assessments that have been conducted by the Yucca Mountain program. Results of recent performance assessments demonstrate that the current repository design is able to meet, by a large margin, a 15 mrem CEDE individual-protection standard and the ground water protection and human-intrusion standards.

This section presents and discusses performance assessment results that have been conducted by DOE for Yucca Mountain. It also discusses conservatism in the models and assumptions that led to the assessment results, and alternative results that might be obtained through selection of alternative dose receptors or repository designs. The sub-sections of this chapter examine DOE's performance assessments to date and the use of conservatism in the definition of the performance scenarios and their analysis.

There will always be uncertainties inherent in modeling the interaction of the natural and engineered components of the repository system over the long time frames involved in projecting the repository's performance, and the performance projections are always subject to these uncertainties. Uncertainties should not always be assumed to mean the repository performance will be worse than quantitative estimates indicate, but it is always desirable to reduce uncertainties to the extent possible and practical. To reduce uncertainties, the DOE repository effort could elect to enhance the repository engineered components to reduce or eliminate the potential effects of the uncertainties, or expend additional effort to characterize and model the interaction between the natural and engineered systems more realistically to remove overly conservative assumptions used in prior assessments. The results of the assessments described here indicate that the repository design evolution was not driven by the components of the EPA standard, but rather by the uncertainties in the interaction of the natural and engineered systems at the repository site, as well as the very conservative approach taken in framing the performance scenarios in the DOE performance assessments.

4.1 Performance in Comparison with the Proposed Individual-Protection Standard

The TSPA-SR included a comprehensive TSPA effort, and was intended to be a complete demonstration of the ability of the system to meet proposed technical requirements. The TSPA-SR performance evaluations used a complex system of linked computer codes to model the performance factors; and used a suite of highly conservative assumptions concerning performance of the engineered features of the repository as the basis for the performance models. Most notably, the TSPA-SR assumed violent disruption of the repository by strombolian igneous intrusion, leading to complete destruction of waste packages contacted by the magma. As discussed in Section 3.7, both the existence of strombolian activity at Yucca Mountain and the subsequent behavior of the magma in contact with waste packages are questionable, and are likely to be extremely conservative. Modification of any of the key assumptions associated with the igneous scenarios would likely lead to negligible releases from the repository in the 10,000-year performance period.

The TSPA-SR represents the latest step in an evolution of the TSPA of Yucca Mountain. The earlier TSPA-VA methodology and assumptions were used to produce the performance assessment results presented in the DEIS for a repository at Yucca Mountain (DOE99). A key point is that the TSPA-VA analyses of the anticipated conditions (nominal scenario) were generally more conservative than those in the TSPA-SR. Despite this additional conservatism, the TSPA-VA was able to meet all applicable and proposed standards for Yucca Mountain. Consequently, TSPA-VA results for the nominal scenario continue to be relevant as a conservatively biased representation of Yucca Mountain performance relative to current understanding and the current EDA II design. Furthermore, this means that conclusions made in the DEIS regarding the ability of Yucca Mountain to meet performance objectives are still correct and appropriate.

Minor modifications to the TSPA-VA models were made for the DEIS evaluations in order to accommodate the DEIS options that were considered (e.g., alternative areal mass loadings and alternative waste quantities disposed), but the intent for the DEIS performance evaluations was to use the same basis used for the TSPA-VA evaluations. The DEIS included estimates of radionuclide concentrations in ground water that can be compared with EPA's ground water protection standards, discussed in Section 4.2.

The uncertainties in performance of the EDA II repository are also significantly less than those for the VA repository; as previously discussed, and as illustrated in Table 3-5, the EDA II design features were selected specifically to reduce performance uncertainties as well as to improve the margin between expected performance and the regulatory standard.

In summary, it is evident that the expected performance in TSPA-SR is significantly better than that of the VA repository; this is the result of design features specifically selected to improve expected performance and to reduce uncertainties in expected performance. Furthermore, improved model rigor and supporting data have eliminated consideration of juvenile failure mechanisms that led to early releases in TSPA-VA. Currently, the only credible mechanisms for release from the repository in the performance period are associated with igneous activity. As discussed earlier, this scenario is treated with extreme conservatism. A more reasonable treatment of igneous activity would likely lead to negligible releases from this scenario.

The proposed EPA individual-protection standard of 15 mrem/yr at 10,000 years and 20 km therefore is not controlling or forcing DOE's approach to repository design. As discussed in Section 3, the evolution of the repository design, performance assessment methodology, and performance assumptions has been driven by factors other than the EPA IPS standards.

4.2 Performance in Comparison with the Proposed Ground Water Protection Standard

In the DEIS for Yucca Mountain, DOE calculated and reported ground water concentrations of radionuclides released from a repository at Yucca Mountain. The evaluations used the VA design and modeling methods and were, therefore, as previously noted, highly conservative, i.e., they overstate the expected concentration by several orders of magnitude. Furthermore, they overstate expected concentrations with respect to the current EDA II design and the TSPA-SR results.

The results of the DEIS concentration evaluations for the radionuclides released during periods up to 10,000 years and transported to locations at 5, 20, and 30 km downstream from the repository are summarized and compared to the current (1976) Maximum Concentration Limits (MCLs) in Table 4-2. The DEIS concentration values are strongly influenced by the assumed juvenile waste package failure at 1,000 years and by assumptions of limited dilution during transport. As a result of the assumptions that maximize the amount of release from the repository and minimize dilution during transport, the radionuclide concentrations shown in Table 4-2 are much higher than would reasonably be expected with more realistic assumptions for the performance scenarios.

Table 4-2. Comparison of DEIS Ground Water Radionuclide Concentrations With MCLs

Radionuclide Contributors to 10K-Year Dose	Current (1976) MCL, in pCi/L	Mean Conc. for 85 MTU/acre*, 5 km 20 km 30 km	95th Percentile Conc. for 85 MTU/acre, 5 km 20 km 30 km	Mean Conc. for 25 MTU/acre, 5 km 20km 30 km	95th Percentile Conc. for 25 MTU/acre, 5 km 20 km 30 km
Tc-99	900	45 30 10	390 84 130**	17 7.3 4.5	1.9 14 6.3
I-129	1	0.13 0.07 0.04	0.57 0.12 0.20	0.10 0.50 0.02	0.40 0.15 0.0
C-14	2,000	2.1 1.1 0.64	8.2 1.8 3.1	1.6 0.79 0.40	5.6 5.9 0.21

* The 85 MTU/acre thermal loading is the VA design value. The DEIS Proposed Action corresponds to the VA design, but the DEIS also considered options of 60 and 25 MTU/acre.

** The apparent inversions of concentrations with distance are a consequence of the modeling methods used for the DEIS performance evaluations.

As can be seen in Table 4-2, the concentrations reported in the DEIS for the TSPA-VA repository are well below the current MCL values despite the conservative assumptions and design that are the basis for the performance calculations.

As shown above in Section 3.7, no radionuclide releases from the EDA II repository would be expected during 10,000 years unless it is violently disrupted by volcanic activity. The results for the EDA II design from the TSPA-SR for comparison with the ground water protection MCLs are shown in Figures 4-1 and 4-2. The ground-water protection analyses assumed a representative water volume of 1285 acre-feet/yr centered on the highest concentration in the plume in the saturated zone. It was recognized in the TSPA-SR (TRW00a) that the regulatory time period for ground-water protection is 10,000 years. However, the analyses were carried out to 100,000 years to ensure that no significant degradation of the performance occurs after 10,000 years.

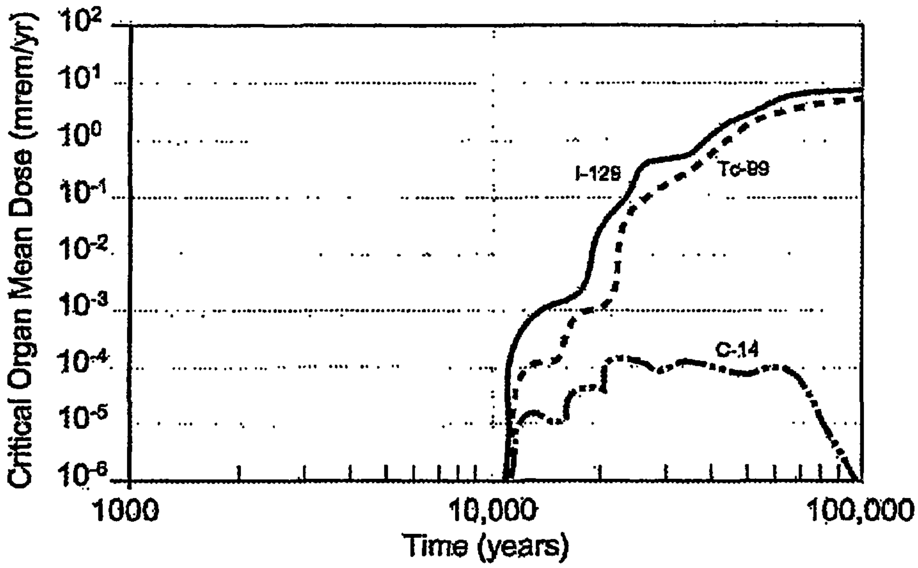


Figure 4-1 Summary of Groundwater Protection Performance Results of the TSPA-SR: Combined Beta and Photon-Emitting Radionuclides (Figure adapted from TRW00a).

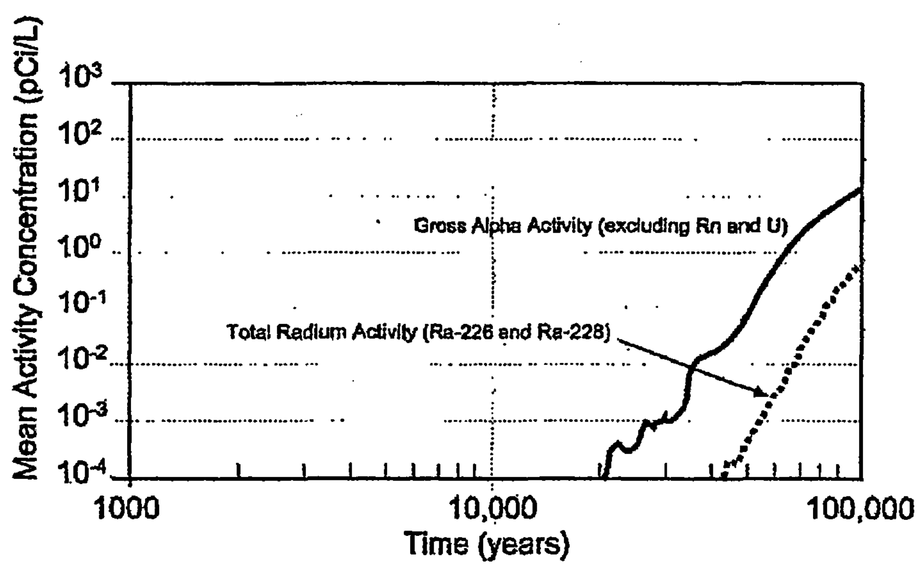


Figure 4-2 Summary of Ground-Water Protection Results for TSPA-SR for Gross Alpha Activity (Figure adapted from TRW00a).

The performance of the repository in the TSPA-SR is shown to be significantly improved compared to the performance presented in Table 4-2 for the TSPA-VA over 10,000 years. This dramatic improvement in calculated performance is the result of improved design and more credible treatment of the failure of waste packages.

Sequential analyses on several designs and using several TSPAs have been analyzed for comparison with current groundwater MCLs. These have included comparisons in the DEIS, TSPA-VA, and TSPA-SR. In the TSPA-VA the MCLs were met by a substantial margin, despite significant levels of conservatism built into model assumptions, which would increase the compliance margin to orders of magnitude if more realistic scenario and model assumptions were used. In the DEIS, the MCLs were met despite even more conservatism applied to the analysis. In the TSPA-SR, ground-water concentrations are projected to be zero for the first 10,000 years. The current ground water protection MCLs therefore are not expected to affect the repository design or costs.

4.3 Conservatism in the TSPA-VA, TSPA-DEIS, AND TSPA-SR Evaluations

As previously noted, DOE exercised considerable conservatism in the modeling methods and assumptions for the TSPA-SR dose projections. These assumptions were more realistic and less conservative than the earlier TSPA-VA approaches for the nominal scenario, but still retain a significant conservative bias. Both TSPA-SR and TSPA-VA reports, and their supporting technical basis documents, provide a comprehensive description of the modeling methods and assumptions. The DEIS states that the TSPA-VA methods and assumptions were used to produce the TSPA-DEIS results, except for minor modifications to accommodate the waste inventory and thermal loading options considered in the DEIS but not considered in the VA. Since the TSPA-VA has been shown to be more conservative than the TSPA-SR for the nominal scenario, the results and conclusions of the DEIS remain appropriate.

The strategic approach used by DOE for TSPA-VA, DEIS, and TSPA-SR modeling and assumptions can be summarized as follows:

- Values and distributions for natural system performance parameters such as water infiltration rates were as realistic as possible on the basis of data available at the time of the analyses. Uncertainties in these performance factors were so high that it would be difficult to identify and characterize conservatism for them; values for many of these parameters, such as dilution during transit of the saturated zone, were based, as necessary, on the results of expert elicitations.

- Biosphere dose-conversion factors were as realistic as possible on the basis of standard pathway parameters and local data on current human locations and activities such as farming.

- Some performance factors that could contribute significantly to deferral of radionuclide release from the repository, to reduction of release quantities, and to reduction of radionuclide concentrations in the biosphere were simply omitted from the performance model system if parameter values and distributions of values could not readily be established and defended. Such factors include dilution of radionuclide concentrations in water within a failed package, delays in radionuclide release from a failed package as a result of low water entry rates, and dilution of ground water concentrations at the dose receptor location as a result of pumping. Each of these factors will tend to either delay doses to later times, or to lower the peak dose.

- Conservatism was exercised for engineered barrier system performance parameters, for which a data and/or experience base exists and enables a characterization of conservatism. This implementation of conservatism is discussed below for specific performance factors: juvenile failures, crevice corrosion, water flow into the package interior, exposed waste form area, and in-package dilution and transport delays .

4.3.1 Assessment of Juvenile Failure

In the TSPA-VA, doses prior to 10,000 years were dominated by juvenile failures, specifically by the potential for weld failures associated with defects at emplacement despite rigorous inspection procedures. The potential for juvenile failures is inevitable, owing to the possibility for human errors in manufacturing, inspection, and emplacement. In the absence of such effects, the design basis lifetime for the waste package in the TSPA-VA was very long, and precluded releases during the first 10,000 years, with early corrosion failures limited to less than 20 waste packages out of a population of about 10,000 within 10,000 years (DOE98a, Volume 3, Fig. 4-13). In the TSPA-VA, therefore, the potential for these problems was treated using a conservative screening approach. The subsequent results therefore constituted a real-world worst case scenario.

Penetration of a single waste package was assumed in the TSPA-VA base case to occur at 1,000 years as the result of a phenomenon such as failure of a bad weld. The TSPA-VA assumed entry and exit holes form at the same time. Seepage was assumed to enter the package, since the entire waste package was assumed to be wetted. These assumptions provided essentially an instantaneous high release rate, which is an unrealistic and very conservative treatment of weld-failure effects. The penetration was assumed to result in immediate release of radioactivity from 1.25% of the cladding. This single package failure assumption contributed about 50% of the base-case 10,000-year dose rate of 0.04 mrem/yr. For this juvenile failure to occur, water would have to drip directly onto a bad weld. Absent this juvenile failure assumption, penetration of a waste package wall was not be expected to occur sooner than about 4,000 years, and penetration at that time would occur only if crevice corrosion occurs.

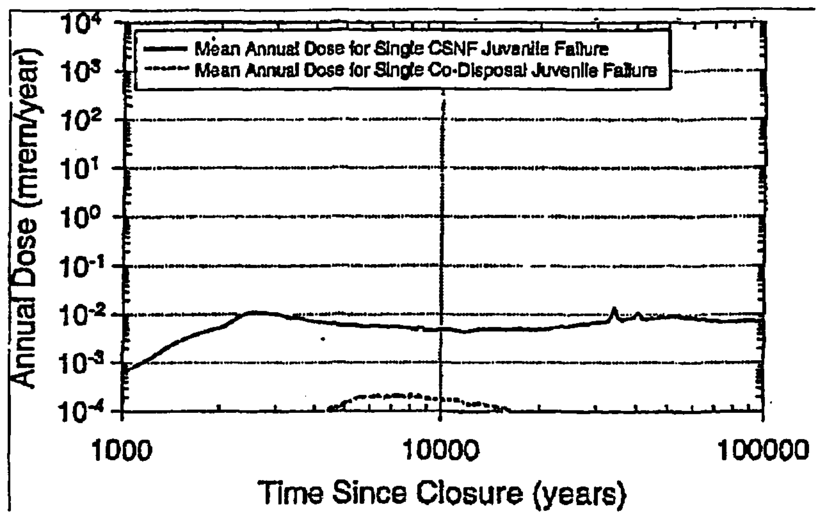


Figure 4-3 Estimates of the Consequence of an Artificial Juvenile Failure.

This mode of failure was determined to lack credibility for the design used in TSPA-SR. Instead, juvenile failures were evaluated using a more elaborate model of the corrosion of the EDA II design system accounting for the likelihood of technical, administrative, and inspection failures and their distribution at the waste package surface. As discussed in Section 3.7, the resultant treatment of corrosion remains quite conservative in its treatment of the details of the corrosion mechanisms (e.g. hydrogen absorption, stress corrosion cracking, crevice propagation).

In addition, sensitivity analyses were conducted to assess introduction of an artificial juvenile failure (TRW00) at 100 years for the EDA II design. This assessment is not based on any known mechanism, and *is not considered to be a credible occurrence.* It was evaluated solely for the purpose of evaluating extreme behavior in the system and investigating the role of the waste package in system performance. In addition, the release mechanisms associated with this juvenile failure were, as discussed above, treated in a very conservative manner leading to rapid releases from the waste package. Hence, this analysis represents a comparable approach to the manner in which waste package failure was treated in the TSPA-VA. Results of this juvenile failure are shown in Figure 4-4. Even in these extreme conditions of unrealistic failure behavior at very early times, the resulting doses are not large.

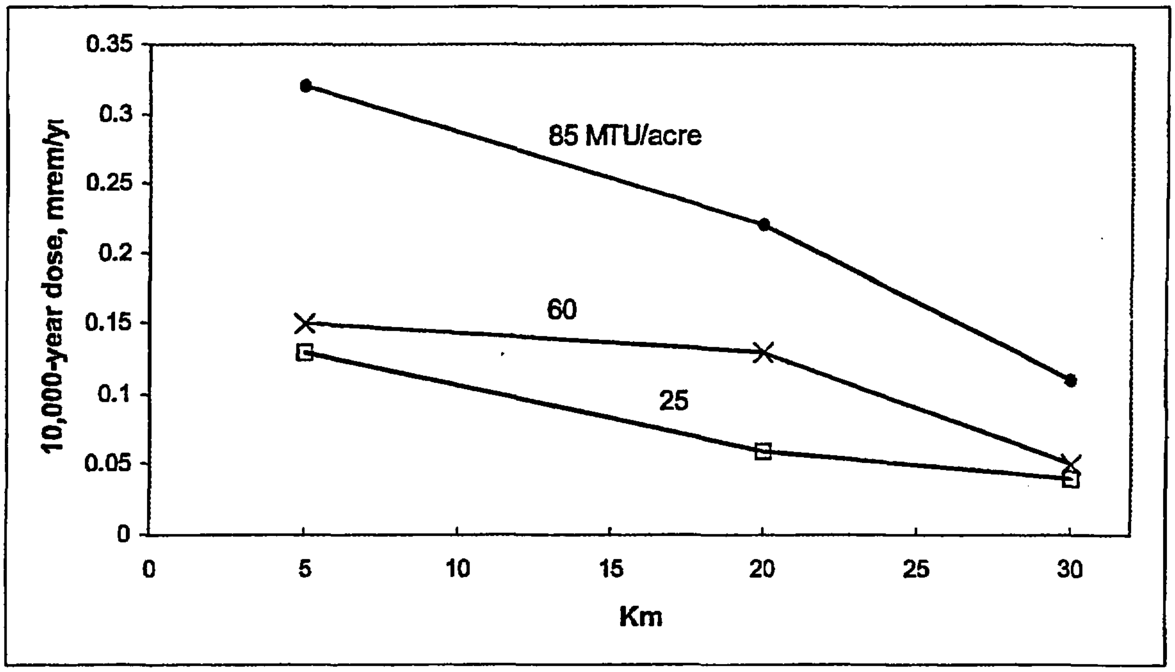


Figure 4-4. 10,000-Year Dost Rates for Alternative Areal Mass Loadings (compiled from DOE 99)

4.3.2 Local Crevice Corrosion of Alloy 22

Early penetration of the corrosion-resistant Alloy 22 waste package was assumed in the TSPA-SR to occur as a result of crevice corrosion, which produces a local pit-type penetration. The Alloy 22 is assumed to be potentially vulnerable to crevice corrosion as a result of water dripping directly on it from a point in a failed drip shield. The electrochemical conditions for crevice corrosion are not expected to occur in the repository (TRW00a). This is a significant modification from the TSPA-VA design and analysis, in which crevice corrosion initiated as a result of its being under a carbon steel outer wall. As a result of this design modification, crevice corrosion of this type no longer plays a significant role in early waste package failures. Consequently, in the TSPA-SR the waste packages fail either as a result of manufacturing defects or by general corrosion. The net effect of this change in mechanism is a significantly longer expected lifetime for the containers, with juvenile failure becoming far less important than in the TSPA-VA.

4.3.3 Water Flow Into the Package Interior

The amount of water that enters the interior of a penetrated package and can contact the exposed waste form depends on the precipitation rate onto the top of the mountain, the fraction of the precipitation that infiltrates into the mountain, the fraction of the infiltration flow that arrives at the repository horizon as percolation flux, the fraction of the percolation flux that seeps into the drifts, the extent to which the surface of a waste package contacted by seepage flow is wetted, and the fraction of the waste package surface area that is open, as a result of corrosion, to permit seepage water to enter the interior.

Key elements of the TSPA modeling of these performance factors included the following:

- Precipitation and infiltration as a function of location in the repository footprint were characterized, for current climate conditions, using available site characterization data.
- After 600 years, the climate is assumed to change to what was termed long-term average conditions, under which the precipitation and infiltration rates are approximately five times greater than for current climate conditions. This is a modification from the TSPA-VA, in which the change was assumed to occur 5,000 years in the future. The estimate of a 600-year initiation of this wetter climate state is argued in the TSPA-SR to be representative of past climatological cycles. However, EPRI (EPR00) has suggested that this assumption does not adequately account for greenhouse effects on climate over the next few hundred years. They argue that greenhouse effects may well lead to a drier climate over a significant length of time.

- The total percolation flow at the repository horizon is assumed to be the same as the infiltration flow, i.e., there was no holdup or lateral diversion during flow through the unsaturated zone above the repository horizon. Current data do not appear adequate to justify alternatives to this assumption.

- The portion of the percolation flow that was in fractures is assumed to be available to seep into drifts.

- The surfaces of waste packages contacted by seepage flow into the drifts are assumed to be totally wetted. This assumption may well be overly conservative at low flow rates.

- Seepage water that contacts and wets a waste package was assumed to enter the package interior in proportion to the fraction of the waste package surface area that is open as a result of corrosion.

- A seepage flow model was developed in which, under current climate conditions, about 5% of the waste package inventory would be contacted by seeps into the drifts, and the seepage flow contacting each package would be on the order of 10-20 liters per year. Under long-term average climate conditions, about 25% of the waste packages would be contacted, and the seepage flow onto each waste package would be on the order of 100-200 liters per year. It was stated in the TSPA-VA that there "...is a great deal of uncertainty about seepage, particularly in the fraction of waste packages contacted by seepage." In addition, as discussed previously, there is recent evidence that the threshold for seepage may be much higher (200 mm/yr) than the threshold used in the TSPA-SR. Indeed, while the value of 200 mm/yr is treated as an extreme minimum value in the TSPA-SR analysis, this value was obtained in field data for the middle nonlithophysal unit of the Topopah Spring Tuff (DOE01, pg 4-92). Applying a higher threshold value would significantly increase the amount of time before the packages are wetted.

Within this modeling framework, the assumptions concerning infiltration, percolation, and seepage rates constitute conservative conditions based on currently available information. These assumptions are likely to more strongly influence the timing of the release than the potential peak. However, by delaying the release sufficiently, doses in the first 100,000 years may be dramatically decreased using alternative assumptions.

The assumption that the entire surface of a waste package that is dripped on by seepage water is wetted and therefore susceptible to aqueous corrosion is highly conservative. It is reasonably to be expected that only water that drips onto a narrow band of the top of the package (e.g., at most a 20-degree arc of the 180-degree arc of the top half of the package) has real potential to initiate aqueous corrosion. To totally wet the package surface, such drips, (which could occur, according to the seepage model, at a maximum rate of 10-20 liters per year under current climate conditions), would have to spread uniformly over the package surface, which has a total area of about 40 square meters. This situation would produce a water film only about 0.2 millimeters thick, which is an unrealistic condition to produce and sustain the Alloy 22 corrosion that is presumed to be the mechanism for waste package failure.

4.3.4 Exposed Waste Form Area

For commercial spent nuclear fuel (CSNF) waste packages, which are the dominant (by two orders of magnitude) source of radionuclide releases in the TSPA-VA analyses, the exposed waste form area that can be a source of released radionuclides is related directly to the status and performance of the CSNF cladding as a barrier. The TSPA-SR analyses assumed that 8% of the cladding will be failed at the time of emplacement owing to creep failure and stress corrosion cracking. The TSPA-SR noted that "this mean percentage is very conservative and likely above the amount of creep and SCC that the NRC will tolerate of operators of dry storage facilities." The stainless-steel-clad rods were assumed to be distributed among the waste packages, and the entire CSNF area in any failed rod was assumed to be exposed for contact with water. Zircaloy cladding degradation by general corrosion and other means such as crushing by rockfall was assumed to be a long-term phenomenon of no significance to 10,000-year dose estimates.

The assumptions concerning CSNF exposed area are highly conservative. Specifically:

- Stainless-steel-clad fuel rods will not be distributed throughout the waste packages except as a result of deliberate effort. Less than 1% of the CSNF assemblies have fuel rods with stainless-steel cladding, and they probably would actually be disposed together in less than 1% of the total waste package inventory, in order to reduce personnel exposures and operating costs.

- The estimate that 8% of the Zircaloy-clad fuel rods are failed at the time of emplacement is very conservative in comparison with available data. The observed historical incidence of failure is less than 0.05%, is perhaps as low as 0.01%, and is confined to fuel manufactured in the early days of nuclear power or subjected to external failure factors such as debris in the reactor coolant. Fuel yet to be discharged from operating reactors (about 50% of the ultimate repository inventory) can be expected to have no failures, so the incidence of at-emplacement rod failure in the final repository inventory will be significantly less than the historical incidence to date and significantly less than the incidence assumed for the TSPA analyses.

- In over 90% of the cases, "failure" of Zircaloy cladding has been found, in post-service examinations, to consist of pinhole penetrations or hairline cracks. Therefore, only a very small fraction of the fuel contained in a failed rod will be exposed as a source of released radionuclides if contacted by water. In contrast, the TSPA evaluations assumed that the entire spent fuel area in a fuel rod would be exposed for contact with water and release of radionuclides. This assumption overstates the exposed area, based on available data, by about three orders of magnitude.

- Many potential modes of Zircaloy cladding degradation, such as hydride formation and creep failure, have been identified and characterized because cladding integrity is so important in its reactor service conditions. EPA has performed and documented a comprehensive review and analysis of available information and has concluded that degradation of cladding by any of the failure mechanisms is not expected to occur under repository conditions after emplacement for disposal. The exposed waste form area will therefore be that which exists at emplacement for disposal until very long-term failures, such as package crushing by a rockfall, occur (SCA99).

Collectively, the TSPA-SR assumptions concerning exposed waste form area overstate the area available for nuclide release by about four orders of magnitude (i.e., three orders of magnitude on the exposed area per failed rod, and a factor of ten on the number of failed rods). They also overstate the potential for long-term degradation of the cladding. If realistic assumptions concerning performance of the EDA II repository are used, water would not contact the cladding for more than 100,000 years, and cladding performance would be irrelevant to dose potential before that time. Cladding performance will, however, be important to estimation of long-term peak doses. In comparison with the preliminary estimate of peak dose of 85 mrem/yr at 650,000 years for the EDA II repository (Table 4-1), a realistic estimate of cladding performance and exposed waste form area would decrease the peak dose estimate by several orders of magnitude.

It is important to note that assumptions concerning cladding performance as a barrier and the amount of waste form area exposed for radionuclide release are essentially independent of assumptions concerning performance of engineered features of the EDA II design. The link between the EDA II design features and cladding performance is the design temperature limit for the cladding. This limit is the same, 350 degrees C, for both the VA and EDA II designs, and the expected actual maximum cladding temperature in both designs is about 250 degrees C. The 8 percent failure rate used in the TSPA-SR was acknowledged to be very conservative. It represents a mean value for failure rates at low (177-227 C) temperature. However, DOE also report the mode of this distribution as about 2 percent. Hence the mean appears to be skewed to a high value by a few outlier high values (the maximum value is 19.4 percent). With "blending" of subassembly allocations to the waste packages in order to reduce thermal gradients, confidence in assumptions concerning cladding performance that are less conservative than those used for the TSPA evaluations would be increased.

In summary, the TSPA evaluations are highly conservative regarding cladding performance in comparison with reasonable interpretations of the available information base. Assumptions of exposed waste form area exposed for nuclide release for each failed fuel rod exceed actual exposed areas by about three orders of magnitude; assumptions concerning the number of Zircaloy-clad failed rods exceed the actual number by about a factor of 10. A realistic approach to these assumptions based on principles of Reasonable Expectation is described in Section 5. Nonetheless, despite these highly conservative assumptions, releases from the waste packages do not occur within 10,000 years according to the TSPA-SR. Modification of these assumptions may, however, improve long-term dose estimates for times greater than 10,000 years.

4.3.5 In-Package Dilution and Transport Delays

If water enters a penetrated waste package at the seepage rate or some fraction thereof, significant delay could occur before the water contacts exposed CSNF and initiates radionuclide release. For example, if the package interior fills slowly from the bottom up (as a result of trickle-down from a small hole in the top and needs first to corrode through basket materials), and if the exposed CSNF area(s) are in a subassembly near the top, thousands of years could pass before contact between the water and the exposed waste form occurs.

Subsequent to water/waste contact, released radionuclides that are mobile must be transported to the point of exit from the package interior by advective and/or diffusional processes. By the time release and transport occur, temperature gradients will be too low to drive significant advective transport processes, and temperature levels will be too low for inside-to outside wall corrosion to occur and to create an exit path at the bottom of the package. Consequently, radionuclide transport rates will be low, the package interior will have to fill with water in order to enable radionuclides to exit through the same penetration that provides water ingress, and the volume of water to fill the package interior will be available to dilute the radionuclide concentrations.

The void volume of the interior of a 21-assembly PWR waste package is about 3,000 liters. If water enters and exits the packages at rates in the range 6 to 400 liters per year, which corresponds to the seepage rate range for the TSPA-SR long-term-average climate conditions, at steady state and with complete in-package mixing, the in-package dilution factor would be in the range 3,000/400 ~ 7 to 3,000/6 = 500. Additional dilution would then occur during transit of the near-field, the unsaturated zone, and the SZ by the contaminated water that exits the package. Such dilution mechanisms may be particularly important for radionuclides not limited by theor elemental solubilities, such as I-129.

These in-package delay and dilution possibilities were considered and analyzed in the studies described in the TSPA-VA Technical Basis Document (DOE98a). They were not, however, included in the base-case performance assessment models for TSPA-VA and TSPA-SR because of uncertainties, and an inability to justify the assumptions. If included in the models, they could have reduced the predicted TSPA-VA 10,000-year dose by one to two orders of magnitude, depending on how probabilities for the relevant performance factors are taken into account.

To incorporate these performance factors into the TSPA models, it would have been necessary to develop probability distributions for factors such as time elapsed between water entry to the package interior and time of water contact with the exposed waste form. DOE chose to develop probability distributions many of the performance factors external to the packages, but chose to omit the in-package performance factors and associated probability distributions, from the TSPA models. It is worth noting that the in-package performance factors are potentially as important to the TSPA results as climate change and seepage rate. It is reasonable, for example, to expect, at a minimum, some degree of dilution of contaminant concentrations in water exiting a waste package as a result of mixing with nearby water in the near field and the UZ.

As for the role of exposed waste form area in performance of the EDA II repository, the in-package performance factors will not be important to evaluation of 10,000-year doses if realistic assumptions concerning performance of the EDA II drip shields and waste packages are used, such as has been done in TSPA-SR. The in-package performance factors could, however, help to show that long-term peak doses will be low in the period after 10,000 years. Specifically, penetration of the EDA II waste packages will occur so far into the future that there will be virtually no thermal driving force for radionuclide release and transport in the waste package interior. Mixing and homogenization of concentrations within the waste package would have to be driven by diffusional processes.

4.4 Radiation Doses to Alternative Receptors

To date, eleven alternative dose receptors have been identified by DOE, the NAS, NRC, EPRI, and EPA as the potential basis for evaluating compliance with individual-protection standards for Yucca Mountain. The options include alternatively-characterized individuals and critical groups. Each has, to some degree, taken cognizance of site-specific conditions and each has, to some degree, utilized ICRP principles for designating a group or individual receptor, e.g., to base assumption of the future receptor's habits on present-day habits. Each also seeks to identify and characterize the receptor with the highest dose potential, without being extreme, in order to assure protection of other individuals.

DOE's TSPA-VA, DEIS, and TSPA- SR used the so-called "average resident" as the dose receptor. This individual was located 20 km from the repository, and had habits corresponding to those of current residents, as determined in a survey performed by DOE. The TSPA-VA states that this person consumes part of his food from local sources and consumes 1.8 liters per day of drinking water contaminated with radionuclides released from the repository, at the maximum contaminant plume concentration. The DEIS, which was stated to use the same TSPA evaluation methodology as the VA, states that the average resident receptor consumes 2.0 liters of contaminated water per day. The TSPA-SR states that the average-resident receptor in Amargosa Valley consumes slightly more than 2.0 liters of water per day (753 L/yr), and this value is used in the assessment. With this water consumption rate, the DOE's average-resident is essentially equivalent EPA's proposed "rural residential" RMEI dose receptor.

Results of the DOE's average-resident dose evaluations at 10,000 years, based on the assumptions and methods described above in Section 3.7, can be summarized as follows:

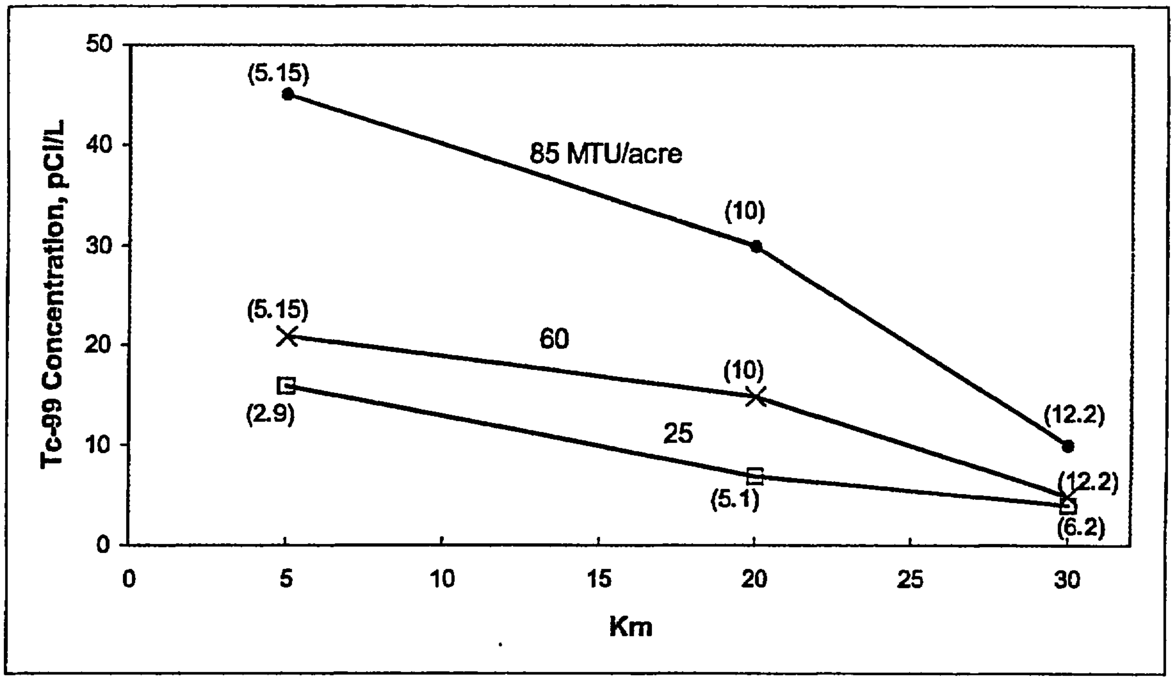
- TSPA-SR mean all-pathways dose (using probabilistic evaluations) is 0.10 mrem/yr. This value is the same as the mean value at 10,000 years for the TSPA-VA. However, this agreement is fortuitous, as entirely different scenarios are associated with the dose. For the TSPA-VA, the dose was associated with juvenile failures of waste packages that were unrealistic and gave high releases. The TSPA-SR treats these juvenile failures more realistically, and these failures do not affect pre-10,000 year doses int he TSPA-SR. By contrast, in the TSPA-SR the dose at 10,000 years is associated with igneous intrusion, with subsequent releases to ground water. This scenario appears to be highly conservative, giving unrealistically high releases as well.

- VA base-case dose using an evaluation with all parameters set at their expected values: 0.04 mrem/yr. A similar result is not reported for TSPA-SR. Instead, the range of doses at 10,000 years is about 10^{-4}-10^{0} mrem/yr (5th to 95th percentiles), with the mean about 10^{-1} mrem/yr and the median about 10^{-2} mrem/yr.

- DEIS mean all-pathways dose for the Proposed Action, which corresponds to the VA repository: 0.22 mrem/yr (this result presumably differs from the VA result of 0.10 mrem/yr because of modeling adjustments made for the DEIS evaluations in order to be able to address the DEIS options concerning waste inventories and thermal loadings).

Since the DOE's average resident corresponds to EPA's proposed rural residential RMEI, these results are representative of the results that would be obtained using the EPA's rural-residential RMEI at 18 km as the receptor and the TSPA-SR methodology and assumptions. As previously noted, and discussed in Section 3.7, these results overstate the dose to be expected as a result of the conservative assumptions used in the evaluations.

The DEIS also evaluated doses to the average resident at alternative locations and for the alternative areal mass loadings considered. Results are shown graphically in Figure 4-4; corresponding Tc-99 concentrations in ground water, and assumed saturated-zone dilution factors at each distance, are shown in Figure 4-5. Variations of I-129 concentration with location and areal mass loading are similar to those for Tc-99, but I-129 concentration levels are about two orders of magnitude less than those of Tc-99.



The MCL for Tc-99 is 900 pCi/L. Numbers in parentheses are the dilution factors used at each distance.

Figure 4-5. Tc-99 Concentrations for Alternative Mass Loadings
(compiled from DOE99)

The reason for dose variation with areal mass loading is not evident from available documentation. For example, repository temperatures, which would affect corrosion rates, are virtually identical for the 85 and 60 MTU/acre loadings during the period from 1,000 to 10,000 years, while the repository temperatures for the 25 MTU/acre loading are about 40 degrees C less (DOE99). Similarity of results for the 85 and 60 MTU/acre cases might therefore be expected; Figures 4-3 and 4-4 show, however, that the results for 60 and 25 MTU/acre are most similar. Also, Figure 4-4 does not show any correlation between SZ dilution factors and distance from the repository.

The variations of dose with areal mass loading may be the result of differences in repository areas and attendant differences in transport and dilution in the unsaturated zone. The 85, 60, and 25 MTU/acre repositories, for the reference inventory of 70,000 MTU of wastes, occupy 740, 1050, and 2,520 acres, respectively. The 60 MTU/acre repository occupies two emplacement blocks and the 25 MTU/acre repository is spread over several emplacement blocks.

Transport and dilution in the UZ may therefore have been modeled differently for the three loading options.

While the DEIS evaluated doses for the same receptor at alternative locations and for alternative repositories, the VA characterized doses for alternative receptors. The VA reported dose evaluation results for only the average resident as receptor, but it also characterized doses for a subsistence farmer receptor and a so-called residential farmer receptor. All food and water ingested by the subsistence farmer was assumed to be contaminated; only part of the food consumed by the residential farmer was assumed to be contaminated. DOE's surveys found no current residents who correspond to either of these receptors. The characterizations determined, however, that the Np-237 biosphere dose conversion factor (BCDF) for the residential farmer would be three times greater than that for the average resident, and the BCDF for the subsistence farmer would be about six times greater. The I-129 BCDF for the subsistence farmer was stated to be about 10 times greater than that for the average resident. The VA also stated that the most important factor for doses due to I-129 and Tc-99, which are the only radionuclides of significance released in the 10,000-year time frame, is leafy vegetable consumption, and that direct consumption of contaminated ground water contributes about 50% of the dose.

In addition to these earlier treatments, the critical group receptors evaluated in the TSPA-SR are subject to exposures to contaminated ash in the eruption scenario.

The NRC defines a critical group as the dose receptor in the proposed 10 CFR Part 63 regulations for Yucca Mountain. The critical group is described as residing within a farming community located approximately 20 km south of Yucca Mountain. Members of the group would have characteristics that are consistent with current conditions and that result in the highest expected annual doses. The group would be a farming community of up to 100 individuals residing on 15 to 25 farms. The behaviors and characteristics of the average member of the critical group would be based on the mean value of the group's variability range.

The average member of the NRC's critical group would be predicted to incur less dose than either the DOE average resident or the EPA's rural residential RMEI, and this choice of dose receptor would therefore be less protective of the general population. Less dose would be predicted for two principal reasons: the dose conversion factors for the NRC critical group would be based on mean values of the dose factors, whereas the EPA's RMEI uses maximum values for one or more of the dose factors (e.g., drinking water rate); and the members of the farming critical group would be so spread out that only a fraction of the group would use contaminated water at the maximum concentration. The current average size of an alfalfa farm, which is the dominant farming activity, is about 255 acres; in the most compact configuration, a square, 25 farms of current average size would occupy an area more than three miles long on each side. The VA shows (p.3-137 of Volume 3) that the contaminant plume width is only about 1 mile at 20 km distance from the repository. Many of the members of the NRC's critical group would therefore in reality receive no dose or significantly less than the maximum dose, so that the average would be unrealistically low. Groundwater flow systems dominated by fractured rock hydrology would be expected to produce narrow contamination plumes (see the BID for descriptions of the fracture-flow dominated hydrological system at the Yucca Mountain site.)

If 25 average-size alfalfa farms are located 20 km from the repository (e.g., at Lathrop Wells), the number of farms that intercept the plume at that distance will depend on how the farms are located relative to each other. If the farms are in an east-west line, only one farm would intercept the plume; If the farms are adjacent to each other in a square, at most five farms would intercept the plume. If the farms are in a north-south line, some of the farms would extend beyond 30 km from the repository, i.e., beyond the current Amargosa Farms area (SCA00, Yucca Mountain Docket No. A-015-12, V-B-3).

In summary, the dose receptors considered in DOE's TSPA-VA and TSPA-SR are similar to the EPA's RMEI as described in the rule, and may actually be somewhat more conservative. For instance, the TSPA-SR assumes slightly more than the 2 liters/day drinking water consumption specified in the rule. Dose estimates in both of these TSPAs are well below the 15 mrem/yr individual protection limit, despite the use of very conservative assessment scenarios and models. Based on these considerations, the EPA's choice of an RMEI rather than a critical group for the dose receptor does not have any impact on repository development costs or progress. As described above, the proposed farming community critical group potentially makes assessment defensability more difficult and subject to challenge, owing to the requirement for arbitrary assumptions on the size and location of farms. These may not necessarily be consistent with current and projected land use in the area, so as to ensure that all members of the critical group receive some level of exposure.

4.5 Alternative Means to Reduce Uncertainties and Doses

As noted in Section 3.4.1, principal objectives in selecting the EDA II design as the basis for the Site Recommendation were to improve the real performance potential of the repository and to reduce uncertainties in projections of performance. The benefits of the EDA II design are illustrated in the differences between dose projections in the TSPA-VA and the TSPA-SR, which shows that projected doses for the EDA II repository up to 10,000 years are substantially less than those for the VA repository. Indeed, the EDA II design only produces doses in the first 10,000 years as a result of potential igneous activity. In terms of performance for the nominal behavior of the system, the improvement in performance over 10,000 years is extremely dramatic. As shown in Figure 3-2, the nominal case for the EDA II analysis exhibits no releases over 10,000 years.

Overall, it can be said that the objective of the EDA II design is to defer and reduce the potential for, and uncertainties in, thermally driven degradation processes such as corrosion and advective radionuclide transport. Alternatives to the EDA II design that address this objective are illustrated by the EDA options considered, from which the EDA II option was selected for the TSPA-SR (Table 3-3). Comparison of these options shows that they reflect widely different strategies for meeting the objective. For example, the EDA I option takes a direct approach by reducing the area mass loading and repository temperatures. The EDA V design takes the opposite approach: it drives the temperatures to high levels in order to greatly defer the time at which water can enter the repository and initiate high-rate degradation processes.

Other advanced repository designs which incrementally improve the VA design might have been identified and evaluated. For example, the waste package design with the Alloy 22 on the outside could have been adopted with all other EDA II parameters except use of drip shields and backfill. This choice would have considerably increased waste package performance by eliminating the crevice corrosion process that greatly accelerated package failures in the VA design (17 packages failed by this mechanism within 10,000 years), thereby extending expected waste package lifetimes beyond 10,000 years. Another incremental design feature that could be added would be to tilt the packages along the axis at emplacement in order to have drips run off the surface, or to use weld shields rather than drip shields that cover the entire package. These are simple, inexpensive design features that could reduce the potential for juvenile failure and subsequent releases.

With respect to the impact of juvenile waste package failures, their treatment in the TSPA-VA was extremely conservative and consequently releases from wsuch failures dominated doses within the 10,000 year period. In the TSPA-VA, an exit hole in a waste package was assumed to exist as soon as an entry hole was created. Under this assumption a juvenile failure from a manufacturing defect (weld failure) resulted in immediate releases into the waste package surroundings. In the TSPA-SR, a more realistic treatment of juvenile failures was incorporated, eliminating the extreme conservatism of the TSPA-VA treatment. These modeling changes, along with the move to an improved waste package design that eliminated the potential for accelerated failure associated with crevice corrosion, were sufficient to greatly improve the projected performance. Improving performance projections and reducing uncertainties could be done in a variety of ways, with cost impacts that vary according to the extent and nature of changes in the repository and waste package design, and according to increases in data needs for the assessment of performance.

Analysis results for the EDA options that are presented in Table 3-3 show that the options meet the objective to varying degrees and with different costs. In examining the performance factor results in Table 3-3, it is important to remember that these results were produced using the same performance models and conservative assumptions that were used to produce the TSPA-VA results. More realistic evaluations, using reasonable parameter values, models, and assumptions, would produce peak annual doses at least several orders of magnitude less than those shown in the Table. Realistic evaluations and assumptions that would lead to lower doses are discussed in Section 5, which addresses Reasonable Expectation.

To paint a realistic picture of repository performance potential, it is important to acknowledge the benefits of the design features in the models and assumptions used to make performance predictions. For example, the backfill/drip shield/waste package design features of the EDA II repository completely eliminate the real potential for juvenile waste package failures or corrosion-related radionuclide releases for 10,000 years and more. Similarly, assessments of long-term peak dose potential that use reasonably-expected parameter values and assumptions will show dose levels that are orders of magnitude less than those that have been reported to date, even without including performance factors such as in-package dilution that have been omitted from the model hierarchy to date.

In summary, the EDA II repository design, which is the basis for the TSPA-SR, is a highly conservative design with extensive redundancies that assure no radionuclide releases in the nominal scenario during 10,000 years. The design has enabled modifications to the TSPA models and assumptions that reflect the benefits of the design to repository system performance. The use of this robust design has allowed DOE to use a number of very conservative assumptions in its assessment. Modification of these assumptions to more reasonable, yet still credible, approaches would result in very significant delays in releases from the repository; there is the potential that modified assumptions would produce no significant calculated doses in the first 100,000 years.

4.6 Current Repository Design and Safety Strategy

As part of its program evolution to the TSPA-SR, DOE has recently revised its Repository Safety Strategy previously described in 1998 (DOE98d). The most recent description of the revised strategy and plans for its implementation is provided in TRW00.

The TRW00 Rev 3 strategy updates the previous version of the strategy (DOE98) which was the basis for the VA. It reflects the EDA II design (Section 3 of this document), which is the current stage of evolution of the repository design. The revised strategy also reflects recent additions to the program data base; response to the regulatory framework; and internal and external comments on the VA design and TSPA-VA methodology, and the eventual implementation as TSPA-SR. Under this strategy, the postclosure safety case is based on developments and evaluations in five principal areas: performance assessment; safety margin and defense-in-depth; consideration of potentially disruptive processes and events; insights from natural analogs; and long-term performance confirmation.

The design evolution (from the VA to EDA II) and the safety strategy evolution are intended to be responsive to the concerns about uncertainties and technical issues associated with the TSPA methodology and assumptions as it evolved from TSPA-VA to TSPA-SR. The approach will reduce potential difficulties during licensing reviews by reducing or eliminating the TSPA uncertainties and issues that would create difficulties in licensing reviews.

The EDA II design and the Rev 4 safety strategy are the latest step in evolution of the repository concept. Over time, as shown in Table 4-3, the relative contributions of the engineered and natural system features of the repository to overall performance have inverted: site characterization has shown that the natural features will not contribute nearly as well to performance as was expected in the SCP, and the performance of the engineered barriers has

Table 4-3. Change Over Time of the Roles of Natural and Engineered Barriers.in Repository System Performance

Project Era	Infiltration Rate	GWTT*	WP** Lifetime	EBS Features
SCP (1988)	1 mm/yr max	9K - 80K yrs	300 - 1,000 yrs	Thin-walled can, vertical in floor
Early TSPAs (1991-1995)	1 mm/yr max	9K - 80K yrs	Various designs, 300 ~ 10,000 yrs	Horizontal, robust WP considered
Viability Assessment (1998)	8-40 mm/yr now; 200 in superpluvial	As short as 50 yrs for fast paths in the UZ	Less than 20 packages fail within 10,000 years; 20,000 years for general corrosion	Horizontal WP used steel over Alloy 22
TSPA-SR (2001)	0.4-12 mm/yr now 4.7-20 in monsoon climate	Mean delay in UZ is 1,000 years and mean delay in SZ is 1,300 years	expect no radio-nuclide release for 10,000 + years	Alloy 22 on outside of WP; add drip shields

* GWTT = Ground Water Travel Time to the Accessible Environment
** WP = Waste Package

been increased dramatically to compensate for the lesser natural barrier performance expectations, and to respond to licensing requirements for defense in depth and minimization of uncertainties and technical issues.

Another facet of the Safety Strategy has been an extensive evaluation of parameter uncertainty and sensitivity. The TSPA-SR (TRW00a) reported three kinds of evaluations of parameter uncertainty and sensitivity: Uncertainty Importance Analysis, Sensitivity Analysis, and Robustness Analysis. *Uncertainty Importance Analysis* refers to the use of regression analyses to determine the most important parameter contributors to the spread of output results, and classification-tree analyses to determine the parameters leading to extreme outcomes in the distributions. *Sensitivity Analysis* refers to single-parameter sensitivity analyses, in which one parameter is varied while the others are held at particular values. *Robustness Analysis* (also referred to as Degraded Barrier Analysis in the TSPA-SR) refers to a focused approach to examining parameters associated with extreme degradation behavior of individual barriers, keeping intact the remaining analysis of the system.

Uncertainty importance analyses were performed beginning with stepwise linear rank regression analysis. The results of this analysis were evaluated using classification and regression tree analysis to determine decision rules that determine whether a particular realization would produce doses at the upper or lower end of the output distribution. These approaches were used to evaluate the spread in doses at a particular time and the spread of times needed to produce a particular dose. Particular attention was also focused on the extreme high end of the output distribution, to determine which parameters lead to the extremes of the output.

The uncertainty importance analyses showed that the waste package and saturated zone processes are the most important factors in the nominal scenario, whereas the probability of the occurrence of igneous disruption of the repository is the most important factor for igneous scenarios. As discussed in the TSPA-SR, the assessment that these are the "most important" in this uncertainty importance analysis reflects two factors: the change in variance of dose rate with variance of the parameter, and the change of the dose rate itself with changes in the parameter. If either of these two derivatives is small, the techniques used in the TSPA-SR will tend to show the parameter to be unimportant.

Sensitivity analysis, as used in the TSPA-SR, refers to a single parameter variation method. This is considered to be a complementary technique to the uncertainty importance analysis. In this approach, a single parameter was ranged between its 5th and 95th percentiles, and other parameters were fixed at particular values.

Robustness analysis was conducted by setting a suite of parameters associated with a particular barrier at their 5th or 95th percentile, whichever tends to maximize the dose rate over the time period of interest. For the sake of completeness, the results are also shown compared to results from the same suite of parameters set at the opposite end of the behavior (i.e., values which tend to minimize dose consequences). The intent of these robustness analyses is to present the behavior of the system as a whole if any part of the system degrades quickly, and functions according to its extreme behavior. Robustness analyses were conducted on nine facets of system behavior (TRW00a):

- UZ. This barrier represents the function of the UZ above the potential repository in limiting the amount of water that reaches the potential repository. This barrier includes the climatic conditions at Yucca Mountain, the processes at and near the surface that lead to infiltration, and flow through the UZ above the potential repository. Parameters treated in the robustness analysis were the seepage-uncertainty factor and the flow-focusing factor. Degraded conditions for these parameters resulted in a small increase in dose rate over the base case.

- Seepage into emplacement drifts. This barrier represents the function of the drifts themselves as a capillary barrier that limits the amount of water that enters the drifts. Both infiltration and seepage parameters were set to their degraded behavior for this analysis. Degraded conditions for these parameters resulted only in about a factor of 5 increase in dose rate over the base case.

- Drip shield. The first of the engineered barriers, the drip shield limits the amount of water that reaches the waste package. In the robustness analysis, the general corrosion rate parameters were set to their extreme values. While the drip-shield lifetime is significantly degraded in this analysis, there is almost no change in the dose rate. This results reflects the fact that the waste package degradation model is independent of the drip shield function. This appears to be an example where the high degree of conservatism in one model masks the importance of a different function, as discussed in TRW00a.

- Waste package. The primary engineered barrier, the waste package limits the amount of water that reaches the waste form and limits radionuclide transport out of the EBS. Degradation parameters considered in the robustness analysis were: residual hoop-stress state and stress intensity factor at the closure-lid welds, Number of manufacturing defects at the closure-lid welds per waste package, Alloy-22 general corrosion rate, microbially-induced corrosion enhancement factor for general corrosion, and enhancement factor for Alloy-22 general corrosion from aging and phase stability. The enhanced case (optimistic parameters) led to no releases from the waste package for the first 100,000 years. The degraded parameters show a somewhat earlier failure profile, with first failure occurring at 7,000 years compared to 12,000 years for the base case. For the degraded case there is 50 percent probability that 1 percent of waste packages fail at about 10,000 years and 10 percent of waste packages fail at about 12,000 years. For the base case it is about 25,000 years for the 1 percent failure and about 50,000 years for the 10 percent failure. Accordingly, the predicted mean dose starts earlier (about 8,200 years versus about 15,000 for the base case), and the predicted mean dose rates are much higher.

- CSNF cladding. The Zircaloy cladding is an engineered barrier that is part of the waste form. It limits the amount of water that reaches the CSNF portion of the waste and limits radionuclide transport out of the CSNF waste form. (CSNF is planned to be approximately 90 percent of the mass of waste in the potential repository.) Four of the five parameters in the cladding degradation model were evaluated in the robustness analysis: the number of rods initially perforated in a CSNF waste package, the uncertainty in localized corrosion rate, the uncertainty of the CSNF degradation rate, and the uncertainty in the unzipping velocity of the cladding. It was concluded that these parameters are unimportant for performance in the first 100,000 years, but that they contribute to the spread of doses during the period 100,000-1,000,000 years. The effect of these parameters on dose rate in the robustness analysis is not reported by TRW00a.

- Concentration limits. This barrier represents the function of environmental conditions and radionuclide solubility limits in limiting radionuclide transport out of the EBS. The primary dose contributor in the first 30,000 years is technetium-99. The solubility of Tc-99 is assumed to be large (1 M), and is not treated as uncertain. The primary radioelements for the period after 30,000 years are neptunium, americium, and uranium. The solubilities of each of these is controlled by pH in the TSPA-SR model. The pH, in turn, is assumed to not vary widely in the invert. This limits the variability of the dose rate as a function of any other factors in the near-field model. In particular, TRW00a notes that most of the releases are by a diffusive mechanism, hence controlled by diffusion-related parameters. This too appears to be an area in which a strong structural conservatism of the model (in this case the assumed diffusional releases) tend to mask the importance of other effects.

- EBS transport. This barrier represents the function of environmental conditions and diffusion in the drift invert in limiting radionuclide transport out of the EBS. In this case of the robustness analysis, the combined effects of degraded concentration limits and high diffusion cases. The results are reported as a decrease in the time to early-arrival doses (defined as time to 10^{-3} mrem/yr) of several thousand years, and an increase in the peak dose rate of about a factor of 5.

- UZ transport. This barrier represents the function of the UZ below the potential repository in delaying radionuclide transport to the biosphere. An extensive set of robustness analyses were presented for this function. The degraded cases showed between a factor of 5-10 higher dose rates than the base case, whereas the enhanced cases showed significantly improved behavior (many orders of magnitude) over the base case. That is, since the base case is little different than the degraded case but vary different than the enhanced case, this means that the base case is strongly biased toward the conservative end of the spectrum of behaviors.

- SZ. This barrier represents the function of the SZ in delaying radionuclide transport to the biosphere. The robustness analysis was used to investigate parameters associated with travel time in the saturated zone: sorption, and flow rate. The difference between degraded and enhanced performance in these analyses is between one to two orders of magnitude, with the base case very close to the upper end of this variability. Again, this indicates a strong bias toward conservatism in the base case.

The TSPA-SR explicitly acknowledges that the results of these analyses are dependent upon the scenarios and conceptual models implemented in the TSPA-SR. They note that the conservatism of parameter values and assumptions may tend to mask the importance of some of these to the results, or may mask the importance of others. Two of these situations were noted above in the discussion of robustness analysis: the conservatism of the drip shield treatment masks the importance of the waste package behavior, and the assumption that diffusion dominates releases together with an assumption of high solubilities tends to mask the importance of other phenomena in the waste package. These assumptions therefore compound the conservatism of the analysis, since they are, by themselves, conservative, and they also minimize the functional importance of other barriers.

The strong reliance on evaluations of parameter sensitivity and uncertainty analyses skews the evaluation of the TSPA-SR results. Instead, the model is in some cases so structurally biased toward conservatism that appropriate conclusions cannot be drawn. For instance, one conclusion of the TSPA-SR is that the primary factor influencing the consequences of the igneous scenarios is its probability of occurrence. All other parameters investigated in the sensitivity analysis were found to have relatively minor influence on the dose from igneous disruption. However, as discussed previously, such a conclusion ignores the heavy conservative bias of the consequence modeling assumptions. Given the extremely conservative basic assumptions of the consequence model, one would not expect parameter variations to significantly affect the results. By contrast, changes in the basic assumptions about interaction of magma and waste containers could decrease releases and their associated doses by orders of magnitude, or eliminate them altogether. Similarly, the use of a model for release from the waste package in the nominal scenario that assumes diffusion in the absence of significant amounts of water near the package, results in a significant conservative bias. This assumption and associated model masks the importance and utility of the presence of the drip shield. The lack of significance of the drip shield in the TSPA-SR nominal case is therefore seen to be an artifact of the conservative bias of the waste package release model, rather than a fundamental property of the repository.

The reliance on evaluations of parameter uncertainty illustrates (potentially deceptively) small uncertainties in relatively high consequences associated with the repository. Uncertainties in parameters, as shown by the robustness analyses, lead to at most about an order of magnitude increase in dose rate under unfavorable conditions. Application of favorable sets of parameters were shown to potentially decrease the dose rate by several orders of magnitude in some cases, and to push the doses out to much longer times, in some cases past 100,000 years. By contrast, uncertainties in assumptions (conceptual model uncertainty) have the potential to lead to dramatic improvements in consequence analyses. Alternative conceptual models for the igneous scenarios have the potential to lead to minimal or zero releases from these effects, thus eliminating the consequences associated with igneous activity. Alternative conceptual models for the waste package in the nominal scenario would likely show early releases at much later times, perhaps with minimal release in the first 100,000 years. In addition, the use of less extreme assumptions may lead to a better understanding of the effects of design features such as the drip shields. Consideration of these less conservative, yet defensible and physically realistic, models is consistent with the principles of Reasonable Expectation (see Chapter 5), as well as with the concept and intent of Importance Analysis (KOZ97).

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5.0 EPA'S "REASONABLE EXPECTATION" APPROACH TO REPOSITORY PERFORMANCE PROJECTIONS

This chapter discusses the reasonable expectation and reasonable assurance as concepts to be used in implementing the standards. We believe the reasonable expectation approach is more appropriate for repository compliance determinations and provides a more realistic link between design and anticipated performance in the iterative process of developing a repository design for licensing.

5.1 Overview of Reasonable Expectation

The impact of the EPA standards on repository design and data collection is complicated by the fact that NRC will adopt and implement the standards, as mandated by the NWPA. The NRC is therefore the agency that determines what is needed to comply with the EPA standards. The method of implementation of the standards then becomes a deciding factor in evaluation of compliance. This chapter discusses the issue of compliance methodology, i.e., reasonable expectation versus reasonable assurance.

The proposed EPA standards call for use of "reasonable expectation", rather than "reasonable assurance" as a basis for assuring compliance with the EPA standards. Reasonable expectation and reasonable assurance are both compliance assessment approaches and can be distinguished as discussed below. In brief, the intent of reasonable expectation is to recognize the inherent uncertainties involved in repository safety performance evaluations, and to encourage realistic treatment of the uncertainties in performance assessments and evaluations of compliance with the disposal standards. Reasonable expectation takes what might be termed a realistic or best-value approach to dealing with uncertainty in performance projections when compliance issues are complicated by uncertainties imposed by extrapolations of data and projections of performance over long time periods. Reasonable assurance is a concept used in the licensing of facilities which involve only short term extrapolations of performance.

In developing a repository design, there is an iterative process between design and performance assessment that evolves over time to a final design and compliance calculations that are presented for licensing. A process that recognizes and deals realistically with inherent uncertainties would offer an efficient approach to optimizing design and performance.

The proposed 40 CFR Part 197 standards require that DOE demonstrate compliance with the individual-protection, human-intrusion, and ground water protection standards under principles of "reasonable expectation." The proposed standard states, at §197.14, that reasonable expectation requires less than absolute proof, because absolute proof is impossible to attain for disposal due to the inherent uncertainty in projections of long-term performance. The proposed rule also states that Reasonable Expectation (RE) focuses performance assessments and analyses upon the full range of defensible and reasonable parameter distributions rather than only upon extreme physical situations and parameter values.

The Preamble to the proposed 40 CFR Part 197 describes RE and its use as follows:

- *In carrying out performance assessments under a "reasonable expectation" approach, all parameters that significantly affect performance would be identified and included in the assessments. The distribution of values for these parameters would be made to the limits of confidence possible for the expected conditions in the natural and engineered barriers and the inherent uncertainties involved in estimating those values. Selecting parameter values for quantitative performance assessments would focus upon the full range of defensible and reasonable parameter distributions rather than focusing only upon the tails of the distributions as is more commonly done under the "reasonable assurance" approach. The "reasonable expectation" approach also would not exclude important parameters from the assessments because they are difficult to quantify to a high degree of confidence.*

5.2 Prior Consideration and Use of Reasonable Expectation

Reasonable expectation is the basis for evaluation of compliance with the Subpart B and C standards in EPA's 40 CFR Part 191 (amended at 58 FR 66414, Dec. 20, 1993), and is implemented in 40 CFR Part 194, the criteria for certification of WIPP (61 FR 5224, February 9, 1996). Use of the concept was upheld by the U.S. Court of Appeals, First Circuit, in its decision concerning the suits brought against the EPA for the 40 CFR Part 191 standards issued in 1985. The Court stated, in its decision:

- *Given that absolute proof of compliance is impossible to predict because of the inherent uncertainties, we find that the Agency's decision to require "reasonable expectation" of compliance is a* *rational one. It would be irrational for the Agency to require proof which is scientifically impossible to obtain. Any such purported absolute proof would be of questionable veracity, and thus of little value to the implementing agencies. Nor can we say that this provision is arbitrary and capricious because it will afford the implementing agencies a degree of discretion, since such imprecision is unavoidable given the current state of scientific knowledge. Thus we are again faced with a decision that is within the Agency's area of expertise and on the frontiers of science, and, as such, we refuse to substitute our judgment for that of the Agency.* (824 F.2d 1258 (1st Cir. 1987, at page 1293)).

The use of reasonable expectation is the same in 40 CFR Part 191 and 197. Part 191 states, at §191.15, Individual-Protection Requirements,

- *Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, through all potential pathways from the disposal system to any member of the public in the accessible environment to exceed 15 millirems (150 microsieverts).*

The proposed individual-protection standard for Yucca Mountain is stated, in §197.20, as

- *The DOE must demonstrate, using performance assessment, that there is a reasonable expectation that for 10,000 years following disposal the reasonably maximally exposed individual receives no more than an annual committed effective dose equivalent of 150 microsieverts (15 mrem) from releases from the undisturbed Yucca Mountain disposal system. The DOE's analysis must include all potential pathways of radionuclide transport and exposure.*

5.3 Comparison of Reasonable Expectation and Reasonable Assurance

Reasonable expectation can be compared to reasonable assurance, used by the NRC in licensing of nuclear power reactors and other engineered fuel cycle facilities. In engineered facilities licensed by the NRC, parameter values usually lie within a narrow range around an expected value which is well known as a result of testing and experience, and the range itself will be based on actual testing and experience. For example, testing multiple samples of an alloy to measure the brittle fracture strength will result in a mean value with a small range of variability.

For reactors, the projected performance of engineered components of the facilities can be verified during their in-service lifetimes, which are only a few decades long. Consequently, the extrapolation of laboratory testing results over the relatively short reactor operating lifetime allows confirmation of the projections. This "real time" verification has been a part of the licensing experience for power reactors. Extrapolation of important natural processes in reactor licensing is limited to predictions of seismic hazards which in practice is done only for short periods of decades.

In contrast, repository performance projections involve the extrapolation of natural processes and events, and laboratory performance testing of engineered materials over time periods of 10,000 years and beyond. Such extrapolations have to date been applied only to WIPP in EPA's certification of that disposal facility.

All engineered elements of a reactor are subject to performance verification, integrity of welds can be confirmed, quality of construction can be verified, and training of personnel can be confirmed. The NRC can, therefore, establish a measured pedigree for every factor important to system performance and can expect and require, to a very high degree of assurance, that the facility will operate as intended and expected. Principles and methods of reasonable assurance were developed to serve these circumstances. Transferring reactor licensing experience and expectations unaltered into regulatory decision making for deep geological disposal is not an appropriate adoption of reasonable assurance used for licensing of reactors and other fuel cycle facilities. In adapting the reactor-based reasonable assurance to the geologic repository application, NRC has adopted a weighted probabilistic approach to evaluate performance projections. This approach moves significantly toward a recognition of the inherent differences between reactor licensing and deep geological disposal (e.g., the difficulty in verifying long time frame performance projections). However, a probabilistic approach does not, by itself, unequivocally guarantee that repository performance projections will appropriately incorporate the inherent uncertainties in these projections in a way that is not excessively conservative.

In contrast to reasonable assurance, reasonable expectation takes into account, for long-term, deep geologic disposal, the fact that many relevant performance parameters cannot be clearly characterized as can those for an engineered facility with a forty-year lifetime. Specifically, many natural features important to repository performance cannot be extensively characterized, and many exhibit a high degree of inherent variability. In addition, performance characteristics of engineered features of the repository must be extrapolated well beyond the time period for which measurements can be made.

For example, ground water flow in the volcanic rocks in the vicinity of Yucca Mountain will occur primarily in fractures which have highly variable physical characteristics such as width, length, and connections to other fractures. Tests can establish characteristics of fractures for locations where the testing was done, but testing at various locations will produce different results, which can vary widely. (Reflecting these variations, yield from water supply wells located in fractured rocks can vary widely over short distances.) In addition, the hydrological behavior of a fractured rock system can change over time, as tectonic processes and seismic activity readjust the stress state in the area. Fracture networks could be enlarged, and their connectivity and flow behavior could be gradually altered either favorably or unfavorably over long time periods. In aggregate, thorough test results will produce a picture of what is a reasonable interpretation of the range of results, and this would be the basis for implementation of the concept of reasonable expectation. It would not be reasonable to base performance assessment models and parameter values only on results which show limited fractures and limited flow, or on results which show extensive fracturing and high flow rates.

A specific example for Yucca Mountain is the case of so-called bomb-pulse Cl-36 detected at the repository horizon in the Exploratory Studies Facility (ESF) (FAB98). These data indicate that there are pathways in the rock formations above the proposed repository horizon that can rapidly transmit infiltration water to the repository horizon in about 50 years; the pathways may extend to greater depths. However, the data showed that the bomb-pulse Cl-36 was present in only a small fraction of samples taken at the repository horizon, and these results could be correlated with well-known fractures (FAB98).

These results demonstrate that it would be reasonable to expect that some relatively small fraction of the entire UZ flow will occur via fast paths, and that modeling of UZ flow should take this into account. It would not be reasonable, however, to base the evaluation of UZ performance on fast paths alone. The reasonable expectation is that most of the UZ flow and radionuclide transport will occur in accord with the bulk characteristics of the UZ geohydrologic regime.

In comparison with the reasonable assurance concept, reasonable expectation accommodates the necessity for performance assessment results for a geologic repository to recognize the inherent uncertainties and limitations of characterizing the natural system. Performance models can be defined with as much mathematical sophistication as they are for reactors, and the analyses can be as analytically complex as they are for reactors, but some of the models and parameters used in repository performance analyses will inherently be less well defined than those used for reactors. This can lead to particularly difficult problems if parameters are expected to be measured to too high a degree of confidence, accuracy, or precision; in such a case, excessive conservatism may be applied in an attempt to offset the inability to meet these unrealistic data objectives.

The analyses should be based on reasonable models and reasonable parameter values, not biased toward extremes by unrealistically conservative assumptions and parameter value selections. This approach recognizes that uncertainty encompasses the high-end aspects of performance potential, as well as the worst-case potential.

5.4 Use of Reasonable Expectation for Yucca Mountain

Given the long time frame of the regulatory period for geologic disposal, the possibility that changes in the repository system will occur over time, and the fact that, unlike reactors, prediction with certainty of such changes and ability to remedy them is not possible, assumptions concerning the agents and means of change are necessary. Similarly, assumptions are needed concerning performance factors that are difficult or impossible to characterize reliably, such as the extent to which dripping water will wet the surface of a waste package. Reasonable expectation requires that assumptions are reasonable, rather than purely biased toward conservatism, and that performance factors that can be identified and potentially have a significant impact on performance be reasonably valued and not omitted from the models and evaluations simply because they are difficult to characterize. Consistent selection of conservative parameter values, and omission of beneficial aspects of performance, because accurate characterization is difficult, would result in unduly conservative performance assessments that represent situations of very low probability. Decision-making using such analyses would be unavoidably biased.

It is reasonable to expect, for example, that climate conditions in the future can be estimated and bounded on the basis of evidence of past and present climate conditions. It would be unreasonable, however, to assume that future climate conditions will be extreme in comparison with the past. Also, in implementing the NAS finding that future performance of geologic features can be bounded for periods up to one million years (NAS95), it would be reasonable to base the assumptions on reasonable, not extreme, interpretations of past processes and events. Similarly, it is not reasonable to assume that long-term changes will always be in the direction of worsening performance, and to exclude positive aspects of such changes.

One of the most important aspects of reasonable expectation is to make reasonable assumptions concerning performance factors that are difficult to quantify with confidence. There are numerous performance parameters that can contribute significantly to system performance, but are difficult to quantify accurately, such as the area of a waste package wetted by dripping water and the area of spent fuel exposed in a breached fuel rod. To establish a realistic characterization of the performance capability of the engineered barrier system, it is necessary to make reasonable estimates for these factors and to include them in the performance models. As discussed in Section 4.3, DOE used highly conservative assumptions for such factors in the TSPA-VA evaluations or omitted them from the models because they were difficult to quantify. Our studies have convinced us that the TSPA-VA results were consequently highly conservative and understated the performance potential of the disposal system by several orders of magnitude.

The effects of some of the TSPA-VA conservative assumptions on results of the TSPA-VA evaluations can be estimated as follows:

- Assumption that the waste package is as wide as the drift: conservative by a factor of three, since the package diameter is about one-third that of the drift.
- Assumption that the Alloy 22 is penetrated rapidly as a result of crevice corrosion: conservative by a factor of 25, since the crevice corrosion rate was assumed to be 25 times higher than the general corrosion rate. This assumption was subsequently modified to reflect the updated EDA II design, and this mode of degradation was eliminated from TSPA-SR.
- Assumption that stainless-steel clad fuel rods are distributed among all packages and fail immediately when the package is penetrated by water: conservative by about a factor of about 10, since these rods can be packaged together in about 1% of the total number of packages, and radionuclide releases were assumed to occur from Zircaloy-clad fuel rods as well as the stainless-steel clad rods.

- Assumption that 0.1 % of the Zircaloy-clad rods are failed at the time of emplacement: conservative by a factor of 5-10, since an extensive data base shows that 0.05%-0.01% are failed.

- Assumption that the entire waste form area in a failed fuel rod is exposed and leaches radionuclides when contacted by water: factor of 100 to 1,000; data show breaches of cladding are primarily small hairline cracks, and all evidence shows that no significant deterioration of cladding is expected after disposal.

Overall, many of the assumptions used in the TSPA-VA analyses can be shown, as illustrated above, to have understated the reasonably expected performance of the repository by at least three to four orders of magnitude. These arguments apply to the TSPA-VA, as a mechanism for illustrating the concept of reasonable expectation.

Consideration of reasonable expectation in the TSPA-SR evaluations for the EDA II repository design included the following:

- Use of a base case that is based on expected performance of the drip shields and the waste package. As shown in the TSPA-SR, under these conditions, no radionuclide releases would be expected for more than 10,000 years. Early waste package failures were treated as possible, but their likelihood evaluated probabilistically and shown to be unimportant in 10,000 years.

- Realistic estimates of seepage rates, the fraction of seeps that drip onto the drip shields and subsequently onto waste packages, and the fraction of waste package surfaces that is wetted. Realistic estimates can be based on emerging data which show that the seepage threshold may be as high as 200 mm/yr, i.e., 20 times higher than the estimate of current infiltration rates. These were not used in the TSPA-SR (a mean threshold of only 10 mm/yr was used), but may be included in future iterations of the TSPA.

- Realistic estimates of the rate and mechanisms of penetration of the waste package wall by corrosion. A rapidly growing data base for corrosion of the wall materials replaced the assumed values used in the TSPA-VA that were based on expert elicitation results.

- Improved estimates of the rate at which water can enter the waste package interior through wall penetrations were not used in TSPA-SR, but could be adopted for future iterations. Models of penetration blockage that were recognized for the TSPA-VA and TSPA-SR evaluations but not included in the models can be adopted. Modified assumptions for these effects would likely results in releases occurring at significantly later times than found in the current model.

- Realistic estimates of the time required to achieve contact between water that enters a waste package and the exposed waste form. As a result of low seepage rates and limited entry pathways, the elapsed time to fill the package interior and achieve water/waste contact can be tens of thousands of years.

- Realistic estimates of the duration and means for radionuclides mobilized from the waste form to transport within, and exit, the interior of the waste package. As discussed in Section 6.3, release of radionuclides from the package interior would be expected to be controlled by extremely slow diffusional processes. By contrast, the diffusional model included in the TSPA-SR is highly conservative, to the extent that the majority of the releases are by diffusion. Modification of these assumptions would lead to a qualitatively different type of release rate, in which significant releases would not occur until substantial breaching of the waste container would permit advective flow to dominate. Accommodating these alternative assumptions would likely delay releases from the facility for 10s of thousands of years.

- Realistic estimates of radionuclide transit times and concentrations for migration from the repository to the dose receptor location. The expanding data base for the UZ and SZ regimes should enable data-based estimates of UZ and SZ flow and transport.

- Realistic estimates of radionuclide concentration dilution associated with pumping by the dose receptor. As previously noted, this performance factor was omitted from the TSPA-VA and TSPA-SR evaluations. Realistic studies including those done by the NRC staff for the Issue Resolution Status Reports, indicate that the dilution factor for this performance factor could be in the range 10-50.

- Realistic estimates of the type of igneous activity expected in the Yucca Mountain region rather than extreme strombolian events could be incorporated in future TSPAs. Changing this assumption, by itself, may eliminate or greatly reduce the consequences of an entire scenario (eruption) from the dose results of the first 10,000 years, although not necessarily eliminating the occurrence of the igneous event.

- Realistic models of the contact between magma and waste packages, which account for temperature decreases, may eliminate all consequences from igneous scenarios. By accounting for these effects, the potential exists for the repository to be a zero-release facility during 10,000 years.

Implementation of these applications of reasonable expectation would be expected to predict that no radionuclide releases will occur until more than 10,000 years after disposal. In addition, long-term dose rates would occur at much later times, and be significantly lower than those published in the TSPA-SR.

In TSPA-SR, as discussed in Chapter 4, DOE has introduced a variety of "uncertainty importance" analyses, intended to investigate the extreme ends of output distributions. These analyses include regression analysis and classification tree analysis (TRW00a). Regression analysis involves conducting stepwise linear rank regression between total dose and all input parameters, to determine the strength of the relationship between parameters and the output they produce. Classification tree analysis is a method for determining which variables or groups of variables produce a particular category of results. In particular, this approach is used to look at extremes in the output range, and to categorize which input parameters are associated with those extremes.

Since these uncertainty importance analysis techniques are focused purely on parameter uncertainty, the degree to which they are consistent with the concept of reasonable expectation depends on the conservatism of the underlying models and scenarios expressed by the parameterizations they represent. For scenario and model representations that are reasonable representations of the expected phenomena, it may well be appropriate to investigate and act upon the boundaries of the output distributions. However, if the scenario and model descriptions themselves are highly conservative, then making decisions based on the extrema of the parameter distributions compounds the conservatism, and is not consistent with reasonable expectation. As discussed in Chapter 4, several examples of models in the TSPA-SR appear to be so conservative that they fall outside of the realm of expected system behavior, and the tails of the parameter distributions appear to compound these conservatisms.

The igneous scenarios in the TSPA-SR appear to be an example of compounding conservatisms. The annual probability of occurrence is highly uncertain, and one must look to the high end of the possible values for the probability to consider the scenario at all, based on NRC guidance on probability of scenarios (NRC99). The scenario description itself is for an extreme type of volcanic event in a location in which such events are highly unlikely. The model for magmatic interaction with the waste packages also takes extremely conservative assumptions, so that waste packages are entirely destroyed, and the radionuclides are mobilized as an extreme finely ground-up, easily dispersed powder. Despite these extreme assumptions, the central tendency of the output distribution associated with parameter uncertainty provides a probability-weighted mean dose of around 10^{-2} mrem/yr (see Figure 3-3 above). However, the distribution that produces this value includes a few realizations of very low probability with substantial doses. Figure 6.1-2 of TRW00a illustrates that a few realizations produce doses in excess of 10 mrem/yr in the first 10,000 years. The potential exists to use uncertainty importance analysis methods to identify conditions (input parameters) that lead to these high doses, and to use that information in decision making: for example, to seek design modifications to the repository to mitigate them. However, the concept of Reasonable Expectation would recognize that it is inappropriate to use the results of extreme values of parameters applied in an extremely conservative model in an extremely conservative scenario for prudent decision making. Similar, though less extreme, examples are possible to elaborate for the nominal scenario of TSPA-SR as well.

5.5 Impact of Implementation of Reasonable Expectation for Yucca Mountain

The concept of Reasonable Expectation was developed by EPA to recognize that "absolute proof" of repository performance projections can not be obtained in the commonly understood meaning of the term, because of the long time frames and inherent uncertainties of the extrapolations involved in projecting repository performance. The approach, however, is intended to encourage realistic assumptions and assessments of repository performance, which recognize these inherent limitations. "Bounding" approaches that exclude important processes which will affect performance because these processes are not readily quantified with high precision and accuracy, or that frame performance scenarios unrealistically, have the danger of disguising important aspects of the site performance. The effect of overly conservative analyses can be to drive repository design efforts to unnecessary extremes or to set performance expectations beyond what can be reasonably demonstrated with conservative but reasonable analyses.

As discussed above, the EPA standards for Yucca Mountain were developed under the concept of reasonable expectation. In examining the conservative basis for the TSPA-SR results, a reasonable expectation approach to framing the performance scenarios and assumptions indicates that expected performance would be orders of magnitude better than the TSPA-SR results. This difference would be more than enough to compensate for the uncertainties in the assessments.

We believe the reasonable expectation approach is more appropriate for repository compliance evaluations and provides a more realistic link between design and anticipated performance in the iterative process of developing a repository design for licensing.

6.0 COST IMPACTS OF THE STANDARDS IN THE RULE

Preceding sections of this EIA have provided perspectives on the evolution of engineered design features for a repository at Yucca Mountain; the evolution of understanding of the performance potential for natural features of the Yucca Mountain site; the relationship between engineered and natural barrier contributions to repository system performance; and the series of repository system performance assessments that have provided insights leading to the current repository design concept.

This section discusses the impact of the EPA's individual-protection standard, human-intrusion standard, and ground water protection standard on the costs of the Yucca Mountain program and the costs of the repository. Section 6.1 underscores the fact that individual-protection standards are fundamental to radiation protection, and that the costs for the Yucca Mountain program and repository design have evolved independent of the EPA IPS. Section 6.2 notes that the HIS is the same as the IPS, and that it imposes no incremental costs. Section 6.3 demonstrates that the GWS also imposes no incremental cost impacts.

In sum, the data and analysis requirements are the same for evaluating compliance with the IPS, HIS, and GWS standards, and the Yucca Mountain program, repository design, and costs have evolved without having been driven by the EPA standards.

6.1 The Individual-Protection Standard

As previously noted, the need for an individual-protection standard is fundamental to radiation protection in general and to protection of health and safety for deep geologic disposal of radioactive wastes. The issue here is not whether or not to have a standard; the issues are, What level of protection should be required, and is there a cost impact of a standard that is more stringent than an alternative? The choices under consideration are the 15 mrem/yr (CEDE) standard proposed by EPA and the 25 mrem/yr standard advocated by the NRC.

The issue concerning incremental cost for the more stringent standard can be addressed by determining if there are any data collection requirements or design improvements imposed by the more stringent standard. For Yucca Mountain, the basis for assessing the need for incremental cost is provided by considering the information presented above in Sections 3 through 5 concerning the design features and projected performance for the EDA II design. As discussed in

Sections 3 and 4, the TSPA-SR shows mean doses two orders of magnitude less than the 15 mrem/yr standard for the reference individual at 10,000 years and 20 km, and the reference individual corresponds to the EPA's proposed RMEI. In addition, these doses are only realized for a highly catastrophic and unlikely volcanic event.

The assessment results are based on highly conservative assumptions, to the point that some of them are highly unrealistic. Despite the conservatism, the results still showed potential to demonstrate compliance with EPA's proposed individual-protection standard. If the EPA's approach of "reasonable expectation" was used to frame the igneous scenario and assumptions, the projected dose results may have been negligible during the first 10,000 years.

The spread of the dose curves associated with parameter uncertainty shows that uncertainty in the peak dose covers at least 5 orders of magnitude during the first 10,000 years (see Fig. 6.1-2 of TRW00a). A very few of the realizations appear to have extreme consequences, to the extent that mean value is strongly biased by the high dose results. Indeed, for a portion of the curve this bias is so strong that the mean value exceeds the 95th percentile of the dose curves. This suggests that the mean dose curve is strongly influenced (perhaps unduly influenced) by a few realizations representing the extreme tails of the distributions. In viewing these results, it must also be kept in mind that the curves are themselves the result of the scenario and model assumptions discussed above. Modification of these assumptions to reflect more reasonable system behavior would likely decrease all of the output dose curves to negligible values in the first 10,000 years.

Demonstration of compliance with individual-protection standards for Yucca Mountain requires detailed, in-depth characterization of engineered and natural barriers and analysis of performance potential that assures a high degree of confidence in results presented for licensing reviews, and results that indicate that the predicted performance is substantially better than the required performance. As demonstrated clearly by Figure 3-2, current estimates of performance are significantly better than either the 25 mrem/yr standard or the 15 mrem/yr standard, and there is no need for increased costs for design improvements or data acquisition to demonstrate compliance with the 15 mrem/yr standard in comparison with the 25 mrem/yr standard. Indeed, it can be argued that adoption of the EDA II design, with an incremental cost of only S0.8 billion out of a total forward cost of nearly $22 billion (Section 3.8), is an effective time and cost saving strategy. It reduces the uncertainties and issues that were of concern for the VA design, and it improves the expected performance of the repository by several orders of magnitude, without facing the costs and time involved in trying to reduce uncertainties in the performance of the natural barriers, perhaps without definitive results. It can also be argued that more realistic treatment of juvenile waste package failures in the TSPA-VA, together with a relatively minor design change to switch the corrosion-resistant layer to the outside of the package, would by themselves have sufficiently improved performance. By this line of argument, the full change to the EDA II design may have been unnecessary, so that even a simply modified VA design may have been able to meet the IPS standards by orders of magnitude. In contrast to the several orders of magnitude improvement in performance for the EDA II design as shown in the TSPA-SR, the proposed NRC and EPA individual-protection standards differ by less than a factor of two. The practical implication of this observation is that the proposed design can be expected to protect the public far better than is required by either of the slightly different standards.

6.2 Cost Impacts of the HIS Requirements

The proposed standards for human intrusion, a performance standard unique to long-term geologic disposal, are the same as those for the IPS. All parties to evaluation of factors important to this demonstration of compliance concur with the NAS finding that a stylized scenario of intrusion and its consequences is needed because circumstances of intrusion cannot be predicted on the basis of scientific evidence. Therefore, the issues to be addressed in licensing reviews and compliance evaluations are

- whether the intrusion scenario considered for licensing is reasonable, and
- what are the dose consequences of the appropriate scenario.

The EPA's proposed standard for individual exposure limits for human intrusion (15 mrem/yr) is no different from the individual exposure limits applicable to gradual processes that will eventually degrade the repository's functional capability. Protection of human health is independent of the means by which it might be threatened. It is therefore appropriate and necessary for the EPA to prescribe that the standard for human intrusion be no different than that for the RMEI under undisturbed performance of the repository. The EPA is concerned only with the fact that individuals potentially affected by human intrusion be protected to the same extent as others. Details of the stylized intrusion scenario given in the rule are based on the recommendations of the NAS to EPA for the rulemaking (NAS95). EPA has adopted those recommendations it agrees with, to make clear to DOE and NRC the intent of the standard. However, EPA has not prescribed the scenario in excessive detail, thus allowing DOE and NRC to exercise their appropriate roles as applicant and regulator in implementing the EPA standard.

Considerable flexibility has been left in the standard to explore the effects of alternative processes associated with releases from the repository and transport through natural barriers.

As discussed above, it is apparent that the proposed HIS requirements have no impact on the costs of the DOE program for Yucca Mountain because, in fact, they are no different than the IPS requirements, as should be the case (i.e. , protection is independent of the circumstances that require protection). Program schedules and costs for DOE have been established basically on the basis that demonstration of compliance with the basic IPS is needed and crucial; demonstration of compliance with HIS requirements can be developed independently through the intrusion scenario characteristics accepted for the basis for licensing reviews. Parameter values needed for the HIS analyses are available either from the parameters used in the IPS analyses, or may be based on straightforward assumptions without the need to collect additional field or laboratory data, as shown in Table 6-1.

The key point is that the proposed EPA standard is designed to assure that future populations are afforded the same protection as present populations. DOE programs and projected costs have been developed on the basis of the Department's expectations with regard to licensing review requirements for demonstration of compliance with EPA's proposed standard. They have not been based on an assessment of the impact of EPA standards on compliance with regulatory standards.

TSPA-SR estimates of the impact of inadvertent human intrusion to be about 3 orders of magnitude below the proposed standard, as shown in Figure 3-3. Differences are negligible between the proposed NRC approach to assume intrusion at 100 years, and the reasonable expectation approach, which would suggest that the waste package will be identifiable for much longer times. It can be concluded that neither the HIS requirement nor its timing have any impact on repository cost.

Data and analysis requirements for assessing compliance with the human-intrusion standard, which fall within the framework of requirements for assessing compliance with the individual protection standard, are summarized in Table 6-1. From this table, it is apparent that parameters and data necessary to analyze exposures are either defined in the rule or are already available from the IPS assessments. Consequently, no additional demands for data collection are imposed by the HIS. As a result, no additional significant program costs are imposed by the HIS requirements.

Table 6-1. Data and Analysis Requirements for Assessing Compliance With the Human-Intrusion Standard

Data/Analysis Requirement	Source of the Information
Nature of the intrusion to be modeled	Defined in the standard: waste package penetration by water well drilling with current technology; connection to the saturated zone
Probability of the intrusion	Defined as unity (1.0) in the standard
Time frame for the intrusion	Derived from corrosion modeling done for the IPS assessments
Mechanism for release of radionuclides from the penetrated waste package: • direct fall down borehole • leaking package or diffusion release	Assumptions for the analysis; no testing required
Transport of radionuclides through the saturated zone to the compliance point	Required to use the same methods as for the IPS assessments
Doses to the receptor: • definition of the receptor • path through the biosphere	Same definition and analyses as for the IPS assessments

6.3 Cost Impact of the GWS Requirements

The Ground Water Protection Standards do not impose any additional costs on the program. The information required to evaluate compliance with the GWS is radionuclide concentration in the ground water as a function of distance from the repository. This is the same information as is required for assessment of compliance with the IPS, and no incremental costs or effort to assess ground water concentrations with a higher degree of certainty for the GWS in comparison with the IPS is appropriate or necessary. As shown in Figure 3-2, the GWS is of the same order of magnitude as the IPS, and the characteristics of the data base that are needed for licensing reviews are the same for the GWS and the IPS.

As shown in Figures 4-1 and 4-2, the TSPA-SR analysis indicates no potential for impact of the GWS within the performance period, as there are no releases in the nominal scenario during this period. As noted in Section 4.2, concentrations were calculated in the period out to 100,000 years to demonstrate that no significant degradation occurs even after the 10,000-year time period is ended.

Data and analysis requirements for assessing compliance with the ground water protection standards are summarized in Table 6-2.

Table 6-2. Data and Analysis Requirements for Assessing Compliance With the Ground Water Protection Standard

Data/Analysis Requirement	Source of the Information
Water flux through the unsaturated zone above and into the repository (precipitation, infiltration, seepage into drifts, etc.)	Characterization data, models, and analyses for the IPS compliance evaluations
Source term for radionuclide releases from the repository (container failure profiles, exposed waste form areas, radionuclide leach rates, solubilities, etc.	Engineered barrier system characterization, testing and modeling as required for the IPS compliance evaluations
Characterization of saturated zone flow and radionuclide transport (hydroponic conditions down-gradient to the compliance point; only average values are required by the GWS)	Characterization data, flow and transport models, and analysis of the type required by the IPS compliance evaluations, but GWS requires less detail
Methods for calculating radionuclide concentrations in the Representative Volume	Methods defined in the standard; no further effort required

7.0 SUMMARY DEMONSTRATION THAT THE EPA STANDARDS HAVE NO COST IMPACTS ON THE YUCCA MOUNTAIN PROGRAM AND REPOSITORY

7.1 Principal Bases for Findings of No Cost Impacts

This Economic Impact Assessment (EIA) has demonstrated that DOE's strategy for development and design of a possible repository at Yucca Mountain has evolved to the point that EPA's 40 CFR Part 197 standards will have no impact on the total life cycle costs of the repository. This has been demonstrated through an examination of the factors that influenced evolution of repository design and a review and analysis of DOE's performance assessments. The principal factors that provide the basis for a finding of no cost impact of the standards are:

- The DOE plans for repository design strategy, data acquisition, and budget allocations and requirements have been established independent of the proposed EPA standards. DOE's plans and cost estimates reflect, as suggested above, expenditures and activities not needed as a direct consequence of the EPA standards.

- Earlier performance assessment results (TSPA-VA), which are based on highly conservative assumptions that would not be used under principles of Reasonable Expectation, suggest expectation of compliance with EPA's IPS, HIS and GWS limits. More recent performance assessment results (TSPA-SR) show even greater margins for compliance with the proposed EPA standards than the TSPA-VA results. The newer design (EDA II) is augmented to produce improved expected performance for the nominal case, and design features have been selected to reduce the potential for significant issues during licensing reviews. Figure 3-2 demonstrates dramatically the assertion that EPA's standards have no impact on Yucca Mountain program costs. Under the nominal scenario there is no release during the time period over which the IPS, HIS, and GWS would apply. Releases may only expected to occur if violent volcanic activity occurs at the site, and this is unlikely considering the volcanic history of the site. The magnitude of releases associated with volcanic activity are very conservatively estimated in the TSPA-SR in comparison to reasonably expected conditions.

- The data and analysis requirements for assessing compliance with the ground water protection and human-intrusion standards are the same as those required for assessing compliance with the fundamental and essential individual-protection standard. The ground water protection standard and the human-intrusion standard therefore impose no incremental costs.

These factors are discussed in more detail in Sections 7.1.1 through 7.1.3. Section 7.2 discusses alternative standards and their relationship to repository performance, and Section 7.3 provides an overall summary and conclusions.

7.1.1 Evolution of the Repository Design and Roles of Natural and Engineered Features

The initial repository design concept, described in the Site Characterization Plan (SCP) issued in 1988, anticipated that natural features of the repository system, such as very low rates of water movement in the unsaturated zone (UZ), would dominate repository performance. Engineered features would be the minimum necessary to meet the subsystem performance requirements of the Nuclear Regulatory Commission's (NRC) 10 CFR Part 60 standards, such as substantially complete containment of radionuclides within the waste package for 300-1,000 years.

In contrast to SCP expectations, acquisition and analysis of subsequent site characterization data revealed that the SCP's performance expectations for the natural system would not be achieved, e.g., there are paths for rapid movement of water through the UZ and rates of ground water infiltration were higher than earlier thought. Consequently, the performance capabilities of the engineered features of the system have been revised from the SCP concept to one in which the engineered features play the dominant role in disposal system performance during the regulatory period: more specifically, the use of highly corrosion resistant waste package wall materials and drip shields to defer contact of the waste packages by water that drips into the repository. The design features are intended to provide defense-in-depth for performance and to minimize uncertainties and technical issues associated site performance that could become contentious issues during the licensing process.

The inversion of performance roles of the natural and engineered features of the repository system has evolved as a result of site characterization findings, guidance from external reviews such as those of the Nuclear Waste Technical Review Board, and interactions with NRC staff which provide guidance on licensing requirements. **The evolution has been independent of the EPA standards, the major components of which have remained essentially unchanged since the 1985 promulgation of the generic 40 CFR Part 191 standards for geologic disposal.**

7.1.2 DOE's Use of Performance Evaluations

The Department has used a series of Total System Performance Assessments (TSPA) to guide selection and prioritization of site characterization activities, to guide selection of engineered features and parameters, and to make projections of repository safety performance. TSPA models and methodology have evolved in parallel with the evolution of the site data base and engineered design concepts.

The TSPA for the Viability Assessment in 1998 (TSPA-VA) was the first TSPA for a potential repository system at the Yucca Mountain site. Despite use of conservative models and assumptions, TSPA-VA results for the base case using average parameter values showed dose rates at 10,000 years, for a dose receptor at 20 km distance from the repository and with characteristics comparable to EPA's proposed Reasonably Maximally Exposed Individual (RMEI), that were two orders of magnitude lower than the EPA's individual-protection standard of 15 mrem/yr CEDE. More reasonable assumptions in framing these scenarios and the associated conceptual models would show lower projected doses of at least several orders of magnitude.

In response to reviews of the TSPA-VA which found that there were uncertainties in the models and results that could produce significant technical issues for licensing reviews, DOE subsequently adopted the current engineered design, EDA II, which has as principal features use of titanium drip shields and a highly corrosion resistant waste package outer wall. This engineered barrier design concept is significantly augmented in comparison with the VA design. TSPA-SR estimates of performance for this design indicate that, under expected conditions, there will be no radionuclide releases and no potential for radiation doses for more than 10,000 years after repository closure, unless the repository is disrupted by volcanic activity. Even in that extreme occurrence, the repository is shown in the TSPA-SR not to exceed the exposure limits. The performance scenarios and conceptual models in the TSPA-SR were also developed using conservative assumptions, although more realistically than the TSPA-VA approaches. Expected releases would be considerably lower for even more realistic assessments.

All of the above actions were completed or underway by the time NRC put forth its proposed 10 CFR Part 63 regulations in February 1999 and EPA put forth its proposed 40 CFR Part 197 standards in August 1999. In particular, DOE program plans, repository

design concepts, and program cost estimates had all been documented before EPA's proposed standards were issued for public comment.

7.1.3 Impact of the EPA Standards on Data and Analysis Requirements

The third perspective included in this EIA is an examination of the data and analysis requirements imposed by the individual-protection, ground water protection, and human-intrusion standards. Each of these components of the standard requires a quantitative evaluation of projected repository performance, and a data base of performance parameters for the repository's natural and engineered features, for compliance assessment. This EIA demonstrates that the data and analysis requirements for assessing compliance with the ground water protection and human-intrusion standards are the same as those required for assessing compliance with the fundamental and essential individual-protection standard. **The ground-water-protection and human-intrusion provisions therefore impose no incremental cost impacts.**

7.2 Comparative Impacts of Alternative Dose Limits for the Individual-Protection Standard

An important issue in developing the individual-protection standard has been comparative impacts of alternative dose limits, e.g., 15 mrem/yr versus 25 mrem/yr. Figure 3-2 (which is the same as Figure ES-1) shows the performance projections EDA II designs given in TSPA-SR.

As seen in Figure 3-2, the EDA II repository design demonstrates performance such that projected doses are significantly less than either the 15 mrem/yr or the 25 mrem/yr dose limit. Indeed, the only doses that occur in the first 10,000 years are the result of potential volcanic activity scenarios that are very conservative. It is therefore evident that selection of a 15 mrem/yr dose limit rather than a 25 mrem/yr limit will not impose any additional cost impacts on the repository. This is a highly significant finding in that the 15 mrem/yr CEDE dose limit is consistent with the recommendations of the National Academy of Sciences and regulatory precedents for deep geologic disposal applications (WIPP).

As noted in Section 4 of this document, the TSPA-VA evaluations of potential VA-repository performance used highly conservative models and assumptions, such that the actual expected performance of a VA repository would be at least several orders of magnitude better than was reported in the TSPA-VA results. Similarly, with the enhanced engineered barrier system design for EDA II, the performance as evaluated in the TSPA-SR is significantly better than that projected for the VA. No radionuclide releases are expected to occur for more than 10,000 years, and even if highly-improbable violent stombolian eruption occurs, the repository design easily meets either the 15 mrem/yr or the 25 mrem/yr limit. Performance scenarios in the TSPA-SR analyses and the models used to evaluate them, although different in many respects from the TSPA-VA, are still very conservative. Analyses using more realistic, yet still defensible, assumptions would show performance results considerably better than the one presented in the TSPA-SR.

The projections of repository performance for the EDA II design are shown in Figures 3-2 and 3-3 compared to the proposed EPA and NRC regulations. As can be seen in this figure, and as noted above in the discussion of the alternative dose limits, performance in all cases considered is significantly better than required by the standards. The highly conservative igneous intrusion and eruptions considered in the TSPA-SR show dose estimates one to two orders of magnitude below the limits imposed by the standards; the expected performance (nominal scenario, excluding volcanic events) within the regulatory time period for the EDA II repository shows no releases relevant to the proposed standards.

As discussed in Section 3.4, the EDA II design and the refinement of repository strategy serve primarily to ease concerns for uncertainties and technical issues that were associated with the TSPA-VA methodology that could be difficult to resolve in licensing reviews, and to add to the performance margin with use of drip shields to implement defense-in-depth concepts. The new design was not driven by requirements in the EPA rule, but rather as a means to compensate for uncertainties in performance projections.

7.3 Summary and Conclusions

The need to demonstrate compliance with the individual-protection standard is fundamental to assurance of protection of public health and safety for deep geologic disposal. There is also need, for geologic disposal, to provide protection in the event of inadvertent future human intrusion and there is need to protect ground water resources for future generations. Imposition of, and compliance with, the HIS and GWS standards is essential for consistent and comprehensive application of EPA policy concerning ground water protection and for appropriate application of generic principles set forth in 40 CFR Part 191 to the Yucca Mountain setting.

As shown in this document, the evolving understanding of the Yucca Mountain site characteristics, and the resulting information base needed to provide defense-in-depth and to reduce uncertainties during licensing reviews has driven the Yucca Mountain program data acquisition program and evolution of design concepts. Because of site-specific conditions, DOE's strategy for development and design of a possible repository at Yucca Mountain has evolved so that EPA's 40 CFR Part 197 standards will have no impact on the costs of the repository program. This document has also shown that EPA's generic 40 CFR Part 191 standards did not influence evolution of the Yucca Mountain program or the repository design. Moreover, as illustrated by Figures 3-2 and 3-3, expected performance for the current repository design is significantly better than is required by the EPA standards for HIS, GWS, and IPS.

The information base required for demonstrating compliance with the HIS and GWS standards is the same as that required for demonstrating compliance with the individual-protection standard. Costs and effort above those needed to evaluate compliance with the IPS therefore do not have to be incurred to evaluate compliance with the HIS and GWS standards.

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Joint NEA-IAEA International Peer Review of the Yucca Mountain Site Characterisation Project's Total System Performance Assessment Supporting the Site Recommendation Process

Final Report

December 2001

Summary

This Summary presents the key results of the international peer review of the US Department of Energy (USDOE) Total System Performance Assessment supporting the site recommendation process (TSPA-SR) issued in December 2000 for the Yucca Mountain site. The review was carried out at the request of the USDOE Yucca Mountain Project (YMP) and was jointly organised by the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD), and the International Atomic Energy Agency (IAEA) of the United Nations. The primary intended audience for this review is USDOE higher level management and relevant technical staff. However, it is hoped that this review will also be of value to the regulators, various ongoing review groups and other stakeholders including the public.

This review is the outcome of the work of an international review team of ten members, over a period of about four months. The main focus of the review is the TSPA-SR document, with partial review of some supporting documents. Given the limited time available, the IRT was primarily concerned with the higher level features of the methodology rather than with details of individual sub-models that are subject to change and that are undergoing detailed peer reviews by specialists in the relevant areas. It is therefore an expression of findings based on a brief review and cannot be considered as an in-depth analysis of all of USDOE's work on Yucca Mountain over the last ten years.

Objectives

The primary objective given to the International Review Team (IRT) was to review and critically analyse the performance assessment methodology and rationale used by the USDOE in support of the current site-recommendation decision process in order to:

- Identify consistencies and inconsistencies between methods that were implemented by the USDOE and those being considered or developed in international recommendations, standards and practices;

- Provide a statement regarding the adequacy of the overall performance assessment approach for supporting the site recommendation decision;

- Provide detailed recommendations for specific technical and other improvements that would help performance assessment better support the next programmatic decision point, if the site is recommended and subsequently approved, which entails the preparation and submission of a license application.

These three aspects are considered below.

International perspective

Yucca Mountain setting

The conditions prevailing at Yucca Mountain are significantly different to those considered in other national repository programmes in that Yucca Mountain is in a closed basin and the repository is in an oxidising environment above the water table. The IRT has taken due account of these differences in conducting the review.

Rationale

The rationale chosen by the YMP in support of the site-recommendation process was as follows. A total system performance assessment was carried out to determine whether it is likely that the selected repository concept at the Yucca Mountain site will be able to meet the quantitative licensing requirements of the USEPA standard and the USNRC proposed rule. The dose rate requirement for the 10 000 year period was met by designing the engineered barriers (with redundant features) so that, based on available corrosion data, there would be no release from the waste package under normal conditions.

This rationale is capable of addressing many important issues. However, at present, the extensive knowledge accumulated in many years of characterisation and analysis of the site is not utilised to its fullest extent. The IRT is also of the opinion that it would have been desirable to have placed greater emphasis in the TSPA-SR on the performance of the geological barriers in their own right. Moreover, a broader safety case should have been developed to support the site recommendation decision.

Methodology

The overall structure of the TSPA-SR methodology, and the USDOE approach of building on an iterative series of performance assessments, conform to international best practice. Moreover, the structured abstraction process linking process-level models to assessment models is at the forefront of international developments.

One of the first steps in a safety/performance assessment is identification of the potentially relevant features, events and processes (FEPs). The IRT has found the FEP methodology used in the TSPA-SR to be in agreement with international best practice, and recognises the contributions to the international development that has come from work within the YMP.

The YMP places far greater emphasis on probabilistic assessment than equivalent programmes in other countries. Some known issues, and particularly "risk dilution", considered in the international fora such as the Probabilistic System Assessment Group of the NEA, have not been fully addressed in the TSPA-SR.

The YMP TSPA does not emphasise natural analogues as much as in some other international studies.

Regulation

The regulatory requirements set down and proposed[1] for the YMP are somewhat more prescriptive than in many other countries, both in specifying compliance requirements and in directing how these must be met. Particularly relevant in this regard is the specification of a period of 10 000 years for which the applicant must provide reasonable assurance (USNRC proposed regulation) or reasonable expectation (USEPA) that a radiation dose limit will not be exceeded. Other examples are: (i) the detailed specification of a stylised human intrusion scenario; (ii) the precise specification of the distance to the receptor area; (iii) specification of the representative volume of groundwater to be used in human uptake and dose rate calculations; and (iv) the requirement that events with probability of occurring as low as 10^{-8} per year should be modelled and assessed numerically.

The way the regulations are formulated has contributed to the tendency of the TSPA-SR to focus more on demonstrating numerical compliance with quantitative criteria than on demonstrating an understanding of repository performance. Also, the US approach to regulation has focussed attention on the presentation of aggregated results that can be compared directly with regulatory requirements. The IRT considers that more intermediate results and dis-aggregated end results should be given. This would provide more information to decision-makers, a point emphasised in recent international recommendations on the safety of radioactive waste disposal.

[1] Since the work of this review, both the NRC and DOE have finalised their regulations. The IRT considers that its conclusions and recommendations are not called into question by the changes made. See Appendix 4.

Statement by the International Review Team

In response to the request by the USDOE to provide a statement regarding the adequacy of the overall performance assessment approach for supporting the site recommendation decision, the IRT considers that:

While presenting room for improvement, the TSPA-SR methodology is soundly based and has been implemented in a competent manner. Moreover, the modelling incorporates many conservatisms, including the extent to which water is able to contact the waste packages, the performance of engineered barriers and retardation provided by the geosphere.

Overall, the IRT considers that the implemented performance assessment approach provides an adequate basis for supporting a statement on likely compliance within the regulatory period of 10 000 years and, accordingly, for the site recommendation decision.

On the basis of a growing international consensus, the IRT stresses that understanding of the repository system and its performance and how it provides for safety should be emphasised more in future iterations, both during and beyond the regulatory period. Also, further work is required to increase confidence in the robustness of the TSPA.

Recommendations for future assessments

To provide better support to the next programmatic decision point, namely the preparation and submission of a license application, the IRT recommends that a number of improvements should be made in the USDOE approach to assess the performance of the repository system. Detailed recommendations on specific technical issues and sub-system analysis are provided in the main report. The most important recommendations in regard to overall system performance, sub-system performance and other issues are summarised below.

Overall system methodology

Features Events and Processes (FEPs): The IRT has carried out some spot checks of the FEP identification and screening process. This has identified two additional potentially important FEPs. This points to some shortcomings in the routines and procedures for the FEP identification and screening processes and in the QA of assessment input, which should be revisited and revised as necessary. While the regulatory compliance period is 10 000 years, the YMP team are to be commended for extrapolating some of the TSPA-SR simulations out to longer times in order to estimate the time and magnitude of the maximum expected dose. However, FEPs have been screened out on the basis of demonstrating compliance up to 10 000 years and so the assessment is less reliable at longer times. Thus the IRT recommends that in future the screening of FEPs should be made in two stages. The first stage should retain all FEPs required for a full understanding of repository performance, while the second stage should include regulatory compliance considerations in the screening criteria.

Uncertainty: A comprehensive and systematic methodology for identifying and treating all types of uncertainty should be formulated and implemented. This should include the classification of uncertainties as to whether they are due to intrinsic variability or to lack of knowledge, since the latter can lead to non-conservative results when incorporated into a probabilistic framework. This is termed "risk dilution" and is discussed further in the main report. It is recommended that a study should be carried out of the quantitative importance of risk dilution for the expectation value of dose. The reduction of uncertainty should be a major goal of the YMP, focussing attention on obtaining good laboratory and field data in those areas where uncertainty has the greatest effect.

Probabilistic methodology: Given the regulatory requirements in the USA, it is appropriate to make use of a probabilistic systems analysis framework for the potential repository at Yucca Mountain. However, the IRT is of the opinion that some particular aspects of the methodology require further consideration. The key concern of the IRT is the potential problem of risk dilution. This arises because the parameter distributions used in the TSPA-SR represent the combined effects of stochastic variability and subjective probability due to incomplete understanding of the system. Under some situations the inclusion of subjective uncertainty can lead to non-conservative estimates of the expectation value of dose (so-called risk dilution or uncertainty dilution). When this occurs it means that increased ignorance leads to lower expected doses, which does not appear to be a sensible basis for decision-making, and requires further scrutiny. The IRT is of the opinion that the TPSA-SR presents conditions where risk dilution may have occurred, but that this issue has neither been addressed nor analysed. Consequently, the IRT recommends that an assessment should be carried out of the quantitative importance that risk dilution might have on the magnitude of the performance measure. Also, the limitations and strengths of the probabilistic method need to be addressed as pre-conditions for a defensible analysis.

Sensitivity analysis: The IRT was favourably impressed by the methods and quality of the sensitivity analysis used in the TSPA-SR and supporting documents. The IRT recommends that sensitivity analysis be developed further into a tool to build an integrated and comprehensive understanding of the relative importance and role of different barriers and processes.

Safety Case: A Safety Case should be developed as a higher level document, and include the articulation of a strategy to achieve safety as distinct from the strategy for demonstrating compliance, with an emphasis on obtaining and communicating understanding and facilitating dialogue with the relevant stakeholders. A Safety Case is the integration of relevant arguments in support of the long-term safety of the repository. In particular, a statement of confidence should be included, to elucidate the means that were adopted to achieve sufficient confidence, and to acknowledge the remaining issues, together with a suggested strategy for resolving those issues. This should build upon the current Repository Safety Strategy document.

System understanding: Within the TSPA-SR report most attention is given to demonstrating quantitative compliance with regulatory criteria. Relatively little emphasis is placed on the important issue of presenting an understanding of system behaviour, which is required to enable decisions to be made based on the full body of evidence. The IRT considers that demonstrating understanding should be complementary to demonstrating compliance and of at least equal importance. Two approaches are needed.

The first is to present what is considered to be a realistic (i.e. non-conservative) analysis of the likely performance of the repository using realistic model assumptions and data. This could usefully draw on evidence from natural and archaeological/historical analogues and should aim to communicate the likely evolution of the repository and its surroundings to a range of stakeholders and give an indication of the safety margins inherent in the analysis.

The second approach is an analysis for compliance purposes where conservative assumptions and parameter values are used to make the case more defensible. Specific assumptions and models are needed for this and should be identified separately from the less conservative analysis. Finally, in order to communicate understanding, the USDOE should take steps to improve its corporate memory and make more use of the extensive archive of technical and non-technical reports produced during earlier phases of the programme.

Sub-system methodology

Repository design: There have been major changes in repository design between TSPA iterations (e.g. since the TSPA-VA) but no clear rationale for these changes was discernible from the TSPA-SR report. In a future safety case it would be helpful to include a section in the main body of the report describing the evolution of the disposal concept. In addition to indicating how design changes have responded to safety concerns, this would provide continuity and would enhance confidence by demonstrating that the project is maturing and developing in a logical and systematic manner.

Engineered barrier materials: The selection of materials for the waste package outer barrier (Alloy-22) and drip shield (Titanium Grade 7) are in line with international best practice, having regard to the specific chemical environment at Yucca Mountain. However, in order to build further confidence in the performance of these materials over thousands of years in the anticipated Yucca Mountain repository environment, it is recommended that long-term corrosion tests using multiple specimens are carried out. These should investigate the effects of gamma radiation field, salt deposits, microbes and ageing. A key challenge is to improve confidence in the extrapolation of corrosion measurements to long times. In order to accomplish this, it is recommended that efforts be made to help improve the scientific understanding of the kinetics of pitting and crevice corrosion, and of stress corrosion cracking.

Waste form: The procedure used for screening the radionuclide inventory may have resulted in some potentially important radionuclides (e.g. ^{36}Cl, ^{135}Cs) being omitted from detailed analysis and thus the IRT recommends that this procedure should be reviewed and amended as appropriate. In the TSPA-SR, the fuel cladding remains a significant barrier up to 100 000 years and beyond. The IRT was impressed with the depth of thought given to this issue but found one process (effects of the corrosion of basket components) that was not taken into account and which might compromise the performance of the cladding. Thus further efforts are recommended to strengthen confidence in this area.

Some of the solubility limits for elements (especially Np, Th and Ra) given in the TSPA-SR are simplifications made in the absence of reliable data. It is recommended that more experimental data be obtained to validate thermodynamic modelling, especially with regard to the complex interactions between the degrading waste form and components of the waste package.

Transport within the engineered barrier system: The proposed mechanism of radionuclide diffusion through stress-corrosion cracks, which is assumed to be dominant for many millennia after the waste package is breached, appears to be overly conservative and complex, and possibly not credible. The model requires a continuous film of water to allow diffusion that extends all the way from the waste form to the cracks in the degrading waste package and to the bottom of the invert. In applying the model, the TSPA-SR assumes very conservatively that the process of diffusion occurs even when there is no dripping in the location and the drip shield is intact. The engineered barrier transport model should be independently reviewed. Moreover, questions remain about the likely extent of drift collapse and its effect on engineered barrier performance.

A key issue concerning the near-field repository environment is whether liquid water is likely to exist in and around waste packages, as assumed in the TSPA-SR. Very little water should be able to reach the drifts because of the repository design, causing diversion around the emplacement drifts, or by Nature due to limited precipitation, infiltration and seepage. At the same time, the evaporation potential of water due to heat output from the waste packages is substantial: much more than 1 000 litres per year per package before 10 000 years has been postulated. Thus except in areas where seepage is extraordinarily high, waste packages may remain dry due to evaporation. Design modifications, such as capillary barrier backfill, could be considered in areas of high seepage.

Unsaturated zone: Confidence in the modelling of flow and radionuclide transport in the unsaturated zone should be increased through further experimentation, and the influence of temperature on capillary suction should be accounted for. The TSPA-SR determined that some of the dose comes from colloidal transport of Pu, Th and possibly other actinides, in both the unsaturated and saturated zones. However, this assumption is possibly over-conservative and should be reviewed.

Moreover, natural dripping of groundwater from fractures or pores in the matrix has never been clearly observed[2], primarily as it is affected by drift ventilation, and yet it plays an important role in the analysis. This begs the question as to whether the assumptions about dripping are too conservative. In view of its critical role in the assessment, the IRT recommends that the postulated dripping process should be better understood and quantified.

Saturated zone: The IRT expresses concern about the level of knowledge available for assessing the role of the saturated zone (SZ) in the TSPA-SR, both at the regional scale and at the site scale. Further hydrogeological and hydrogeochemical data are required. Moreover, the treatment of this information to construct and calibrate a regional groundwater flow model is considered by the IRT not to be state-of-the-art. It is therefore recommended that a significant effort be made to improve the regional SZ flow model by collecting new data and improving the calibration. This effort should be closely integrated with the improvement of the site flow model, in order that these two models are made consistent with one another. Once improved flow models have been constructed, calibrated and validated, they should be run in a spatial variability analysis, not by using a large uncertainty factor.

[2] Clarification made. See Appendix 4.

Biosphere: The Yucca Mountain biosphere modelling programme has recently been the subject of a comprehensive international review and thus in general it has not been thoroughly scrutinised by the IRT. However, the IRT considers that a realistic understanding of the long-term fate of radionuclides in the Yucca Mountain basin should be developed.

Natural analogues: The IRT recommends that the USDOE should carry out further work at the Peña Blanca uranium deposit in northern Mexico as a natural analogue for Yucca Mountain and use its characteristics to increase the confidence of both the public and the scientific community in the system performance over very long times. Also, investigations of naturally-occurring uranium and its radioactive progeny in the tuffs at Yucca Mountain should be continued to improve understanding of their mobility within the flow systems of the mountain. Overall, natural analogues should receive more prominent attention as instruments for increased understanding and confidence building.

Disruptive events and human intrusion

Disruptive events: Volcanism at Yucca Mountain is a very low probability event. With regard to volcanism, more explosive rhyolitic eruptions can occur at the same time as basaltic eruptions (so-called bimodal volcanism). This was not discussed in the TSPA-SR. It is recommended that the probability of bimodal basaltic-rhyolitic volcanism should be estimated and, if relevant, the consequences should be analysed. The IRT considers that the TSPA-SR adequately addresses seismological influences and finds the analysis in line with other international studies.

Human intrusion: The stylised human intrusion scenario, as specified by the regulatory agencies, involves drilling of a borehole through the waste package and into the saturated zone. The IRT recommends that in future assessments direct surface water flow into the assumed borehole should be included so that water flows into the degraded waste package in every realisation of the computer model.

Documentation

The full set of documentation, including supporting reports, provides a comprehensive and impressive analysis of relevant issues, models and data. In areas where the IRT has examined supporting documents, they were found to exhibit adequate traceability. Moreover, the documentation has clearly been prepared in a systematic fashion with great care and attention to detail.

Nevertheless the TSPA-SR report has some shortcomings in terms of overall clarity and comprehensibility. This may be due to it being written for a number of different types of readers and is an area where improvement could be made. To address this problem in future, it would be appropriate to produce documents for different sets of stakeholders including a summary document where the whole YM concept, context and safety case is presented in a form suitable for a more general audience.

Contents

1 Introduction

This document presents the results of the international peer review of the US Department of Energy (USDOE) Total System Performance Assessment (TSPA) issued in December 2000 supporting the site recommendation process (TSPA-SR) for the Yucca Mountain site (CRWMS, 2000a). The review has been carried out at the request of the USDOE Yucca Mountain Project (YMP) and has been jointly organised by the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD) and the International Atomic Energy Agency (IAEA) of the United Nations.

The report is intended primarily for a USDOE readership of technical managers and senior management, but is likely to be useful to other individuals with similar backgrounds and interests and to the broader range of interested stakeholders including members of the public. The review comments are offered in a constructive spirit in order to help the USDOE assess its achievements and better steer its working programme in the development of a repository for spent nuclear fuel and high level waste.

1.1 Background to the Yucca Mountain Project

The USDOE has been studying the Yucca Mountain site in Nevada for more than 15 years to determine whether it is a suitable place to construct the first underground repository for US commercial and defence spent nuclear fuel and high-level waste.

In addition to a large amount of site characterisation work and development of the system concept, a number of performance assessments have been carried out over the past decade, the latest of which is the TSPA-SR (CRWMS, 2000a).

The relevant draft[3] regulatory requirements by the United States Nuclear Regulatory Commission (USNRC) and the standards of the United States Environmental Protection Agency (USEPA), which will apply for licensing if the site is recommended by the President and accepted by Congress, are summarised in the TSPA-SR report. For the purposes of this review, key requirements are the use of the probabilistic expectation value of individual dose as the primary quantitative performance measure,

[3] Since the work of this review, both the NRC and DOE have finalised their regulations. The IRT considers that its conclusions and recommendations are not called into question by the changes made. See Appendix 4.

and the specification of a compliance timeframe of 10 000 years following disposal. The standard of proof is that of "reasonable assurance" (USNRC, proposed regulation) and of "reasonable expectation" (USEPA). In this context it is noted that the final decision to be made by the USNRC is based not only on the results of the performance measures but on the "full record" before the regulatory authority.

1.2 Terms of reference, objectives and scope of the review

This review has been conducted according to Terms of Reference (Appendix 1) agreed between the USDOE, IAEA and NEA.

According to the Terms of Reference, the objective of the review is to provide an independent assessment of the methodology developed by the USDOE-YMP as presented in the TSPA-SR report (CRWMS, 2000a). It is a technically oriented and consensus review conducted by an International Review Team (IRT).

The primary objective is to review and critically analyse the performance assessment methodology and rationale being used in support of the current site-recommendation decision process in order to:

- Identify consistencies and inconsistencies between methods being used by the USDOE and those being considered or developed in international recommendations, standards and practices;

- Provide a statement regarding the adequacy of the overall performance assessment approach for supporting the site-recommendation decision;

- Provide detailed recommendations for specific technical and other improvements that would help performance assessment better support the next programmatic decision point, if the site is recommended and subsequently approved, which entails the preparation and submission of a license application.

Based on the expertise and international experience of the team, these three aims are addressed throughout the report and the key issues are summarised in Section 5.

The primary report reviewed was the TSPA-SR document, with each section being reviewed by at least two members of the IRT. Where deemed appropriate to meet the aims of the review, ancillary reports were also reviewed. These included Revision 4 of the Repository Safety Strategy (RSS) (CRWMS, 2000b) and certain Process Model Reports (PMRs) and Analysis Model Reports (AMRs).

The IRT has not reviewed in detail the recent Supplemental Science and Performance Analyses (BSC, 2001) because it was outside the scope of the Terms of Reference and because of assurances from the USDOE that it follows the same basic methodology as the TSPA-SR. In this context, it should be noted that the IRT was primarily concerned with the higher level features of the methodology rather than with details of individual sub-models that are subject to change and that are undergoing detailed peer review by specialists in the relevant areas.

In keeping with the Terms of Reference, in reviewing the relevant reports the IRT has given consideration to the:

- Technical basis for the performance assessment, including identification and justification of the conditions and characteristics modelled at the system level; this includes a review of the abstractions of the adopted design and the scientific basis for determining future environments in the system and its materials and natural systems behaviours;

- Development of the key conceptual models, including the assumptions made with respect to the representations of relevant features, events and processes (FEPs);

- Adequacy of the treatment of the undisturbed and disturbed system performance;

- Adequacy of the methods used, and the cases considered, in sensitivity and uncertainty evaluations; and

- Overall clarity and completeness of the technical report describing this system-level performance evaluation.

With this background, the IRT considered that it was empowered to comment on any matter discussed in the main TSPA-SR report, including the technical and scientific basis for the assessment, scenario development, and the development, abstraction and integration of mathematical models. In particular, the review team focused on the overall question:

- From an international perspective, does the TSPA methodology have the potential to support a credible long-term post-closure safety case?

The conditions prevailing at Yucca Mountain are significantly different to those considered in other repository programmes because the repository is above the water table, in an oxidising environment and in an effectively closed basin. The IRT has taken due account of these differences in conducting the review.

1.3 Conduct of the review

The review was conducted over the period June to October 2001 by ten members of an International Review Team (IRT). It is therefore an expression of findings based on a brief high-level review, and cannot be considered as an in-depth analysis of all of USDOE's work on Yucca Mountain over the last 10 years.

The IRT members have experience in aspects of system-level long-term performance assessment evaluations (Appendix 2). The team members were selected by the Joint NEA-IAEA Secretariat in accordance with a written criteria statement. The team members participated as individuals, rather than representing their organisations.

The review team met for the first time in Las Vegas on the 21st to 23rd June 2001 where they held a number of closed-door meetings where team members discussed the conduct and schedule of the review together with their first impressions of the TSPA-SR report. On the 21st June the review team visited the Yucca Mountain site including viewing the surface geology and characterisation experiments within the mountain. An Orientation Meeting was held on the 22nd June 2001, where USDOE staff and contractors made a series of presentations on the TSPA-SR, each of which was followed by a question and answer session. The Orientation Meeting was open to members of the public, three of whom were invited to make brief presentations at the end of the meeting.

Following the Orientation Meeting, the review team sent an initial list of questions to the USDOE based primarily on the presentations by USDOE staff and contractors. Two further sets of questions were prepared following scrutiny of the TSPA-SR report and some supporting reports. The USDOE responded in writing to each of these sets of questions.

A second set of meetings was held in Las Vegas from the 26th August to the 1st September 2001. Plenary meetings were held with USDOE staff and contractors in order to develop a deeper understanding of the issues raised in the written questions and answers. Observers from the general public, the State of Nevada, and the USNRC were present at all open meetings. Closed-door meetings of the review team were held to discuss substantive issues. At the close of the plenary meeting on the 31st August, the IRT Chairman, Tönis Papp, made an oral presentation of preliminary observations by the IRT to USDOE staff and contractors at an open meeting.

Following the second Las Vegas meeting, the IRT members compiled and reviewed this final report, which was then submitted to USDOE in November 2001, for fact-checking only. Following this examination by USDOE, the IRT received comments, included in Appendix 4, which have been incorporated in this final version.

1.4 Organisation of this report

The organisation of the report is as follows. Section 2 presents some general considerations on the regulatory environment, the performance assessment rationale and approach, and documentation. The methodology and scientific basis for sub-systems, corresponding primarily to Chapter 3 of the TSPA-SR report, are reviewed in Section 3. Section 4 reviews the integrated TSPA methodology corresponding primarily to Chapters 1 and 2 and parts of Chapter 5 of the TSPA-SR report. Finally, the most important conclusions and recommendations of this review are collected together in Section 5. Appendix 1 sets out the Terms of Reference for the review and Appendix 2 presents brief CVs for members of the IRT. Appendix 3 contains detailed comments on the TSPA approach to the saturated zone hydrogeology of the Yucca Mountain area. Appendix 4 contains the comments received from USDOE after fact checking of the draft report, and the IRT responses.

2 General Considerations

2.1 Regulatory perspective

The regulatory requirements set down and proposed for the YMP are somewhat more prescriptive than in many other countries, both in specifying safety requirements and in directing how these must be met. Particularly relevant in this regard is the specification of a period of ten thousand years for which the applicant must provide reasonable assurance (USNRC proposed regulation) or reasonable expectation (USEPA) that a radiation dose limit will not be exceeded. Other examples are: (i) the detailed specification of a stylised human intrusion scenario; (ii) the precise specification of the distance to the receptor area; (iii) the specification of the representative volume of groundwater to be used in human uptake and dose rate calculations; and (iv) the requirement that events with probability of occurring as low as 10^{-8} per year should be modelled and assessed numerically. *The IRT acknowledges and accepts that these regulations are the product of extensive debate in the US and represent a considered view that provides a legal basis for accepting, challenging and implementing decisions.*

Furthermore it is recognised that the role of the USDOE is to provide impartial advice to elected officials, who are responsible for decision making. In this context the IRT has been impressed with the openness of YMP staff in explaining the points of view of project opponents and critics.

The regulations require that a risk-informed approach should be adopted in demonstrating compliance with the dose limit, in recognition of the uncertainties inherent in making assessments over long time frames in the future. It is also required that the assessment should reveal an understanding of the relationship between the performance of the repository sub-systems and the total system performance. Nevertheless despite the prescriptive nature of the regulations, the IRT notes that the proposed licensing regulation 10CFR 63 states that "*consistent with a performance based philosophy, the Commission proposes to permit DOE the flexibility to select the approach for demonstrating this relationship that is most appropriate to its analysis*".

In its review of the TSPA-SR, the IRT has observed a tendency for more focus to be given to the demonstration of numerical compliance with the proposed regulatory requirements than on developing and presenting an understanding of repository performance. Whilst it is completely understandable that the TSPA-SR should give due attention to demonstrating compliance with the prescribed dose limit, an in-depth understanding of the performance of the repository system is necessary to develop confidence in the overall design and safety of the repository and in the results of the assessment. In this regard, there is an emerging international consensus that building confidence in repository performance is of comparable importance to demonstrating compliance with criteria. *Thus it is recommended that in the future equal attention should be given to system understanding as to numerical compliance with regulatory criteria if the project proceeds to the licensing stage.*

In presenting the outcome of the performance assessment, probabilities and consequences are generally combined together emphasizing compounded performance measures. Examples of such compound performance measures are the expectation value for an ensemble of calculations, and the combined results for the nominal evolution scenario and the probability-weighted disruptive events scenario. Whilst this is appropriate for demonstrating numerical compliance with regulatory requirements, it tends to obscure the interpretation of results. For example, it would have been helpful if the TSPA-SR had shown more intermediate results as a means of improving the understanding of system performance, for example the dose-time curves for realizations in which volcanic disruption takes place.

International recommendations recognise the validity of presenting assessment results in both an aggregated and a dis-aggregated manner. Dis-aggregated results provide an aid to understanding, for example by displaying probabilities and consequences separately and enhancing the understanding of the effectiveness of sub-systems (ICRP, 2000). They therefore provide more information for making subsequent decisions on the acceptability of repositories. *Thus it is recommended that in future assessments more emphasis is placed on dis-aggregation of the results.*

Finally it is noted that the US regulations are currently the subject of legal challenges. Thus it would be prudent to ensure that any TSPA is robust to possible regulatory changes, such as the 10 000-year compliance period. As this review considers the TSPA-SR from an international perspective, it is hoped that it might contribute to an understanding of such regulatory robustness.

2.2 Performance assessment rationale

The Terms of Reference require the IRT to review the *"rationale being used in support of the current site-recommendation decision process"*. The rationale chosen by the YMP was to carry out a TSPA and determine whether it is likely that the selected repository design at the Yucca Mountain site will be able to meet the quantitative licensing requirements of the USEPA standard and the USNRC proposed rule. With this rationale, the question of site suitability requires a preliminary evaluation of compliance over 10 000 years. The YMP chose to meet this by designing a waste package that, based on current corrosion data, would last 10 000 years without any release. While the IRT accepts this as one logical way to proceed, it has resulted in a bias towards performance of the engineered barrier system. It is not the only rationale that could have been used. The effect is to undervalue the considerable potential of the geological barriers.

For example the YMP assessment could have focused more on the role of the site in assuring total repository safety. The robustness of the site suitability could have been illustrated by examining possible conditions that would make the site unsuitable and showing that they have low probability.

The TSPA is not an isolated exercise but involves an iterative process where engineering design is adjusted in order to demonstrate compliance with the regulatory requirements. In view of this the flexibility of the engineered barrier concept could have been demonstrated by showing how design adjustments could compensate for reasonable discrepancies between the real and assumed site characteristics.

Alternative rationales for site suitability evaluation could also have been based around the development of a "safety case" to support the decision at hand. Performance assessment is only one component of the safety case, other components being development of a strategy to achieve safety as distinct from the strategy for demonstrating compliance, with an emphasis on obtaining and communicating an understanding of the integrated system ant its performance and favouring dialogue with the relevant stakeholders. The demonstration of the existence of multiple barriers in the repository design and natural system is also a part of a safety case. In addition a safety case should include a statement of confidence in its findings at each stage that acknowledges the existence of any unresolved issues and provides guidance for work to resolve these issues in future development stages (NEA 1999).

The TSPA-SR has in itself some elements of a safety case, but the focus on demonstrating numerical compliance with regulations has taken the foremost priority vis-à-vis understanding and confidence building aspects.

The IRT is of the opinion that it would have been preferable to have incorporated the TSPA within a safety case in support of the site recommendation decision, and to have formulated this within well-developed strategies to achieve safety and to demonstrate compliance. It is recommended that this approach be followed for the next decision point in the programme.

2.3 General approach to performance assessment

The objective of a TSPA is to provide an understanding of the overall system performance and to provide a safety-related basis for decision making, in this case for site suitability. Compared with the evolving international trends in performance assessment, the contents and focus of the TSPA-SR have been more directly influenced by the prescriptive nature of the proposed US regulations than is typically the case. This has caused tension between the objective to develop and demonstrate understanding and the objective to evaluate the likelihood of compliance with quantitative criteria.

The general approach used in the TSPA-SR is set out clearly in Chapters 1 and 2 of the TSPA-SR report together with a useful summary of the regulatory context. In essence the general approach consists of the following five major steps:

- Identifying and screening potentially relevant features, events and processes (FEPs) to develop scenarios;
- Developing models;
- Estimating parameter ranges and uncertainties;
- Performing calculations; and
- Interpreting results.

At this level of detail, the general approach to TSPA, and the USDOE approach of building on an iterative series of performance assessments, conform to international best practice (NEA, IAEA and CEC, 1991).

A sixth step is also mentioned in the TSPA-SR report, namely the development of a repository safety strategy and the principal factors. This step is discussed within a separate Repository Safety Strategy (RSS) document (CRWMS, 2000b) which is potentially the most important safety case report but whose status is somewhat unclear. This represents a move towards implementing the NEA Confidence Document (NEA, 1999), as discussed in Section 2.2 above.

As with any systems approach, the first requirement is to define what is included in the system and is modelled explicitly, and what lies outside the system and influences its evolution through initial and boundary conditions. Given the regulatory requirement to perform a probabilistic assessment the TSPA-SR makes the choice of including virtually all relevant FEPs within the system model, and thereby only considering two scenario classes (nominal and disruptive) reflecting differing external conditions. This has necessitated the development of a complex system model incorporating hundreds of FEPs and their interactions. It is to the credit of the Yucca Mountain Project (YMP) that this has been carried out in a systematic, scientifically competent and professional manner.

In particular, a bottom-up approach has been adopted, linking process-level models to assessment models, which is at the forefront of international developments. In future assessments this might usefully be complemented by a top-down approach in which models are developed to be as simple as necessary from the outset. While most of the Process Model Reports (PMRs) and Analysis Model Reports (AMRs) have not been scrutinised in detail by the IRT, it is clear that they constitute an impressive body of work leading from fundamental science to the system-level models used in the TSPA-SR.

The IRT notes that a complementary more-deterministic approach could have been used, as has been done in a number of other countries, namely to base the assessment on a best-estimate model of system behaviour with major uncertainties addressed by examining scenarios derived from the effects of external FEPs.

While the IRT acknowledges that the broad sweep of the TSPA-SR performance assessment methodology is in line with international best practice, it has encountered some issues worthy of further consideration for future iterations, and these are discussed in later sections of this report.

2.4 Documentation

The full set of documentation, including supporting reports, provides a comprehensive and impressive account of relevant issues, models and data. In areas where the IRT has examined supporting documents, they were found to exhibit a good level of traceability. Moreover, the documentation has clearly been prepared with great care and attention to detail.

A good attempt has been made to integrate the total system performance assessment: it is logical and well structured but the story of the repository evolution is not told particularly well.

The overall clarity and comprehensibility of the report could have been better, and may have been affected by the report being aimed at a number of audiences with different needs. In future it would be appropriate to produce documents aimed at different sets of stakeholders in order to overcome this problem.

In its present form the length and complexity of the documentation make it rather impenetrable to all but specialists. Moreover, in some cases, the descriptions of the sub-systems are incomplete and the interpretation of results could be improved. The Executive Summary could also have been more appropriately written at a higher level and in a more readable style. Some of the illustrations are excellent, some unnecessary and some more appropriate for an oral presentation rather than a scientific report.

The IRT recommends that, at an appropriate point, the USDOE should produce a document of a few tens of pages where the whole YM concept, context, and safety case is presented in a form amenable to a more general audience. This should emphasise the expected performance of the repository up to and beyond the compliance period. A relevant example is the summary of the Canadian Environmental Impact Statement (AECL, 1994).

3 Sub-system methodology

3.1 Repository design

There seem to have been rather large changes in repository design between iterations (e.g. since the TSPA-VA) but no clear rationale for these changes was discernible from the TSPA-SR report. Design changes are often made to improve safety or provability. However, in the TSPA-SR it was not clear why backfill was not considered when it has many favourable aspects from a safety perspective. Also, the reasons for changing the sequence of metals used in the waste package and introducing drip shields were not discussed in the TSPA-SR. In previous disposal concepts, cement was to be used in large quantities as a barrier and a seal in the repository, but this now appears to have been abandoned. One result of these changes in design is that it slows the convergence of the iterative series of performance assessments. *The IRT recognises the need for a performance assessment to be well focused on a given design. However, the IRT recommends that a discussion of design improvements and their role in the safety strategy should be included in future safety case documentation. This would provide continuity and would enhance confidence by demonstrating that the project is maturing and developing in a logical and systematic manner.*

Contingencies for dealing with poor ground conditions and heavy fracturing in the repository area, that had not been recognised from prior drilling and excavation of the ESF and Cross Drift tunnels, appear to have developed in a rather *ad hoc* manner. There appears to be only a limited amount of data from boreholes and the present drifts on which to base predictions for rock conditions in the repository area. Thus, plans for waste loading, container and drift spacing, etc., may need to be revised once excavation has begun. More borehole drilling is needed to verify the suitability of the emplacement site.

The proposed USNRC regulation (10 CFR Part 63) requires that the repository design allows for retrieval. However, retrievability is not discussed in the TSPA-SR apart from listing in the FEPs. The potential impacts of the provisions made for retrievability should be discussed in future assessments, including degradation of waste packages and drifts and possible damage to the drip shield carriage system prior to closure.

The IRT also notes that changes in the thermal loading and spacing of waste packages within the repository are under consideration. Changes in design, if adopted, will require a reassessment of the total system performance.

3.2 Engineered barrier materials

The primary components of the engineered barrier system, namely the drip shield and waste package, are depicted in Figure 1. The materials selected for the waste package outer barrier (Alloy-22) and drip shield (Titanium Grade 7) are in line with international best practice, having regard for the specific chemical environment at Yucca Mountain. Also, the waste package design shows a good balance between mechanical strength and corrosion protection. These materials are well known to be highly resistant to general corrosion, local corrosion and stress corrosion cracking (SCC) under a variety of disposal conditions including rock salt, granite and clay.

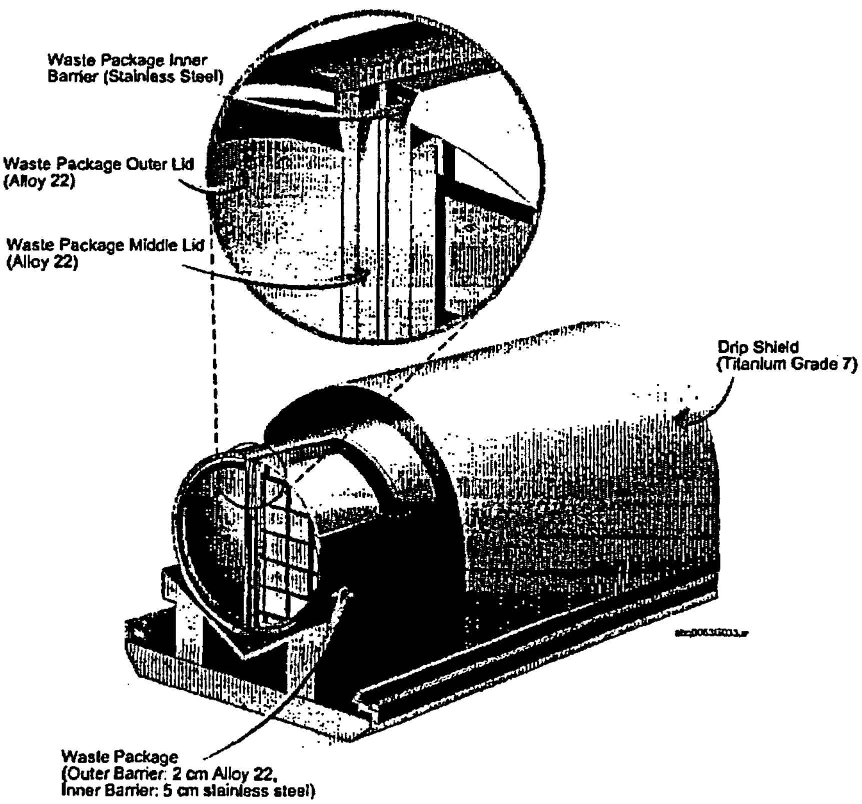

Figure 1: Schematic design of the drip shield and waste package (CRWMS, 2000a).

In the current design, the drip shield is largely redundant since the Alloy-22 barrier is somewhat more effective. However, the use of dual barriers of dissimilar materials provides defence-in-depth and contributes to the overall confidence in the system.

The present investigations under Yucca Mountain conditions indicate good corrosion resistance. The general corrosion rate is extremely low and the experiments performed to date do not indicate a susceptibility to local corrosion. However, these experiments have not covered the full range of conditions expected in the repository. The available limited experimental results on SCC of welds of the Alloy-22 do not allow a statement on the long-term resistance of this alloy to SCC. Moreover, the tests performed to date have been of relatively short duration compared to typical incubation times for localised corrosion in such corrosion resistant materials. In order to build confidence in the performance of these materials over thousands of years in the anticipated Yucca Mountain repository environment, *it is recommended that long-term corrosion tests using multiple specimens are carried out to investigate the effects of:*

- *Gamma radiation field, especially on Alloy-22;*
- *Kinetics of pitting and crevice corrosion;*
- *Salt deposits on local corrosion;*
- *Stress corrosion cracking, especially on welds of Alloy-22;*
- *Microbially enhanced corrosion;*
- *Ageing especially for Alloy-22.*

These experiments need to examine the effects of water chemistry (including pH and Eh) and temperature over ranges relevant to anticipated repository conditions.

In addition to the testing of small-scale coupons, it is recommended that larger specimens from real and model containers (including welds) should be investigated in order to determine the impacts of manufacturing processes and surface area.

A key challenge is to improve confidence in the extrapolation of corrosion performance to the 10 000-year regulatory compliance period and beyond. In order to accomplish this, *it is recommended that:*

- *To the extent possible, improved experimental methods are developed for accelerated testing;*
- *Measurements of the microscopic structure and composition of the passive oxide layers are made as an aid to scientific understanding of corrosion mechanisms;*
- *Models are developed, refined and validated based on scientific understanding, as an aid to extrapolating experimental results in time.*

In order to improve the understanding of the robustness of the system, it would be worthwhile to investigate the consequences of a "what if..." case in which there are a small number of early canister failures. This would address the concern that early failure of waste packages has not been properly considered and modelled. Coupled with this could be further discussion on the effectiveness of the drip shield and waste form to resist the effects of drip movement, and tunnel deformation and collapse.

3.3 Waste form

Twenty-six radionuclides are considered in the TSPA-SR report based on an initial screening process. The IRT notes that some radionuclides (such as ^{36}Cl and ^{135}Cs) that feature as important in other international studies (NEA 1997a) were screened out after the TSPA-1995. It is possible that changes in the disposal concepts or models since 1995 could affect the relative importance of radionuclides.

For instance, ^{36}Cl has been screened out because it is not a fission product. However, it is produced by neutron activation of contaminating Cl in the fuel. It has been shown to be an important contributor to dose in, for instance, the Canadian program (Johnson et al. 1995). Although USDOE calculations appear to have been made to determine its contribution from this source, further examination is required to resolve this issue together with laboratory measurements in spent fuel leaching tests.

The IRT recommends that the inventory screening procedure should be reviewed and amended as appropriate.

Furthermore, it is noted that the biosphere dose conversion factors used in screening out radionuclides did not properly account for short-lived daughters of long-lived parents when determining whether to screen out the parent. However, the USDOE has assured the IRT that plans are in place to deal with this issue.

In the TSPA-SR, the cladding remains a significant barrier up to 100 000 years and beyond. This is not the same as in other international studies where different conditions exist and little credit is given for the cladding. In discussion with the IRT, the USDOE has argued that conditions at Yucca Mountain are more favourable to long-term maintenance of the cladding barrier. The IRT was impressed with the depth of thought given to this issue but found one process (effects of the degradation of basket components on cladding integrity) that was not taken into account and which could compromise the performance of the cladding. *The issue of cladding performance is important because it is one area of possible optimism and because it has a major effect on system performance beyond 10 000 years. Thus further efforts are recommended to strengthen confidence in this area.*

The degradation of the Commercial Spent Nuclear Fuel (CSNF) controls the source term because it dominates the inventory and because it is less durable than the HLW. As modelled in the TSPA-SR, the degradation of the CSNF is relatively rapid because of the oxidising conditions and the presence of carbonates in the water which complexes the uranyl species.

The release of some radionuclides from the waste package is governed by solubility limits, which are given in Table 3.5-8 of the TSPA-SR. Some of the solubility limits for elements (especially Np, Th, and Ra) are simplifications made in the absence of reliable data. The most important area of uncertainty is neptunium solubility and the degree of incorporation of neptunium into secondary phases. Neptunium solubility is a strong function of pH and Eh in the water within the degrading waste package.

The pH and redox potential of the water in equilibrium with the waste package are extremely important variables in determining the release of radionuclides from the near field. The degradation of the CSNF will occur within the same timeframe as other components in the waste package: the steel, Alloy 22, titanium drip shield etc. These processes will consume oxygen and, in some cases, protons and will tend to push the system towards reducing conditions. There is a wide variation in the predicted pH in computer simulations (below pH 3 is some cases), the reason for this variability appears to be due to the presence of sulphur in the carbon steel. If this is a problem it could be overcome by using low sulphur steel. Having regard to the above factors, *it is recommended that more experimental data be obtained to build confidence in the thermodynamic modelling, especially with regard to the complex interactions between the waste form and components of the waste package.*

There is some uncertainty as to whether the fast release fraction of volatile radionuclides has been adequately investigated and included in TSPA-SR. Further discussion on this topic should be included in future assessments.

3.4 Transport within the engineered barrier system

Figure 2 depicts the engineered barrier system during the initial stages of water ingress and degradation. In the TSPA-SR, water ingress and radionuclide transport within the engineered barrier system (EBS) is assumed to occur by the following mechanisms:

- Advection through the degraded container[4]; and
- Diffusion through stress-corrosion cracks.

[4] Diffusion through degraded waste packages was also considered in the TSPA-SR. See Appendix 4.

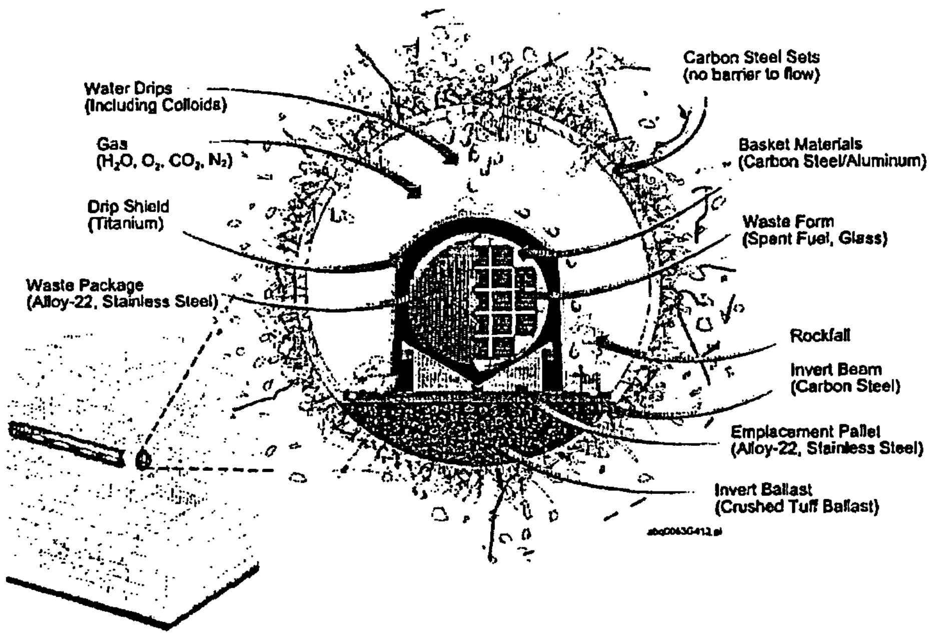

Figure 2: General engineered barrier design features, initial water movement, and rockfall (CRWMS, 2000a).

The second mechanism, which is dominant for many millennia after the waste package is breached, is overly conservative and complex and possibly not credible. The model requires a continuous film of water to allow diffusion that extends all the way from the waste form to the cracks in the degrading waste package and to the bottom of the invert. In applying the model, the TSPA-SR assumes very conservatively that the process of diffusion occurs even when there is no dripping in the location and the drip shield is intact. Furthermore, as discussed below, the existence of a continuous water film seems most unlikely because of evaporation. Moreover, the presence of the emplacement pallet (see Figure 2) is ignored and the waste package is assumed to be lying on the invert.

The model for spatial flow in the engineered barrier system is so complex that it is not easy to determine the effect of the conservative assumptions. The TSPA-SR lists (in Section 3.6.3.1) six noteworthy conservatisms but concludes that the magnitude of the conservatisms cannot be estimated because of the complexity and statistical nature of the model.

One aspect that has not been given sufficient attention is the possibility and probability for any liquid water to exist on and within waste packages over long time scales. The evaporation potential of water due to the decay heat of the waste is in fact substantial, exceeding 1 000 litres per container per year before 10 000 years and will still be of the order of 100 litres per year per container at 100 000 years. It appears that the USDOE have not taken this factor into account. Indeed, it is questionable whether larger seepage rates than the evaporation potential could ever occur over reasonable time scales for assessment of performance. The probability of extraordinarily high seeps should be better investigated. Design fixes, such as capillary barrier backfill, could be considered for any areas where seepage could be too high.

The overall conclusion from the analysis of engineered barrier transport is that the model is at the same time too complex and too conservative. In particular, the IRT recommends that the inclusion of a diffusion pathway in the absence of any advective flow onto or into the waste package, or indeed the presence of any liquid water, should be independently reviewed to determine if it is credible and whether the complexity serves a valid purpose. If this apparent over-conservatism is removed, the calculated repository performance beyond 10 000 years could improve substantially.

The corrosion of engineered barriers and components of the waste package (steels) could result in localised reducing conditions within the degrading waste package (see discussion in Section 3.3). Moreover the iron oxides formed by corrosion processes are known to be highly retentive of radionuclides. Both these factors should retard the release of uranium and actinides from the near field environment and should be considered in future waste package modelling studies.

Concentration limits assumed for the various radionuclides are regarded as a principal factor affecting post closure safety, both with regard to requirements for defence in depth and for contribution to performance. For many radionuclides this factor is, among other things, sensitive to the materials used in the repository. The materials intentionally brought into the repository are of course listed, but there should also be a systematic search for stray materials that could be spilled or unintentionally left in the repository and an identification of sensitive substances that would not be allowed to be brought into the repository.

The possibility of drift degradation by collapse of steel support sets and the tunnel roof appears to have been thoroughly examined in the supporting documents of the TSPA-SR and the integrity of the drip shield is claimed to be maintained throughout at least the first 10 000 years. These conclusions are largely derived from the results of a model that describes the formation and collapse of 'key blocks' in the emplacement drifts. The model shows that largest key block that may form (~ 50 tonnes[5]) is not expected to breach the drip shield although verification and validation of the model has yet to be performed. Therefore, the caveat 'to be verified' applies to these conclusions. The work proposed by USDOE to identify suitable natural analogues for code verification and validation is, accordingly, important and welcome.

3.5 Unsaturated zone

Figure 3 shows a conceptual drawing of water flow within Yucca Mountain. The unsaturated zone (UZ) is the region above the repository and below the repository but above the water table.

Infiltration into the unsaturated zone has been a difficult parameter to quantify at Yucca Mountain (YM). The IRT understands that several methods have been used to determine infiltration but it would have been helpful if these had been described and the level of confidence in each discussed. In the TSPA-SR, fracture flow becomes increasingly important with increase in depth and is allowed to dominate at repository level to simplify calculations while remaining conservative. This approach appears to be appropriate although it is not clear whether the assumption of linear behaviour of flow-path characteristics (e.g. capillary suction pressures in the rock matrix) can be expected throughout the range of infiltration cases and climate scenarios.

Evidence of past climate has been determined, appropriately, from nearby locations (Devil's Hole, Owen's Lake) to derive the three climate states for the next 10 000 years. This approach fulfils the requirement expressed in the review of the TSPA-Viability Assessment that wetter climates be incorporated in the model.

Water leaving the EBS flows through the UZ to the water table a vertical distance of 175 m to 365 m (depending on climatic conditions). Flow calculations within the UZ are done ahead of time for input into the radionuclide transport model.

Modelling of fluid flow and radionuclide transport in the UZ utilises the dual-permeability[6] approach in which flow through fractures is relatively fast whereas most of the porosity resides within the rock matrix. Sorption processes are neglected in the fractures but occur within the rock matrix. Colloidal transport is also modelled for radionuclides that are either reversibly or irreversibly-attached to the colloids. This

[5] The maximum expected key-block size is 37 tonnes, and calculations indicate that no cracks will form in the drip shield up to a key-block size of 52 tonnes. See Appendix 4.

[6] Terminology corrected. See Appendix 4.

treatment is similar to that used in other repository studies where disposal occurs into fissured rock.

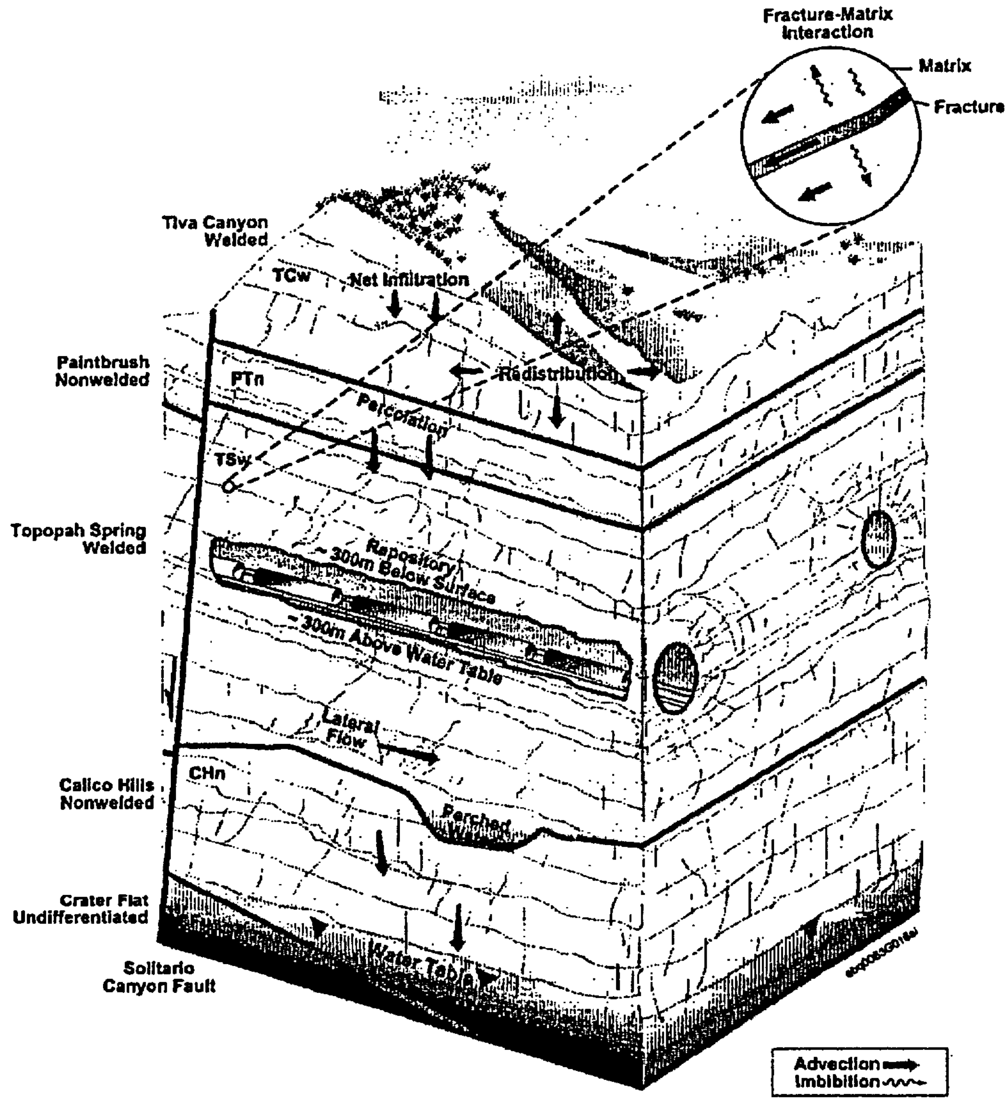

Figure 3: Conceptual drawing of mountain-scale flow processes (CRWMS, 2000a).

The description of transport in the UZ is clearly written and the illustrative figures (see Figures 3.7-9, 10 and 12 in the TSPA-SR) are useful. They show that the average transit times in the UZ are typically 500 to 1 000 years for non-sorbing species such as ^{99}Tc, 1 000 to 10 000 years for ^{237}Np and >100 000 years for irreversibly and reversibly-bound Pu, respectively. This illustrates the ability of the Yucca Mountain geological strata to retain radionuclides, a fact that is otherwise masked in the TSPA-SR by the dominance of engineered barriers for the first 10 000 years and more.

One important caveat needs to be given. The modelling of flow and radionuclide transport in unsaturated media is complicated by the presence of both air and water in the void space. The major uncertainty in the current model is the extent of continuity between water in the fractures and matrix. This can have an important effect on the output of the model. Also, the fracture-matrix exchange-reducing parameter, which is supposed to account for channelling into and clogging of the fracture planes, needs to be validated by additional field tests both for the migration of water and nuclides. *The only real way of resolving these issues is by experimentation and thus it is recommended that experiments be conducted to validate the model of flow and transport in the unsaturated zone.*

Independent evidence of the groundwater flow rate through both the UZ (and SZ) can be obtained by use of groundwater 'dating' (residence time) techniques, such as the measurement of the naturally occurring isotopes ^{3}H, ^{14}C and ^{36}Cl. Little indication of this work is given in the TSPA-SR although there are citations to excellent AMRs on this topic, in which these and other techniques have been applied. What is not clear, however, is whether and how these results have been incorporated in the flow models for the UZ (and SZ).

For representing flow and transport in the UZ, the TSPA-SR has developed a full 3-D model of the site. However, this model has not used the existing large-scale experiment that the present ventilation of the exploratory tunnel is providing. *The IRT suggests that head measurements in the rock matrix and water extraction by the ventilation system should be used to test the 3-D UZ model, and thus potentially confirm the estimate of the present large-scale permeability of the rock and also infiltration rate into the mountain.*

The TSPA-SR determined that some of the dose comes from insoluble or relatively insoluble species of Pu, Th and possibly other actinides. These species are transported, in part, by colloids generated by corrosion of the waste form or in the invert below the waste form. The support for colloidal transport appears to come largely from measurements of Pu at the Nevada Test Site (NTS) although the amounts transported were extremely small in that study. The TSPA-SR supporting documents give a somewhat confusing picture as to whether colloidal transport is at all important. It is possible that it is over-rated as a transport mechanism, but this needs to be clarified. It is noted that the mobility of biological species is treated differently to colloids.

Natural dripping of groundwater from fractures or pores in the matrix has never clearly been observed[7] in the drifts at Yucca Mountain, because it is affected by drift

[7] Clarification made. See Appendix 4.

ventilation, and yet it plays an important role in the analysis. This begs the question as to whether the assumptions about dripping are too conservative. Also, the time and spatial dependence of dripping, if dripping occurs, needs to be understood better. One possibility is that dripping could be controlled by installing a capillary barrier backfill. *In view of its critical role in the assessment, the IRT recommends that the postulated dripping process be better understood and quantified. Also, the influence of temperature on capillary suction should also be taken into account, as the surface tension of water decreases with temperature*[8].

One possible approach to understanding seepage into drifts is to make use of the analogy of stalactites in caves caused by drips from the cave roof. Limestones are fractured in a similar manner to YM tuffs and it is possible that a study of drip frequency, volume and distribution has already been made by speleologists and may be found in the karst or speleological literature. This could form the basis of a model for describing dripping and migration of the drip source.

3.6 Saturated zone

For the purposes of radionuclide modelling, the saturated zone (SZ) extends from the point at which radionuclides reach the water table to the receptor point in the model farming community (see Figure 4). The farming community is assumed to be 20 km downstream in the TSPA-SR but this will need to be adjusted to 18 km following finalisation of the EPA regulation, 40CFR 197 (EPA, 2001).

The IRT expresses concern about the level of knowledge available for assessing the role of the saturated zone (SZ) in the TSPA-SR, both at the regional scale and at the site scale. The geological structure and hydrogeological properties of the Death Valley Basin and of the Yucca Mountain region are clearly very complex. The amount of data that has been collected by the USGS and USDOE, particularly on the site and its surroundings, is significantly too low for adequately supporting the role that is to be played by transport in the SZ, in a multi-barrier approach of a TSPA.

The IRT observes that the SZ flow system at YM is very complex and not sufficiently understood to propose a conceptual model for a realistic transport scenario. A number of site specific features have to be investigated in the continued site investigations before a realistic flow model can be built. This is discussed in detail in Appendix 3 and summarised below.

[8] 10% decrease over the temperature range of 20 to 60 degrees C.

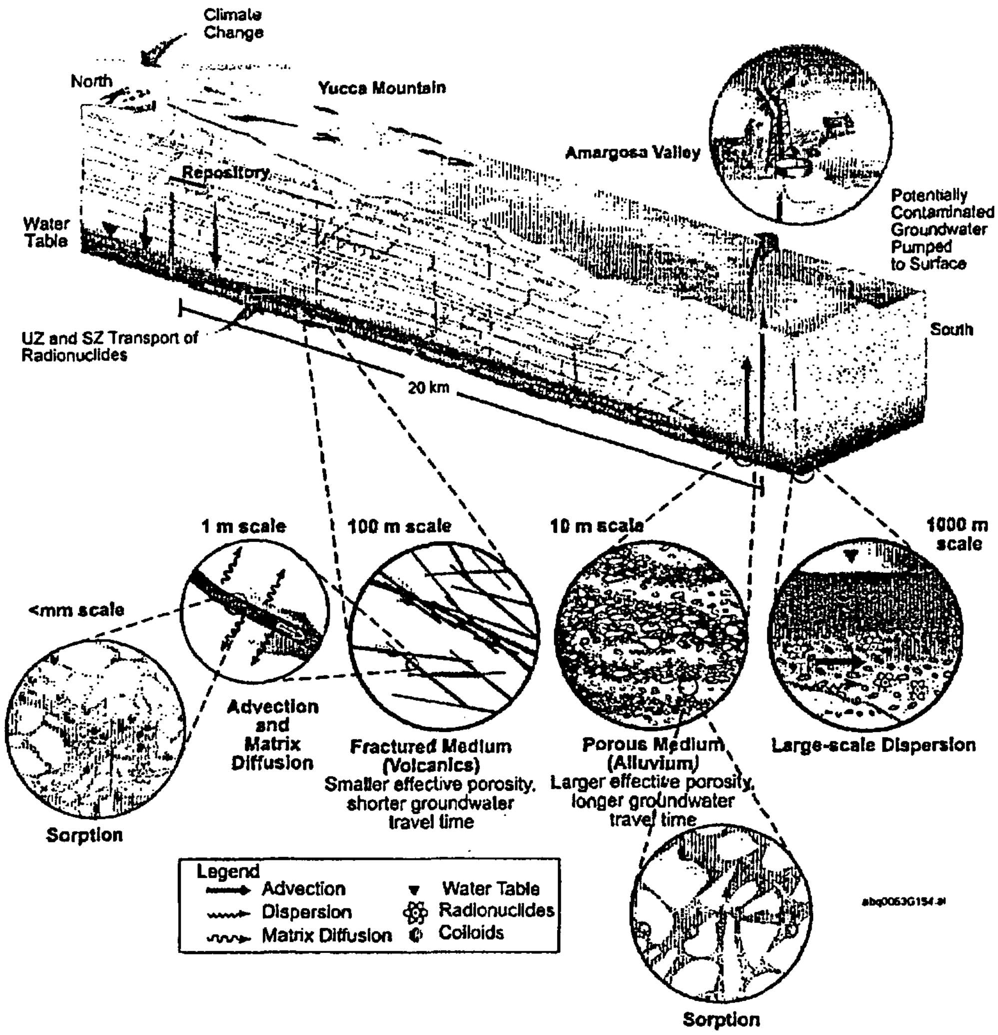

Figure 4: Conceptualisation of features and processes important to saturated zone transport (CRWMS, 2000a).

Regional scale flow model

At the regional scale, the USGS has assembled a significant amount of information. However, the treatment of this information to construct and calibrate a regional groundwater flow model is considered by the IRT not to be state-of-the-art, and to be below what has been done in the US at other sites (e.g. WIPP) or in the oil industry. A reliable regional SZ flow model is necessary to provide the boundary conditions of the site model, and also the predicted regional hydrology in different climatic conditions. *It is recommended that a significant effort be made to improve the regional SZ flow model. This effort should be closely integrated with the improvement of the site model, in order that these two models be made consistent with each other, which is not the case at present.*

Site scale flow model

At the site scale, there is a gap of information between the location of the repository and the potential receptor, 20 km downstream. Furthermore, there are indications from the C-holes study that the single-well tests that have been made so far in the area do not provide results consistent with those of the multi-well tests. This introduces a very significant uncertainty in the understanding of the system, which needs to be resolved in order to qualify the existing single-well data. Finally, there are indications, which need to be confirmed, that the fractured volcanic rocks can display a significant horizontal anisotropy.

The USDOE has built a site scale flow model that, in its description of the geology of the site, is a much better approach than that used in the regional model, but which is very difficult to make consistent with the information extracted from the regional model. However, there is still room for improvement. *It is recommended that the site flow model should be improved based on the new data that is to be collected, and better calibrated, using for instance additional information such as the temperature data that is available in the area.* By interactive adjustments with the regional model, a coherent picture of the SZ flow at both scales should be obtained. Once this model has been adequately calibrated, a conditional approach to the residual spatial variability of the system should be implemented, analogous for instance to work carried out for WIPP. This variability analysis should incorporate both the distribution of permeability and that of recharge, in a consistent way.

Treatment of uncertainty

In the TSPA-SR, the USDOE has fully recognised the large uncertainty that is inherent in the lack of data and the poor quality of the regional model. This uncertainty has been accounted for by assuming an uncertainty range of a factor of 100 in the velocity in the aquifers, and by further assuming that two different conceptual models (isotropic and anisotropic) can be used alternatively with equal probability. Such a large uncertainty in the velocity of the aquifer has been extracted from the judgement of an Expert Elicitation Panel, which thus acknowledges the unreliability of the estimates provided by the regional model.

The IRT has also observed that the uncertainty factor on the velocity in the aquifer creates an equal uncertainty factor in the regional groundwater flux entering into the model. However, in the Monte-Carlo sampling, no correlation has been introduced between the magnitude of this flux and the magnitude of the recharge estimate, which is also randomly sampled in the TSPA. The SZ model can thus have a very large groundwater velocity associated with a very low recharge rate, and vice versa, which *a* *priori* seems inconsistent. While there may be potential reasons explaining this decision, nowhere in the TSPA-SR nor in the AMRs that the IRT reviewed has this feature been addressed. It thus gives the impression that the TSPA-SR contains undefined and unjustified decisions that can potentially affect the outcome of the analysis, and thus the credibility of the results.

The IRT considers that introducing such a large uncertainty in the TSPA is likely to induce "risk dilution" effects (see discussion in Section 4.3), thus impairing a reasonable understanding of the role of the SZ barrier in the system performance measure, and further generating non-conservative biases in the calculated expectation value of dose. This potential effect has not been analysed in the sensitivity study of the system, and is presently unquantified. The IRT consider that it would have been preferable, in the absence of additional data, to have reconsidered the range of uncertainty derived from the Elicitation Panel. This could have been done by reconvening the panel, and then, as in other parts of the TSPA, to have used a conservative model of the SZ rather than the potentially non-conservative approach used in the present TSPA-SR. *For future analyses, the IRT recommends that additional data should first be collected, and an improved model constructed, calibrated and validated, and then run in a spatial variability analysis, not by using a large uncertainty factor.*

Radionuclide transport

Section 3.8 of the TSPA-SR report on transport in the saturated zone is well written and logically ordered. There is, however, a general reluctance to seek out and clearly display hydrogeological/geochemical evidence that could build confidence in the models. Examples of this are the validation of assumed water types that reflect different climates over the last 10 000 years and measurements of the mobility of naturally occurring radionuclides that are also contained in the waste (e.g. ^{14}C, ^{36}Cl, ^{99}Tc, ^{129}I, ^{238}U) in both natural analogues and Yucca Mountain itself. Evidence is needed in the TSPA-SR to support proposed hydrogeological flow paths, modelled groundwater residence times and flow rates, and groundwater redox conditions at discharge zones.

The importance of colloids is again discussed in the TSPA-SR for transport of low solubility radionuclides in the SZ. As noted for the UZ, however, the importance of colloids in contributing to dose may be overrated. Several conservatisms have been made with respect to the role of colloids: filtration of reversible (surface-sorbed) colloids is not considered, minimum values of K_d are used for the highly sorbing radionuclides (Am, Pu, Th) in the SZ, chemical equilibrium is assumed so that mobility is maximised, and K_d values for the least sorbing rock unit in the SZ are used.

This likely results in an overly conservative assessment of the importance of colloids in the SZ.

3.7 Biosphere

The outputs from the SZ transport model are the fluxes of radionuclides crossing into the receptor area. In the biosphere model, radionuclide concentrations in the receptor area are calculated simply by dividing the mass of each radionuclide by the volume of water that is assumed to be used by the model farming community. The volume used in the TSPA-SR will have to be adjusted to the EPA regulation, which is 3,000 acre-feet (3.7 million m^3). Also, as the assumption of a constant pumping rate is an extreme stylisation, other credible evolutions of the pumping rate should be considered.

The biosphere model assumes that all contaminated water from the repository is utilised by the model farming community. Thus no accumulation occurs apart from irrigation of soils for production of crops.

The Yucca Mountain biosphere modelling programme has recently been the subject of a comprehensive international review (IAEA, 2001) and thus in general it has not been thoroughly scrutinised by the IRT. However, one geosphere-biosphere interface issue has arisen in connection with the review of saturated zone hydrology, and this is discussed below.

The TSPA-SR focuses on calculating doses to individuals making use of water from a specified receptor well located 20 km from the proposed repository, as prescribed by regulation. As such, the TSPA-SR document does not address the issue of the long-term fate of the radionuclides leaving the repository in the groundwater.

The IRT considers that this may be a relevant issue in the case of Yucca Mountain, because, contrary to most international planned repositories whose final outlet is the sea, Yucca Mountain is a closed basin system. Thus all releases will eventually end up in some location within the basin (see Figure 5). There is therefore a risk that accumulation and possible reconcentration of radionuclides could occur, leading to potential non-trivial doses.

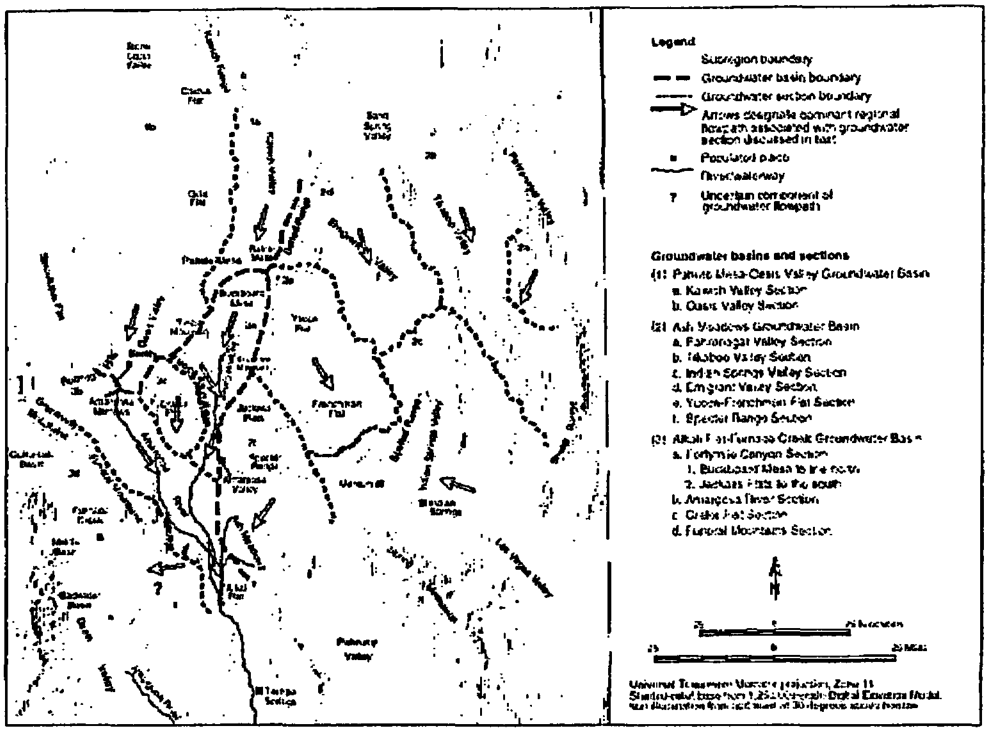

Figure 5: Groundwater basins in the Yucca Mountain vicinity (DOE, 1999).

The TSPA has identified one FEP consistent with this concern, namely "the role of playas". Playas can indeed be final recipients of contaminated groundwater, where it would evaporate and accumulate the transported radionuclides. This FEP has been screened out as "low consequence" by the TSPA-SR. The USDOE is of the opinion that the potential doses in the long term to an exposure group living near a playa would be lower than those from the regulatory farming community wells, located 20 km away from the repository, thus closer to the source.

The IRT considers that this opinion and the screening out of this FEP are probably valid for the regulatory period of 10 000 years, and the regulatory "farming community" receptor. It is however unsatisfactory for longer periods, such as the 1 000 000-year period included in the TSPA-SR, where the long-term consequences of the repository are presented, independently of the regulatory compliance measure. The IRT encourages the USDOE to formulate and analyse such a scenario in order to exhibit its in-depth understanding of the long-term consequences of the construction of the repository.

It is possible that natural analogues could help to determine the long-term fate of radionuclides at Yucca Mountain. For example, uranium at Peña Blanca has not moved very far. This is also the case for uranium at Alligators Rivers even though the conditions are oxidising and far wetter than at YM. This illustrates the importance of making realistic assessments in order to understand the safety margins inherent in the TSPA-SR.

The IRT recommends that long-term fate of radionuclides from the YM repository should be considered in future assessments, including addressing the following questions:

- For the present climate, what is the final fate of the radionuclides reaching the farming community, and supposedly extracted from the groundwater? Since most of the water is used for irrigation, where do the nuclides end up after they leave the soil compartment of the biosphere? Can they reconcentrate and where, and at what rate? Is there a potential pathway to man linked to this potential reconcentration?

- If the water is not extracted by the farming community, what is the fate of the radionuclides? Where do they go, do they reconcentrate, is there again a potential pathway to man?

- For a wetter climate, the TSPA-SR indicates that Death Valley would become a lake again (Lake Manley), and that Fortymile Wash and the Amargosa Valley (see Figure 5) would become perennial streams and eventually discharge into this lake. Will the radionuclides leaving the repository end-up also in this lake? Over what time scales? What would be the fate of the radionuclides in this water, can they reconcentrate, and is there a potential pathway to man?

- The IRT also questions the rationale for keeping constant the volume of water extracted by the farming community, when the climate becomes more humid.

3.8 Disruptive events

Probability of eruption

Recent volcanic activity in the Yucca Mountain Region (YMR) is clearly limited to basaltic eruption of the strombolian type. Probabilistic analysis of volcanic vent alignments in the YMR leads to the conclusion that there remains the possibility of a basaltic dike intersecting the repository during the next 10 000 years. The description in the TSPA-SR of this possibility is rather vague, compared to that of the consequences, and should have been treated in more detail. Details of the probabilistic methods used in estimating the probability of a dike intersecting the repository are covered in supporting documents, but it would have been advisable to have included a brief discussion of the probabilistic volcanic hazard analysis models in the TSPA-SR report.

The volcanic event used in the calculations was defined as a dike, rather than a point process or fissure eruption, for example. Again, even though the reasoning for this assumption is mentioned elsewhere, it should be stated in future safety reports.

The low rates of volcanic activity in the region of Yucca Mountain yield insufficient data to make a precise determination of the probability of volcanic activity affecting the repository. Condit and Connor (1996) were able to make comparisons of actual eruption locations, and probability maps were calculated from a spatio-temporal model developed for the YMR (Connor and Hill, 1995) in the larger Springerville volcanic field, Arizona. The results of such studies applying models developed for the YMR to other larger volcanic fields should be included in future reports.

Consequences of volcanic disruption

The type of eruption assumed in the ASHPLUME model needs to be stated. In the case of strombolian type eruptions (the most probable type in the YMR) few fine-grained particles are produced because fragmentation is not very efficient and only minor amounts of ash are produced. The eruption results in the formation of a scoria cone where pyroclastic fall deposits are generally limited to the close vicinity of the vent, mostly less than 10 km. The probability of fine-grained particles of volcanic or radioactive waste material reaching a distance of 20 km from the eruption source (as depicted in the ASHPLUME model) is extremely low. A strombolian type eruption may rarely become violent, which is more intense with fall deposits having a wider distribution than that of strombolian eruptions. Therefore, a violent eruption is acceptable as a conservative assumption.

However, there are some examples in other volcanic fields, where basaltic volcanic activity is associated with amounts of rhyolitic volcanic activity (e.g. the Newberry Volcano Group in Oregon, and the Higashi-Izu Monogenetic Volcano Group in central Japan). Such association of two different kinds of magma is known as bimodal. Rhyolitic eruptions can form a lava dome at and occasionally under the surface. They are more explosive than basaltic eruptions and would lead to significantly greater amounts of waste particles that are more widely distributed. Also there exists the possibility that the thermal influence would be more intense and of longer duration than that for basaltic eruptions.

Bimodal volcanism was not mentioned or discussed in the TSPA-SR. *It is recommended that future assessments should estimate the probability of bimodal volcanism and, if relevant, should analyse its consequences.*

Seismological influences

The IRT consider that the TSPA-SR adequately addresses seismological influences on the performance of the proposed repository. The TSPA-SR analysis is in line with other international studies. For example a study at the Kamaishi Mine in Japan (Shimizu et al., 1996) showed that earthquakes are likely to have an insignificant impact on the performance of a repository.

3.9 Human intrusion

Human intrusion has the potential to impair the performance of a geological repository. Since the nature of future human activities at a repository is subject to great uncertainty, it is common for regulatory authorities to require assessment of a stylised (i.e. simplified) human intrusion scenario (NEA, 2000).

Both the USEPA and proposed USNRC regulations require assessment of a stylised scenario involving drilling through the waste package to the saturated zone. Although this scenario is unrealistic in several respects, the IRT accepts it as an indication of the resilience of the system to a breach of a waste package coupled with accelerated transfer to the environment.

The TSPA-SR assumes penetration of the waste package (including cladding) by a 8" (20 cm) diameter drill 100 years after closure (a 10 000 year intrusion event is also considered as part of the sensitivity analysis). In the conceptual model, the borehole does not remain open but is degraded by inward collapse of surrounding material. The model allows increased infiltration of water into the hole but not direct flow of surface water. The calculation of mean dose rate is based on probabilistic analysis as in the nominal scenario.

The mean dose calculated by the model rises to about 0.01 mrem/year after 1 000 years and remains fairly constant thereafter. The peak dose is insensitive to the time of intrusion and, significantly, ^{137}Cs and ^{90}Sr make no contribution to the dose since they decay before reaching the accessible environment. This is a powerful demonstration of the resilience of the system to a significant disturbance or early failure by any mechanism of a significant number of waste packages.

However, there is one caveat that should be noted. Insufficient information is provided in the TSPA-SR or supporting documents to determine the extent to which infiltration is increased by the borehole. However, it appears that infiltration remains zero in many realisations. *The IRT recommends that this optimism be removed by allowing direct surface water flow into the borehole so that water flows into the degraded waste package in every realisation of the computer model.*

The current regulations do not require any consideration of deliberate intrusion or sabotage. In this context, the IRT notes that the repository will contain large quantities of uranium, plutonium, titanium, and nickel and that it is conceivable these could be targeted for economic, proliferation or other reasons.

3.10 Natural analogues

Natural analogues are naturally-occurring systems that experience processes similar to those that might occur in a nuclear waste repository. They have typically been used to represent the whole of the repository but the current view is that they are best used to represent specific processes or subsystems of the repository. Natural analogues may provide data that is useful in: (i) understanding long-term processes such as corrosion and mineral dissolution/precipitation; (ii) determining the important parameters of radionuclide migration such as radionuclide flux, sorption sites and groundwater residence times; and (iii) modelling the performance of the repository. However, a more important use is the increased confidence they can give to the assessment of long-term performance of a repository that generally cannot be obtained in laboratory or field studies. The USDOE has identified several sites for natural analogue study and, in 1999, selected the Nopal I uranium deposit in the Sierra Peña Blanca in northern Mexico for limited investigation. The site is very relevant because of the remarkable number of characteristics it shares with Yucca Mountain. These include climate, precipitation, rock types and their mineralogy, presence of both an unsaturated zone and a saturated zone, occurrence of faults, and the predomination of oxidising conditions. A few differences exist (depths, U inventory, and distance to discharge point) but these are not important to the analogy.

Despite prior investigation by other groups, the amount of data and the level of understanding of the analogue are relatively low in comparison with international analogue studies such as Oklo and Cigar Lake. *The IRT feel that the USDOE should now make use of the opportunity to improve understanding of the analogue and use its characteristics to increase the confidence of the public and scientific community in the Yucca Mountain programme.* In particular, to give a better understanding of radionuclide mobility in these conditions, groundwaters, fracture-filling minerals and host rock should be analysed for naturally occurring isotopes, such as ^{14}C, ^{36}Cl, ^{129}I and

U-series nuclides, some of which also occur as major contributors to dose in the TSPA-SR model. The concentration of ^{99}Ru in the playa could be used to investigate long-term accumulation of ^{99}Tc.

In parallel with the Peña Blanca study, the use of naturally occurring U and its radioactive daughters in the tuffs at Yucca Mountain should continue to be investigated by USDOE to improve understanding of the mobility of U and analogue elements within the flow systems of the mountain. A large suite of data have been obtained on the calcites and opals found in fractures at the ESF level and this has given a good understanding of the mechanisms of fracture infilling, processes of seepage flow and ages of secondary infillings. $^{234}U/^{238}U$ activity ratios for perched waters and saturated zone groundwaters have recently been found to be significantly higher than off-site groundwaters indicating that U-series radionuclides are a potential useful tracer for Yucca Mountain recharge as well as providing insight to the migration of U in the mountain. More data are needed for pore fluids in the tuff matrix to verify the preliminary analyses that have shown ratios to be much lower than the other Yucca Mountain groundwaters. Analysis of ^{226}Ra is also suggested to provide analogue data and understanding of radium mobility as well as to indicate the likely source of radon gas which occurs in high concentrations in the Exploratory Studies Facility (ESF) and Cross Drift tunnels in the absence of ventilation.

The IRT recommends that natural analogues should be used throughout the programme to provide long-term data to assist in understanding the important processes and to increase the level of confidence in the assessment, particularly for the public and scientific community.

4 Integrated Total System Methodology

The broad features of the total systems methodology used in the TSPA-SR are set out clearly in Chapters 1 and 2 of the report and are generally in line with international best practice. This section considers some issues where developments of the methodology would be beneficial for future assessments of Yucca Mountain.

4.1 Features, events and processes

From an international perspective a key aspect of performance assessment is the identification and selection of features events and processes (FEPs) that influence repository safety. This is partly due to the fact that it is the starting point for defining the evolution of the repository system, and partly because of the recognised difficulties arising from the long time spans addressed. The IRT has found the FEP methodology used in the TSPA-SR to be in agreement with the international state-of-the-art, and recognises the important contributions to the international development that has come from work within the YMP.

However, the IRT has observed that the regulatory requirements have had a large impact on the FEPs included in the TSPA-SR analysis. This has resulted in certain FEPs that are important for a full understanding of the system behaviour being screened out (e.g. see Section 3.7).

The IRT has carried out some spot checks of the TSPA-SR FEP identification and screening process. This has identified a potentially important FEP that has not been included, relating to cladding/basket interaction, as is noted in Section 3.3. Also, the effect of temperature on capillary suction should be considered, as noted in Section 3.5. This points to some shortcomings in the routines and procedures for the FEP identification and screening process and in the QA of assessment input, which should be revisited and revised as necessary.

While the regulatory compliance period is 10 000 years, the YMP team are to be commended for extrapolating some of the TSPA-SR simulations out to longer times in order to estimate the time and magnitude of the maximum expected dose. For example, this is valuable for comparison with the results of performance assessments in other countries. However, in the TSPA-SR FEPs have been screened out on the basis of demonstrating compliance up to 10 000 years and thus the assessment is less reliable at longer times. The YMP may wish, therefore, to carry out a performance assessment iteration that is focussed more specifically on the long-time behaviour. In view of this, *the IRT recommends that in future the screening of FEPs should be made in two stages. The first stage should retain all FEPs required for a full understanding of repository performance, while the second stage should include regulatory considerations in the screening criteria.*

This dual approach is consistent with having a strategy for building confidence in the safety of the repository together with a strategy for demonstrating compliance with regulatory requirements.

4.2 Uncertainty

Need for a comprehensive framework

Consideration of uncertainty lies at the heart of the TSPA-SR. This is appropriate since uncertainty is inevitable in the assessment of the long-term performance of a repository. However, a consistent overall strategy and approach to the management and treatment of uncertainties appears to be lacking in the TSPA-SR, with uncertainties being treated in a somewhat *ad-hoc* way. This is also the conclusion reached by an internal DOE audit (Rogers et. al., 2001), which reviewed and evaluated the adequacy of the uncertainty treatment in the suite of TSPA-SR technical documents including PMRs and AMRs.

The IRT considers that the current treatment of uncertainty in the TSPA-SR needs to be improved. *It is recommended that future iterations of the TSPA should aim to set out and follow a comprehensive and systematic framework for treating all types of uncertainty.* This should involve the systematic identification, classification and quantification of uncertainty and its effects on the results. Also there should be an identification and ranking of the possibilities to avoid or reduce uncertainty. *The YMP needs to classify uncertainty on the basis of type and in particular whether it is due to intrinsic variability or to lack of knowledge. It is important to identify these latter uncertainties since they can lead to risk dilution* as discussed elsewhere in this review (see especially Section 4.3).

When uncertainty exists there is a tendency to skew the model or values of parameters towards conservatism. This is appropriate for demonstration of compliance but results in embedded conservatism. It is appropriate to attempt to identify conservatisms and possible optimisms (this has been done to some extent by the YMP) and then, additionally, to run the model for the most likely situation (this has not been attempted). Conservatisms and possible optimisms should also be ranked in terms of their importance to overall performance and confidence in the system.

Unnecessary complexity in models is a possible source of uncertainty because it involves the introduction of additional parameters, each of which is subject to uncertainty. The IRT considers that some of the sub-system models especially those that may be difficult to validate within the in-drift environment (see Section 3.4) are unnecessarily complex. Simplification of a model facilitates understanding, reduces computer time and allows effort to be focussed on the most important issues. It could also assist in presentations to the public and acceptance of the facility.

Finally, it is observed that currently there is a very large range of estimated doses based on probabilistic analysis (often extending to four orders of magnitude or more). This large range presents a credibility problem. *The IRT recommends that reduction in uncertainty should be a major goal of the YM project and that attention should be focussed on obtaining good laboratory and field data in those areas where uncertainty has the greatest effect.*

Model uncertainty

Quantification of uncertainty involves running of models to determine the effect of input uncertainty on the output of the model. The sensitivity analyses performed to date have been very useful in identifying the importance of parameter uncertainty for the various barriers in the system, but not for model uncertainty.

Model uncertainty has in general been treated by attempting to select the model that is intrinsically the most conservative. However, it is very difficult to prove that this is the case *a priori*. Thus it is suggested that where appropriate in future assessments, alternative models (with their associated parameters) should be examined as separate calculation cases to determine which is the most conservative when embedded in the full system model. In particular, alternative models suggested by other interested organisations (e.g. EPRI, State of Nevada) should be evaluated in a systematic way. This is an important issue, as model uncertainty can often be the dominant source of uncertainty, but can be overlooked as parameter uncertainty is more easily quantified. In some situations it is likely that deterministic rather than probabilistic calculations would be appropriate for assessing model uncertainties, and would have the added benefit of the results being more readily comprehensible.

Evolution of uncertainty with time

Intuitively one would expect uncertainty in performance measures to increase with time. However, this does not generally appear to be the case with the TSPA-SR. One reason for this is that the relevant FEPs are chosen primarily to be relevant to the 10 000-year compliance period (see Section 4.1) whereas in practice new uncertainties would be introduced over time. However, it is acknowledged that uncertainty related to the engineered barriers can decrease with time as their importance for the performance of the total system decreases with time. This question deserves further investigation by the YMP.

The meaning of numerical calculations and results

At present, the TSPA nominal case is treated probabilistically yet it involves a mixture of embedded conservatism and statistical analyses to determine the mean, median and the various percentiles of the dose distribution. The reported "mean" is therefore not the true mean in a statistical sense. This issue is discussed further in Section 4.3. Moreover this value is reported in the Executive Summary of the TSPA-SR and elsewhere as the expected value of effective dose, without any qualification. This stretches credibility especially as the discrete numerical values are given for times in the far future. The USDOE needs to indicate that, for compliance purposes, a performance indicator has been chosen that is meant to illustrate the safety of the system and argue the compliance with regulation. However "probability" does not indicate the actual probability of occurrence and "dose" has a different interpretation from its usage in operational radiation protection.

The IRT recommends that the USDOE more clearly indicate the meaning of the calculational approach that is taken and of the quantities that are used to report its results.

4.3 Probabilistic methodology

Given the regulatory requirements in the US, it is appropriate to make use of a probabilistic systems analysis framework for analysing a potential repository at Yucca Mountain. However, the IRT is of the opinion that there are some issues that require further consideration. These have previously been considered within the NEA Probabilistic System Assessment Group and are reviewed in (NEA, 1997b). These issues pertain to the most effective use of the Monte Carlo method, its numerical convergence, and the potential for risk dilution.

The IRT considers that issues raised by the Probabilistic System Assessment Group, especially risk dilution, should be addressed in future assessments.

Realism or conservatism

At a fundamental level, it is useful to resort to a probabilistic analysis of a system evolution in time if a realistic model can be attempted but legitimate uncertainties persist. However, if the starting model is built *a priori* to be conservative, exercising it probabilistically has little or no added value, as one would still obtain conservative results. If the modelling attempts to be realistic one can claim that some probabilistic measures e.g., the 99th percentile, constitute, *a posteriori*, a conservative measure of performance. In the TSPA-SR a hybrid conservative/probabilistic methodology is used, which causes assumptions and reality to be mixed in a confusing way. *In the future it may be appropriate to present: (i) a probabilistic analysis based on a realistic or credible representation; and (ii) a set of complementary analyses with different conservatisms, in order to place the best available knowledge in perspective.* These ancillary analyses could be given a probabilistic weight as well. This should satisfy the regulatory requirements whilst providing a better basis for dialogue and decision-making.

Besides, as is shown elsewhere, constantly invoking conservatism, e.g., in establishing probability distributions, has the potential to lead to risk dilution.

The IRT recommends that when a best estimate/best knowledge probabilistic analysis is performed, the best estimate or the most probable range of the calculated "dose" should also be given. This should be in addition to the current upper limiting values at an appropriate percentile, as a measure of the maximum reasonably expected value.

The IRT notes that while the final licensing decision requires a probabilistic approach, this is not necessarily the case for the site recommendation decision, and some complementary deterministic analyses would have been appropriate as an aid to understanding system behaviour.

Finally, it is noted that assumptions and parameters that are conservative for one performance measure may not be conservative for another. For example a calculation that is conservative for the compliance period may not be conservative for longer times.

Convergence

There are questions as to whether the 300 realisations used in the TSPA-SR are sufficient for the mean dose and other statistical measures to be fully converged. With such a low number of realisations, some high-consequence low-probability realisations may be missed. Convergence cannot be judged simply by sight, as it was done for TSPA-SR. *The IRT recommends that in future a more formal approach should be taken to deciding whether the results have converged. Also, alternative sampling schemes (e.g. Monte Carlo rather than Latin Hypercube) and much larger numbers of realisations should be considered. More importantly, the probability density function*

(PDF) of calculated doses should be presented. A peer review by experts in statistics should be considered.

Risk dilution

The probability density functions (PDFs) for parameters used in the TSPA-SR represent the combined effects of stochastic variability and subjective probability representing uncertainty (incomplete understanding). There is a tendency to broaden the PDFs especially when experts are polled and subjective uncertainty is important. This is not necessarily a conservative approach and can lead to a situation where increasing ignorance leads to lower expected doses.

The Probabilistic System Assessment Group of the Nuclear Energy Assessment (NEA, 1997b) stressed that risk dilution is an issue that deserves attention in probabilistic safety assessments. In assigning PDFs to describe the uncertainty in the parameters there may be a tendency to overestimate the uncertainty, that is, to overestimate the width of the parameter distributions. The term "risk dilution" is used to describe a situation in which an increase in the uncertainty of the input parameters of a model may lead to a decrease in the mean of an output quantity. If over-estimation of uncertainty results in mean consequences being reduced, the unfortunate effect is that what appears to be a conservative step (enlarging the range of uncertainty, or advancing the occurrence of unfavorable outcomes) lead to an over-optimistic assessment of mean system performance.

One circumstance in which risk dilution is a concern is when the performance measure in question has a peak in time, and the time of the peak is affected by uncertain parameters. Averaging over the range of values of the model inputs amounts to averaging over alternative situations in which the peak value of the performance measure occurs at different times. At any given time, the mean value of the performance measure is obtained by averaging cases that lead to the peak occurring at around that time with others for which the consequence is smaller. The wider the distribution of the uncertain inputs, the more the averaging process mixes in smaller values. Hence the term "dilution".

A second case arises when increasing the uncertainty range of an input parameter leads to an increase in the time over which radionuclides are released. This can lead to a reduction in the maximum release rate and mean dose.

Finally, averaging over cases or scenarios that have very different probabilities of occurrence leads to a risk dilution effect for the high consequence situation. In this case, dis-aggregation of the results is necessary.

The IRT is of the opinion that the TPSA-SR presents conditions for risk dilution to have occurred, but that this issue has not been addressed nor analysed. This requires further scrutiny.

Consequently, *the IRT recommends that an assessment should be carried out of the quantitative importance that risk dilution might have on the magnitude of the performance measure. In future, the measures taken to avoid risk dilution should be carefully described.*

4.4 Sensitivity analysis

The IRT was favourably impressed by the methods and quality of the sensitivity analysis used in the TSPA-SR and in the supporting documents especially CRWMS (2000b). Sensitivity analysis is necessarily performed to determine the relevance to performance of different components and processes. *The IRT recommends that sensitivity analysis be further developed into a tool to build an integrated and comprehensive understanding of the relative importance and role of different barriers and processes.* This should be an iterative process within the project, which eventually should help to build confidence in the robustness of the barriers and provide a guide for removing complexity when the latter is not necessary.

4.5 Safety case

The development of a deep geological repository is typically characterised by several stages within a step-wise process and, overall, requires several decades for completion. The long duration of this process reflects the desire to proceed by cautious steps with due regard to technical issues and societal acceptance. At the end of each development stage a decision is taken whether to move forward, and whether the requirements for the next development stage need to be adjusted.

The various decisions must be supported by performance assessments with regard to the possibilities of achieving acceptable post-closure safety. To be complete, the decision basis must contain both comprehensive technical material, and less technical information discussing how the remaining unresolved issues, excessive uncertainties or unquantified safety margins are to be resolved. An international consensus has developed over the past few years (NEA 1999, NEA 2001, IAEA 1997) that it is advantageous to present the more technical arguments in respect to repository performance in a TSPA document, and the broader safety arguments in a more generic "safety case" document.

As noted in Section 2.2 *the IRT recommends that if the Yucca Mountain project proceeds to the licensing stage, a safety case should be developed along the lines discussed in the NEA Confidence Document (NEA, 1999), rather than primarily focusing on TSPA.* The key aspects of such a development are discussed below.

The safety case that presents arguments relating to the long-term safety of the repository is one of the key bases in support of the decision that is to be made. International developments in the last decade have progressively emphasised the need for a safety case in addition to more quantitative performance assessment considerations. For example the IAEA (1997) have described a range of considerations aimed at achieving reasonable assurance of the safety of a disposal system including multiple lines of reasoning and the use of a range of indicators.

The NEA Confidence Document (NEA, 1999) describes the general features of a safety case. The growing international consensus that a broadly based safety case document should be produced is further documented in NEA (2001), which expresses the consensus of experts from 20 national programmes. According to this and other NEA documents, the safety case is the integration of relevant arguments, at a given stage of repository development, in support of the long-term safety of the repository. The basis for a safety case lies in science and good engineering practice, and this is reflected in the detailed and rigorous modelling of the disposal system, as well as in semi-quantitative and qualitative arguments made to support long-term safety. The strategy for coupling design adjustments, research and development work and performance assessment methods in order to achieve and prove an acceptable degree of safety should be addressed.

In addition, the safety case must provide a statement of confidence in the overall assessment of long-term safety, and argue the adequacy of the present science, engineering and modelling work for the stage of repository development or function being addressed. The existence of redundant multiple barriers in the system to assure safety in cases where the performance of one or more of the barriers is not realised should also be discussed. The statement of confidence should include an acknowledgement and discussion of uncertainties and unresolved issues, and provide a road map to the work being planned to resolve those issues.

The IRT recommends that key messages from the NEA Confidence Document should be addressed in a safety case report for Yucca Mountain aimed at both the strategy to achieve safety and to demonstrate compliance. In particular, a statement of confidence should be produced, which is an elucidation of the means that were adopted to reach sufficient confidence in the current analyses, an acknowledgement of the remaining *issues, and the suggested strategy for resolving the remaining issues in support of the next decision.*

The IRT recognises that the YMP has been participating in developing the international recommendations in this area and that in future efforts the area of confidence documentation and communication will receive heightened attention in line with the international trends. The current version of the Repository Safety Strategy (RSS) (CRWMS, 2000b) is a first commendable attempt at outlining the strategy for achieving safety and for demonstrating compliance with the regulations as well as the basis for confidence in the analyses. *The IRT suggests that the information contained in the RSS should be updated and extended, and used as a basis for developing the proposed safety case document for the next phase of the programme.*

4.6 System understanding

The TSPA-SR methodology embodies a comprehensive computational framework for estimating possible doses to future generations using a complex systems-level model accounting for hundreds of features, events and processes and related parameter ranges. A key issue with this approach is the difficulty in understanding the meaning of the numerical results. In particular, it is often difficult to understand how the system is likely to evolve and which process and parameters are the most important.

Within the TSPA-SR report most attention is given to quantitative results of the performance analysis. Relatively little emphasis is placed on the important issue of developing and communicating an understanding of system behaviour. However, the sensitivity analysis techniques described in Chapter 5 of the TSPA-SR report shed some light on this question. Also, the Repository Safety Strategy report (CRWMS, 2000b) is a useful starting point for developing and demonstrating a comprehensive system understanding. The IRT considers that demonstrating understanding should be complementary to demonstrating compliance and of equal importance.

Two types of assessment are needed to build an overall understanding of system performance. First, *a realistic (i.e. non-conservative) assessment of system evolution and radionuclide migration should be made, regardless of whether this can be demonstrated with reasonable assurance. This would be able to communicate the likely evolution of the repository to a range of stakeholders beyond the regulators, for example by drawing on natural and historical analogues.*

Secondly, *the understanding of the TSPA results should be improved, making use of a range of approaches*, for example the following:

- Development of an overall understanding of the key safety-relevant factors and arguments, and documentation of this in a fashion that is accessible to a wide range of stakeholders;

- Dis-aggregation of dose results in order to explain which factors or sub-scenarios can lead to large potential doses, explaining as well that the likelihood of occurrence would be small and also that dose – beyond a few hundred years – is not really a measure of detriment in the operational sense of radiation protection (see ICRP, 2000);

- Use of additional performance measures, for example showing the effects of each barrier and the spatial and temporal distribution of radionuclides within each component (e.g. waste package, EBS, UZ, SZ, receptor area) of the system;

- Development of a simplified interpretative or insight model containing only the key processes affecting safety, which can be used by people within and outside the YMP;

- Development of an understanding of the major conservatisms and optimisms in the analysis, and quantification of their impact with respect to more realistic assumptions;

- Development of an understanding of what extreme conditions might give rise to doses above prescribed regulatory criteria, and a description of the factors that make these situations unlikely;

- Description and prioritisation of the features (barriers in a broad sense) that are considered important to keep the releases and doses low;

- Documentation of where the major uncertainties are and how they might be dealt with in the future;

- Documentation of a sensitivity case where some or all engineered barriers are rendered ineffective;

- Presentation of the features and results for sub-scenarios as an aid to understanding and dialogue.

- Comparison of results with related assessments performed elsewhere.

The IRT recommends that a safety case produced in support of licensing should incorporate an improved demonstration of system understanding to counterbalance the present emphasis on uncertainty.

Finally, greater use should be made of the extensive archive of technical reports produced during earlier phases of the programme. In this regard the USDOE needs to ensure that it retains a corporate memory of the YMP.

5 Conclusions and Recommendations

The primary objective given to the IRT was to review and critically analyse the performance assessment *methodology* and *rationale* used by the USDOE in support of the current site-recommendation decision-process from an international perspective and to provide a statement regarding the adequacy of the overall performance assessment approach, and recommendations for future assessments. These three aspects are considered below.

5.1 International perspective

Yucca Mountain setting

The conditions prevailing at Yucca Mountain are significantly different to those considered in other national repository programmes in that Yucca Mountain is in a closed basin and the repository is in an oxidising environment above the water table. The IRT has taken due account of these differences in conducting the review.

Rationale

The rationale chosen by the YMP in support of the site-recommendation process was as follows. A total system performance assessment was carried out to determine whether it is likely that the selected repository concept at the Yucca Mountain site will be able to meet the quantitative licensing requirements of the USEPA standard and the USNRC proposed rule. The dose rate requirement for the 10 000 year period was met by designing the engineered barriers (with redundant features) so that, based on available corrosion data, there would be no release from the waste package under normal conditions.

This rationale is capable of addressing many important issues. However, at present, the extensive knowledge accumulated in many years of characterisation and analysis of the site is not utilised to its fullest extent. The IRT is also of the opinion that it would have been desirable to have placed greater emphasis in the TSPA-SR on the performance of the geological barriers in their own right. Moreover, a broader safety case should have been developed to support the site recommendation decision.

Methodology

The overall structure of the TSPA-SR methodology, and the USDOE approach of building on an iterative series of performance assessments, conform to international best practice. Moreover, the structured abstraction process linking process-level models to assessment models is at the forefront of international developments.

One of the first steps in a safety performance assessment is identification of the potentially relevant features, events and processes (FEPs). The IRT has found the FEP methodology used in the TSPA-SR to be in agreement with international best practice, and recognises the contributions to the international development that has come from work within the YMP.

The YMP places far greater emphasis on probabilistic assessment than equivalent programmes in other countries. Some known issues, and particularly "risk dilution", considered in the international fora such as the Probabilistic System Assessment Group of the NEA, have not been fully addressed in the TSPA-SR.

The YMP TSPA does not emphasise natural analogues as much as in some other international studies.

Regulation

The regulatory requirements set down and proposed for the YMP are somewhat more prescriptive than in many other countries, both in specifying compliance requirements and in directing how these must be met. Particularly relevant in this regard is the specification of a period of 10 000 years for which the applicant must provide reasonable assurance (USNRC proposed regulation) or reasonable expectation (USEPA) that a radiation dose limit will not be exceeded. Other examples are: (i) the detailed specification of a stylised human intrusion scenario; (ii) the precise specification of the distance to the receptor area; (iii) specification of the representative volume of groundwater to be used in human uptake and dose rate calculations; and (iv) the requirement that events with probability of occurring as low as 10^{-8} per year should be modelled and assessed numerically.

The way the regulations are formulated has contributed to the tendency of the TSPA-SR to focus more on demonstrating numerical compliance with quantitative criteria than on demonstrating an understanding of repository performance. Also, the US approach to regulation has focussed attention on the presentation of aggregated results that can be compared directly with regulatory requirements. The IRT considers that more intermediate results and dis-aggregated end results should be given. This would provide more information to decision-makers, a point emphasised in recent international recommendations on the safety of radioactive waste disposal.

5.2 Statement by the International Review Team

In response to the request by the USDOE to provide a statement regarding the adequacy of the overall performance assessment approach for supporting the site recommendation decision, the IRT considers that:

While presenting room for improvement, the TSPA-SR methodology is soundly based and has been implemented in a competent manner. Moreover, the modelling incorporates many conservatisms, including the extent to which water is able to contact the waste packages, the performance of engineered barriers and retardation provided by the geosphere.

Overall, the IRT considers that the implemented performance assessment approach provides an adequate basis for supporting a statement on likely compliance within the regulatory period of 10 000 years and, accordingly, for the site recommendation decision.

On the basis of a growing international consensus, the IRT stresses that understanding of the repository system and its performance and how it provides for safety should be emphasised more in future iterations, both during and beyond the regulatory period. Also, further work is required to increase confidence in the robustness of the TSPA.

5.3 Recommendations for future assessments

To provide better support to the next programmatic decision point, namely the preparation and submission of a license application, the IRT makes the following recommendations.

Understanding

1. The understanding and explanation of the behaviour of the TSPA-SR systems model should be improved, for example by placing more emphasis on dis-aggregation of the results. Also, a realistic (non-conservative) analysis should be made of the likely performance of the repository.

2. The USDOE should take steps to improve its corporate memory and make more use of the extensive archive of technical reports produced during earlier phases of the programme.

Safety Case

3. A safety case report should be developed along the lines discussed in the NEA confidence document.

Uncertainty

4. A comprehensive and systematic methodology should be formulated and implemented for identifying and treating all types of uncertainty.

5. A study should be carried out of the quantitative importance of risk dilution for the expectation value of dose.

6. The reduction of uncertainty should be a major goal of the YMP, focussing attention on obtaining good laboratory and field data in those areas where uncertainty has the greatest effect.

Modelling

7. The engineered barrier transport model should be independently reviewed and improved.

8. A significant effort should be made to improve the regional saturated zone flow model, by collecting new data and improving the calibration. This effort should be closely integrated with the improvement of the site flow model. The improved flow models should be run in a spatial variability analysis, not by using a large uncertainty factor.

9. A realistic understanding, utilising natural analogues, should be developed of the likely long-term fate of radionuclides and potential pathways to man in the closed basin.

Documentation

10. Documents should be produced summarising the performance assessment aimed at distinct sets of stakeholders, including a summary document for the whole YM concept, context, and safety case in a form amenable to a public of informed readers.

11. A discussion of design improvements and their role in the safety strategy should be included in future safety case documentation.

Engineered barrier materials

12. Long-term corrosion tests should be carried out on waste package and drip shield materials and the scientific understanding of corrosion mechanisms should be improved.

Waste form

13. The inventory screening procedure should be reviewed and amended as appropriate, so that all potentially important radionuclides are included in the analysis.

14. Further work should be carried out to strengthen confidence in the role of the cladding as a long-term containment barrier.

15. More experimental data should be obtained to validate thermodynamic modelling, especially with regard to the complex interactions between the waste form and components of the waste package.

Unsaturated zone

16. Additional experiments should be performed to enhance confidence in the model of flow and transport in the unsaturated zone.

17. Head measurements in the rock matrix and water extraction by the ventilation system should be used to test the 3-D unsaturated zone model.

Disruptive events

18. The probability of bimodal basaltic-rhyolitic volcanism should be estimated and, if relevant, its consequences analysed.

Human intrusion

19. Direct flow of surface water into the human intrusion borehole should be considered in future assessments.

Natural analogues

20. The USDOE should carry out further work at the Peña Blanca uranium deposit in northern Mexico.

21. Investigations of naturally occurring uranium and its radioactive progeny in the tuffs at Yucca Mountain should continue to be investigated.

Features, events and processes

22. The screening of FEPs should be carried out in two stages. The first stage should retain all FEPs required for a full understanding of repository performance, while the second stage should include regulatory considerations in the screening criteria.

Probabilistic methodology

23. A best estimate or the most probable dose range plus the upper limit value at an appropriate percentile should be presented as a measure of the maximum reasonably expected value.

24. A probabilistic analysis should be made based on a realistic rather than conservative representation.

25. A more formal approach should be taken to deciding whether the probabilistic results have converged. Also, alternative sampling schemes and much larger numbers of realisations should be considered.

26. The probability density function (PDF) of calculated doses should be presented.

Sensitivity analysis

27. The sensitivity analysis should be further developed into a tool to assist in building an integrated and comprehensive understanding of the relative importance and role of different barriers and processes.

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Appendix 3: Saturated Zone Hydrogeology

In Section 3.6 of this report, the IRT observed that the SZ flow system at YM is very complex and not sufficiently understood to propose a conceptual model for a realistic transport scenario. A number of site-specific features should be further investigated before realistic flow models can be built. This appendix presents a critical review of the present level of understanding and modelling of the hydrogeology at YM and of the features that require further investigation.

The comments in this appendix are based essentially on a review of USGS reports R96-4300 (D'Agnese et. al., 1997) and R96-4077 (Luckey et. al., 1996)), which are referred to as forming the basis of the hydrogeology of the site used in the TSPA-SR report.

In general the level of understanding of the hydrogeology of the site, based on these documents, is low, unclear, and insufficient to support an assessment of realistic performance. Furthermore, the modelling that has been carried out so far at the regional level, is not up to international standards and does not make optimal use of all the available data. This regional modelling is important as it provides boundary conditions for the local model and helps to determine the conditions at the site for future climates.

A better understanding of the flow through the saturated zone is necessary for at least two reasons:

- Estimating the groundwater travel time, and the nuclide travel time and flux at the regulatory limit, potential retardation mechanisms being taken into account, both in present-day conditions, and for a more humid climate;

- Estimating the potential dilution, which could occur between the repository and the selected abstraction zone.

From the evidence presented in USGS reports R96-4300 and R96-4077, it seems that these objectives cannot be met today, with any degree of confidence. With the present level of understanding it is a question of conceptual model uncertainty, not of parameter uncertainty. Therefore, the approach used in the TSPA-SR, namely to assume that a lack of exact knowledge can be compensated for by assigning a range of parameter uncertainties to a selected conceptual model assumed to represent the uncertain mechanisms, is not applicable. The conceptual model of flow in the saturated zone at YM is as yet undecided and uncertain and does not permit the building of a local model of flow and transport that would adequately address the two requirements listed above.

The site is obviously very complex, and the series of stratigraphic units in which flow is taking place is interbedded, fractured, highly variable both vertically and horizontally, and undersampled. The USGS Report R96-4300 describes the regional hydrogeology of the Death Valley system, and will be reviewed first. The USGS Report R96-4077 describes the local hydrogeology of the site, embedded in the regional setting. The first report is at best a preliminary attempt at quantifying this regional system, for which the IRT has some severe reservations. It cannot be viewed as a framework in which the local hydrogeology can be understood nor does it constitute the scientific basis on which to understand the flow system. The second report is more comprehensive and offers a better view of the local hydrogeology. However, it raises a large number of issues and presents several alternative conceptual models of the site, which cannot be judged at the present level of knowledge.

In general, the development of a conceptual model of the hydrogeology of a given area goes through the following steps:

1. Determination of the boundaries of the system;
2. Description of the major lithofacies in the domain, with their geometry, major properties, measured heads, etc;
3. Estimation of the recharge and discharge fluxes;
4. Development of a numerical model of the complex system;
5. Calibration of the model using all existing data;
6. Sensitivity studies.

This logic is followed when reviewing both USGS reports.

Review of Report USGS R96-4300

1. Boundaries. In the USGS report, the selection of the boundaries of the system seems relatively appropriate, although it is not a closed system. It would have been more satisfactory to extend the limits up to the actual physical boundaries of the system being drained by Death Valley; i.e. no-flow boundaries. However, the studied area is already very large, and the fluxes which have to be estimated on some parts of the boundaries which are not "no flow" must be relatively small, and would probably not greatly affect the global hydrologic balance and the understanding of the system.

2. **Lithofacies.** The description of the lithology is good in general terms, and the building of a Geoscientific Information System (GIS) to store and represent all the information on the 3-D geology of the site is a very good step. There are serious gaps in the knowledge because of the existence of large areas with few or no borehole data, or insufficient depth of the boreholes. One absence of data appears to be in geophysics. There is no reference to the use of geophysical data in the report, nor mention of the existence of such data. It is likely that much geophysical data have been gathered as part of the work done towards constructing the geologic model, prior to developing the flow model, because, a lot of useful information can be obtained from aeromagnetic surveys, gravimetric maps, seismic profiling, electromagnetic soundings, electric resistivity maps, etc. At other sites, studied for regional and local hydrogeology, particularly in nuclear waste disposal projects, such geophysical surveys have been made and used. This is all the more true as the second report R96-4077 mentions the existence of a large number of geophysical surveys of the area. The 3-D geologic model should have been consistent simultaneously with the borehole information, the surface geology, and the geophysics.

The information on the head distribution is inappropriately lumped into one single "average" system. There is only one piezometric map for the ensemble (Figure 27), and no attempt was made to present information on the differences in heads between the various units. It is understood that this is difficult, as the position of the screens in the wells is not well known, but some attempts at describing the head differences between hydrogeologic units should have been made. Are there vertical head gradients? Which are the units receiving or releasing water by vertical leakage? Are there low-permeability layers separating the various units? Only one such layer is mentioned, the Eleana formation separating the upper and lower carbonate aquifers (paleozoic rocks). The analysis of the piezometric data is not detailed enough to obtain an understanding of the vertical exchanges between the different lithologic units, nor a realistic understanding of the physics of the system.

When such important data are lacking, a detailed geochemical analysis of the water composition can help understand the importance of leakage (particularly when there are rocks as different as volcanics, carbonates, alluvia, etc). The geochemical signature of the waters could help to better understand the flow system. None of this appears to be considered in the report. By contrast, the second USGS Report R96-4077 puts a lot of effort into analyzing the differences in heads between the various hydrogeologic units, and particularly between the volcanics and the carbonates, which seems to be a very important issue. The use of the geochemical data is also mentioned and used in this second report.

3. **Recharge/Discharge.** Concerning recharge and discharge, it is understood that the problem is difficult, since neither is easily measured. But the presented work is not convincing. For one thing, direct evaporation of water from the water-table, even without any vegetation, is not discussed nor estimated. In arid areas, it is well known that evaporation can withdraw water even if the water-table is very deep. There are measures available with water-tables as deep as 10 m below ground, and empirical rules that relate evaporation to depth. In some areas, in Africa, in the 200 mm/y rain-depth area, there are closed depressions where the water-table is more than 70 m deep (it is not however proven that evaporation is the only cause of these depressions). Similarly, the estimation of recharge as percentages of rainfall, which vary with altitude, or classification of vegetation, slope or soils looks very arbitrary.

Furthermore, in arid climates, recharge often occurs by runoff followed by re-infiltration in wadis or gullies. This is not discussed in the report, nor is it evaluated. Moreover, in such systems, the recharge is often episodic, and occurs only in a few extreme years (e.g. every 30 years in North Africa, on average). If these episodic recharge events are not considered, the global water balance of a large system may be strongly biased. By contrast again, the USGS second report R96-4077 mentions both the infiltration in the Fortymile Wash, and the importance of major flows, the last major flow that occurred was in 1969, but extreme events occurring at frequencies such as every 500 years are mentioned.

When such uncertainties on recharge and discharge are present, it is necessary to use additional sources of information to try to estimate fluxes. Environmental tracers are used, e.g. the salt balance, the ensemble of natural tracers, and the "age" of water is used to determine velocities and hence fluxes and hence recharge. Temperature anomalies in borehole profiles are sometimes used to estimate fluxes, both vertically and horizontally. These are not discussed in USGS reports R96-4300 and R96-4077.

Finally, the hypothesis is made that the system is in steady state. Until calculations have been made that show that a steady state is relatively rapidly established in such a large system, which would be surprising, the assumption of equilibrium seems largely arbitrary: the system may still be reacting to past climate changes. By contrast again, the second USGS report R96-4077 specifically points out that the regional system may not be at equilibrium. Indeed the Winograd and Doty (1980) and Claassen (1985) references in USGS R96-4077 have precisely suggested that the system is still in a transient condition resulting from pluvial cycles during the Quaternary. This is not considered in the report.

4. **Modeling.** The modeling attempt that follows is unsatisfactory. Even if it may be an improvement on previous models, by being partly 3-D, the presented work is rudimentary and not up to standard international practice. For modeling of this complex system, two options were available:

1. Construct a very detailed geologic grid in 3-D from the GIS, supplemented with all the available geophysical information, using millions or even billions of nodes. In general, this grid is very thin in the vertical direction (e.g. 10 cm) and on the order of 10 m horizontally. This scale was for instance used in the study of the London Basin. The exact (or assumed) geometry of each lithologic unit is thus finely described and discretized. Each unit is assigned its estimated anisotropic hydraulic conductivity value. Then, a 3-D calculation grid is superimposed on the previous geologic one, with as many nodes as feasible given the available computing power (but currently closer to a million cells than on the order of 75,000 used by the USGS). A rigorous upscaling of the geologic model hydraulic conductivities to the scale of the flow model is made, giving the anisotropic hydraulic conductivity of the flow model (see for instance Renard and Marsily, 1997). Calibration of such a model is made by changing the hydraulic conductivity of lithofacies of the detailed model, and upscaling again, not by adjusting the flow model conductivity. The importance of each layer can then be assessed individually.

2. Construct a very detailed multi-layer model, where each aquifer lithologic unit is represented by a layer of meshes, and vertical links representing leakage are introduced between layers, with estimated vertical permeabilities. The extension of each layer is not necessarily continuous, and each layer is not necessarily present at all sites. It is common to use up to several tens of superposed layers, if necessary. The fitting of such a model is then based on treating each layer as a more or less homogeneous zone, (or subdividing it if it has known large variations e.g. of thickness, density of fractures, etc) and on calibrating the vertical conductivity between layers as well. This approach is consistent with, for instance, the detailed description of the hydrogeologic units at the site scale given in USGS R96-4077.

Neither of these two options was followed by USGS R96-4300. Instead, an arbitrary coarse mesh of three continuous layers was built. The hydraulic conductivity was assigned to each mesh in a crude fashion, by using the 50 percentile K value for each of the zones in the model, each zone having been defined by limiting the permeability to four different classes in the whole domain. These permeabilities were used as initial guesses, and then an automatic inverse procedure based on linear regression theory was used to improve the hydraulic conductivity distribution in the model. The selected grid size is elementary. Uniform squares were used over the whole domain, whereas it would have made much more sense to have variable size meshes, e.g. nested squares meshes, and to focus the grid on the areas of interest, i.e. the Yucca Mountain area and the downstream area towards Death Valley. This was not done.

The transmissivity in the model is assumed to be constant, and not a function of the saturated thickness of the aquifer. While this may be an acceptable starting point, it is not sufficient and should have been turned into a variable saturated thickness model, in order to study (as a complementary calibration exercise) what happens in the model during a humid period, when the recharge is higher. Such a calculation is for instance suggested in the second USGS Report R96-4077. Since a few indications of past elevation of the water-table are available, this would have been a second independent test of the plausibility of the model. This was not done.

At this stage of the development of the model, using an automated calibration method to improve the fitting is not useful. It may well decrease the discrepancy between observed and calculated heads. However, the structure of the model is so poor that it does not improve in any way the understanding of the actual functioning of each of the lithologic units of the system (whereas the methods (i) or (ii) above would have). The IRT also has strong reservations on the method of calibration. The hydraulic conductivity values have been initially grouped into four zones, each zone being assigned an initial hydraulic conductivity, as indicated above, and then this value is improved by automatic calibration. But the pattern of each zone is kept constant in space. These patterns are given in Figures 44, 46 and 47 for each of the three layers of the model. In fact, more than four zones were introduced, to account for some local complexities, a maximum of nine zones was finally selected. But the essence of the fitting is the following: if two areas of the model, tens miles apart or more, happen to belong to the same zone, the model calibration is forced to assign the same hydraulic conductivity to both zones. This does not make sense, and could be called "under-parameterization". If a zone could be identified with a lithology, this could have been a defensible approach, but given the arbitrary uniform discretization that was used, a "zone" is a complex assemblage of different lithologies. When the role of faults, the variability of facies, the thickness of each layer are so variable, this arbitrary calibration constraint does not make sense. The grid is inappropriate, but even with this grid, an initial manual trial-and-error fitting would have been more reasonable than this automatic calibration. Moreover, the fitting of the model is poor, the head residuals are large, 20 m is considered a good fit, a moderate fit is between 20 and 60 m of residuals, and a poor fit has residuals greater than 60 m. The same applies to spring flow.

5. **Sensitivity.** The sensitivity study that follows adds very little, given all the reservations on the structure of the model, the parameterization, and the fitting. Its only merit is that it is concluded from this analysis that the model is highly nonlinear, and that the linear regression analysis that is presented is only a rough indicator of simulation uncertainty. It does not give any clues to the important pathways for the water in the system (e.g. is most of the water flowing in the paleozoic carbonates? How important is vertical leakage? Are the alluvial sequences draining the system? What is the role of faults? Are the volcanic rocks anisotropic? etc.).

Review of Report USGS R96-4077

This report is a much better description of the hydrogeology of the site (at the local scale) than the previous one (at the regional scale). It provides a comprehensive description of the major hydrogeologic units, their relations, and the various conceptual models, which have been proposed to explain the observations. Although this work has been superseded by the new local SZ model developed by USDOE (TRW, 2000), the IRT's concerns about this report are as follows:

- Page 3. The IRT disagrees with the statement that *"because ground-water travel time in the saturated zone probably is much shorter than travel time in the unsaturated zone (US DOE, 1988) only limited characterization of it may be appropriate".* For one thing, the transfer in the unsaturated zone is no longer considered to be very long, and second, the dose to man is assumed essentially to occur through receptor wells at the regulatory limit, the flux to this limit cannot be accurately determined if the hydrogeology is not understood.

- Although the existence of geophysical data is mentioned (page 7), it is not clear how much of it was used to construct a detailed geological model of the site at the local scale, neither in this report nor in TRW (2000). To prepare for a model of the site, a GIS would be needed, as was done for the regional scale, but with a finer scale and intensive use of geophysics.

- The existence of an impervious (or semi-pervious) layer between the volcanics and the carbonates is very important to the understanding of the site, and the presence or absence of the Eleana formation needs to be more firmly established. It is realized that this would be a costly analysis.

- On page 36, it is mentioned that the fractured volcanic rocks are probably anisotropic. The work of Erickson and Waddell (1985, page 24-29, reference in R96-4077) is reported which gives an anisotropy ratio of 5 to 7 in the only case where an attempt was made at measuring this anisotropy (well USWH-4). This is an extremely important issue, because with such an anisotropy, the direction of flow may be very different from what is assumed today based on the gradient direction. This uncertainty was recognized in the TSPA-SR as a random choice (50%-50%) alternative, but was not resolved.

- Concerning the interpretation of the well tests, it is surprising that the dimensionality of the flow tests was never determined. Reference is made to the work by Barker (1988) who showed that the analysis of pumping tests could be done by also fitting the spatial dimensionality of the medium being investigated (this spatial dimension may vary between 1 and 3, and is sometimes referred to as fractal). Such an analysis is particularly relevant for fractured media, and can indicate the degree of connectivity of the fractures and, if the assumption of equivalent porous medium is applicable, to the fractured system. This method has been successfully applied in Sweden to characterize fractured granite.

- The IRT fully support the statement (page 44) that *"hydrochemical and isotopic data, where adequate data are available, can provide qualitative information for checking numerical flow models"*, and would have liked to see this done, at the regional scale and at the local scale.

- The IRT disagrees with some of the suggestions (page 55 and following) that some of the uncertainties about the conceptual model of the site can be lifted with adequate numerical simulations. A particular case in point is the statement on page 56 that *"investigations as to whether the system can be treated as an equivalent porous medium or if discrete features need to be accounted for can best be carried out using a series of numerical simulations"*. If one type of model can give better numerical results compared with the existing data, it will necessarily only deal with flow, and not with transport. Since the objective of the numerical simulations will, in the end, in the TSPA, be to predict transport of nuclides, it is not correct that, with the existing data, numerical simulations can adequately answer that question.

- The IRT fully supports the statements about the need for additional data.

Conclusions

The overall conclusion after reviewing USGS reports R96-4300 and R96-4077 is that the flow system at YM in the saturated zone is really very complex, and not sufficiently understood to propose a conceptual model on which scenarios of radionuclide transport from the repository can be made with any degree of realism. The major issues seem to be:

1. The role of the paleozoic carbonate (is water coming from or going to the carbonate, or both, as suggested in the report to explain the zones of high and low gradients, as an alternative to a perched water-table local aquifer);

2. The horizontal anisotropy of the fractured volcanics, to determine the direction of flow, the velocity in the fractures;

3. The connectivity of the fracture network, to determine how much mixing could occur in the system;

4. The recharge in the regional system, for different climatic conditions;

5. The relation between the volcanics and the alluvium. How layered are the alluvial deposits? Is there vertical mixing in the alluvium? At the contact between the volcanic tuffs and the alluvium, how is the flow distributed? Is it along the whole thickness of the alluvium, over a fraction only, mostly at the surface, or at depth?

6. What is the exact geometry of the alluvium in the area lying between YM and the Amargosa Farms area?

Until these questions are answered, it is not possible to develop a realistic conceptual model of the site, or to build a probabilistic SZ local model.

The local flow model developed by the USDOE of the SZ at Yucca Mountain (TRW, 2000) is a piece of work of much higher quality, up to international standards. But this model uses the USGS regional model as boundary conditions, and is therefore biased by the poor quality of the USGS work. This translates in the TSPA to an uncertainty factor of 100 in the flux coming form the regional model to the local model, as discussed in Section 3.6 of the IRT report. The preliminary modelling work developed by the State of Nevada (Lehman and Brown, draft, August 2001) is an interesting alternative that proposes to use temperature data to calibrate the model, and to improve the description of the faults and fractures in the system. Such an effort should be continued.

The regional and local modelling efforts should be combined and the two models recalibrated, once a realistic model of the regional hydrogeology of the site has been constructed. It is advisable that the same group of hydrogeologists develops both models at the same time, as the iterative interaction of both models is necessary during the calibration phase.

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NOT YET CALENDARED FOR ORAL ARGUMENT

Case Nos. 01-1516, 02-1036, 02-1077, 02-1179, 02-1196

IN THE

United States Court of Appeals

FOR THE DISTRICT OF COLUMBIA CIRCUIT

STATE OF NEVADA, *et al.*,
Petitioners,

v.

UNITED STATES DEPARTMENT OF ENERGY, *et al.*,
Respondents.

PETITION FOR REVIEW FROM FINAL DECISIONS, ACTIONS, AND FAILURES TO ACT OF UNITED STATES DEPARTMENT OF ENERGY AND FINAL DECISIONS AND ACTIONS OF THE PRESIDENT OF THE UNITED STATES

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CERTIFICATE AS TO
PARTIES, RULINGS, AND RELATED CASES

Pursuant to Circuit Rule 28(a)(1), Petitioners respectfully certify as follows:

(A) Parties and *Amici*: As these consolidated actions involve the direct review of agency and Presidential decisions and actions, there were no proceedings before the district court. The parties, intervenors, and *amici* before this Court are as follows:

- Parties:
  (1) State of Nevada, Petitioner
  (2) Clark County, Nevada, Petitioner
  (3) City of Las Vegas, Nevada, Petitioner
  (4) United States Department of Energy ("DOE"), Respondent
  (5) Spencer Abraham, Secretary of Energy, Respondent
  (6) George W. Bush, President of the United States, Respondent
- Intervenors: The Nuclear Energy Institute ("NEI") has intervened in Action No. 01-1516.
- *Amici*: NEI has been granted leave to participate as an *amicus curiae* in Actions Nos. 02-1179 and 02-1196. The National As-

sociation of Regulatory Utility Commissioners has been granted leave to participate as an *amicus curiae* in action No. 01-1516.

Because Petitioners are not corporations, associations, joint ventures, partnerships, syndicates, or other similar entities, Circuit Rule 26.1 does not require the filing of a disclosure statement.

(B) Rulings Under Review: Petitioners seek review of the combined final rules issued by DOE, titled "Office of Civilian Radioactive Waste Management; General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories; Yucca Mountain Site Suitability Guidelines; 10 C.F.R. Parts 960 and 963," published at 66 Fed. Reg. 57,298 (Nov. 14, 2001). A copy of these rules may be found in the Statutory/Regulatory Appendix that Petitioners have filed with this brief.

Petitioners also seek review of the Secretary of Energy's February 14, 2002 recommendation to the President of the Yucca Mountain site. To Petitioners' knowledge, no official citation to this recommendation exists. A copy of this recommendation will be included in the deferred appendix.

Petitioners also seek review of the President's February 15, 2002 recommendation to Congress of the Yucca Mountain site. To Petitioners' knowledge, no official citation to this recommendation exists. A copy of this recommendation will be included in the deferred appendix.

Petitioners also seek review of the Final Environmental Impact Statement ("FEIS") prepared by DOE and released on February 14, 2002. To Petitioners' knowledge, no official citation to this recommendation exists. Relevant excerpts from the FEIS will be included in the deferred appendix. Petitioners also seek review of whether DOE and the Secretary of Energy have failed to take certain actions required by law.

(C) Related Cases: The matters under review were not previously before this Court or any other court. While Petitioners do not believe that there are any cases pending before the Court that constitute "related cases" within the meaning of the Court's rules, Petitioners note that pending before the Court are two groups of cases, involving different respondents, that, like this case, generally concern issues relating to the proposed nuclear waste repository at Yucca Mountain, Nevada:

- *Nuclear Energy Institute, Inc. v. Environmental Protection Agency*, No. 01-1258 (consolidated with Nos. 01-1268, 01-1295, 01-1425, and 01-1426) (the "EPA Case");

- *State of Nevada, et al. v. United States Nuclear Regulatory Commission,* No. 02-1116 (the "NRC Case").

By order dated November 7, 2002, this Court directed that this case be heard in tandem with the EPA Case and the NRC Case, and that the Clerk calendar all three groups of cases for oral argument on the same day or the same week, and before the same panel, in September 2003.

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TABLE OF AUTHORITIES

Authorities upon which Petitioners chiefly rely are marked with asterisks.

Statutes

<u>Other</u>

GLOSSARY

CEQ - Council on Environmental Quality

DOE - United States Department of Energy

EA - Environmental Assessment

EIS - Environmental Impact Statement

EnPA - Energy Policy Act (1992)

EPA - Environmental Protection Agency

FEIS - Final Environmental Impact Statement

GWTT - groundwater travel time

HLW - high-level radioactive waste

ISFSI - Independent Spent Fuel Storage Facility

MRS - Monitored Retrievable Storage installation

NAS - National Academy of Sciences

NEPA - National Environmental Policy Act (1969)

NRC - United States Nuclear Regulatory Commission

NWPA - Nuclear Waste Policy Act of 1982. Citations to the NWPA in this brief are to the Public Law section rather than to the United States Code section. A copy of the NWPA as amended, with cross-references to Code sections (*e.g.*, NWPA § 113 is codified at 42 U.S.C. § 10133; NWPA § 114 is codified at

42 U.S.C. § 10134), is included in the statutory/regulatory appendix filed with this brief.

NWPAA – Nuclear Waste Policy Act Amendments of 1987.

NWTRB or TRB – Nuclear Waste Technical Review Board

RCRA – Resource Conservation and Recovery Act

ROD – Record of Decision

SCP – Site Characterization Plan

SNF – Spent Nuclear Fuel

NOTE: Citations to the three Certified Records submitted by DOE are identified herein by source, document number, and page number in the following formats:

Guidelines Case Record:	GR-25-10
Recommendations Case Record:	RR-1.0025-10
NEPA Case Record:	NR-1.0025-10
Supplemental Appendix:	SA-025-10
Final Environmental Impact Statement:	FEIS-2-25

The Supplemental Appendix contains documents important to this case that Petitioners believe should have been included in the record.

JURISDICTIONAL STATEMENT

This action involves five petitions for review. Actions 01-1516 and 02-1036 challenge final regulations issued by the Department of Energy ("DOE") pursuant to the Nuclear Waste Policy Act ("NWPA") on November 14, 2001, and DOE's failure to take actions required by the NWPA. This Court's jurisdiction derives from NWPA Section 119(a)(1). These actions were timely filed (December 2001 and January 2002) within 180 days of the challenged decisions or failures to act, under NWPA Section 119(c).

Action 02-1077 challenges DOE's February 14, 2002 decision recommending the Yucca Mountain, Nevada ("Yucca") site, and the President's February 15, 2002 decision approving that selection. This petition also challenges DOE's failure to take actions required under the NWPA. This Court's jurisdiction derives from NWPA Section 119(a)(1). This action was timely filed (February 2002) under NWPA Section 119(c).

Actions 02-1179 and 02-1196 challenge DOE's February 14, 2002 Final Environmental Impact Statement ("FEIS"), as well as procedural violations related to issuance of the FEIS and DOE's February 14, 2002 recommendation. This Court's jurisdiction derives from NWPA Section

119(a)(1). These June 2002 actions were timely filed under NWPA Section 119(c).

STATEMENT OF ISSUES

(1) Whether final rules issued by DOE (the "Guidelines") conflict with NWPA requirements that:

(a) deep geologic isolation form the primary means of containment for the nation's nuclear waste;

(b) DOE's guidelines specify detailed geologic considerations that shall be primary criteria for the selection of repository sites;

(c) DOE's guidelines specify factors that qualify or disqualify any candidate site, including Yucca, from development;

(2) Whether DOE, upon determining in fact that Yucca's geologic characteristics were not primarily capable either of qualifying Yucca as a suitable repository or of assuring that a Yucca repository could meet applicable statutory or regulatory requirements, failed to take actions required by the NWPA.

(3) Whether DOE failed to take actions required by the NWPA when the Secretary of Energy ("Secretary") recommended Yucca to the President without having completed site characterization.

(4) Whether the Secretary's and the President's recommendations of the Yucca site were contrary to law because they were predicated on application of DOE's unlawful Guidelines.

(5) Whether the Secretary violated the NWPA, the National Environmental Policy Act ("NEPA"), and NEPA regulations by:

(a) withholding from Nevada the FEIS, thereby failing to receive and respond to Nevada's comments prior to the recommendation;

(b) rendering his site recommendation without providing thirty days for public availability of the FEIS;

(c) rendering his recommendation without preparing a Record of Decision;

(d) adopting a distorted and implausible definition of the "no action" alternative in the FEIS that undermined the baseline comparison between the proposed action and the reasonably foreseeable consequences of rejecting it;

(e) selecting a "proposed action" in the FEIS that is *ultra vires* and inconsistent with the NWPA's commitment to a geologic repository;

(f) defining a "proposed action" in the FEIS that diverged from the action recommended to and approved by the President;

(g) adopting an unstable, inconsistent, and incomplete definition of the "proposed action" in the FEIS and recommendation, and segmenting out the project's transportation component;

(h) including in the FEIS a design option proscribed by the NWPA;

(i) including in the "proposed action" and recommendation disposal of wastes precluded from Yucca by the NWPA;

(j) ignoring the requirement to obtain from Nevada disposal permits under the Resource Conservation and Recovery Act ("RCRA"); and

(k) failing to consider the risks and reasonable consequences of sabotage in spent fuel transport to Yucca.

STATUTORY / REGULATORY APPENDIX

Pertinent statutes and regulations are included in a separately bound appendix.

STATEMENT OF THE CASE

Petitioners bring this action challenging guidelines promulgated by DOE setting the criteria for selecting the site for the nation's permanent nuclear waste repository. Petitioners further challenge the decisions of the Secretary and the President, made pursuant to those criteria, to select Yucca Mountain in Nevada as that site. Those new guidelines, and accordingly those decisions, violated the NWPA. The site selection also violated NEPA.

With the NWPA, Congress answered this question: How are we to isolate highly radioactive material from the human environment for the almost unimaginable time necessary for its toxic properties to diminish to safe levels? Based on the judgment of the scientific community and of DOE itself, Congress concluded the best course was to put the wastes in packages as formidable as engineers could devise, *but*, as a mandate for longer-term assurance, bury them deep underground in isolating rock formations. Thus, the animating idea of the NWPA was to dispose of wastes through a sequence of independent "barriers," both man-made and natural.

Congress assigned DOE the task of developing more detailed guidelines by which a potential repository site would be evaluated, or "characterized." Congress charged the Nuclear Regulatory Commission ("NRC") with the responsibility, after a site suitable under the NWPA's standards was selected, to license construction and operation of the repository.

DOE's original guidelines, specifying qualifying and disqualifying conditions for a site, conformed to the NWPA. Due to the expense of evaluating several sites, in 1987 Congress focused DOE's characterization activity on Yucca, but Congress neither changed the standards nor mandated that the Yucca site be found suitable.

By the late 1990s, the data from DOE's characterization work determined that Yucca site's geology would disqualify it under DOE's guidelines, particularly with respect to Yucca's inability to constrain groundwater flow through the repository and into the biosphere. Such a development was clearly contemplated by Congress. 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.

H.R. Rep. No. 97-491, Part 1, at 32 (1982).

Notwithstanding this premise, DOE stopped site characterization and aborted its standards, substituting new guidelines that are the subject of this case to justify Yucca's selection. Under these guidelines, no specific examination of the contribution of the natural setting to isolate waste is to be made, in favor of a gross examination of how the "total system" of the repository will work. If DOE's new guidelines are lawful, a repository need not be put underground, since man-made barriers will do all the work – at least until they fail.

Petitioners contend the actions of the Executive Branch to secure the Yucca selection violated express terms of the NWPA and NEPA, terms that rest on both the Congressional determination that safe, permanent disposal must rely on the geologic setting as the primary barrier to isolate wastes from the biosphere, and Congressional insistence that the environmental impacts of this major federal action be fairly analyzed.

STATEMENT OF FACTS

A. Spent Fuel and High-Level Waste

The operation of nuclear power plants, research reactors, and military reactors all produce spent fuel. Spent fuel is lethally radioactive, posing a serious hazard not only to those exposed to it,[1] but also, because resulting biological effects can be passed on, "to future generations."

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[1] Mere micrograms of plutonium ingested in drinking water can cause cancer. *See* Voelz and Lawrence, "A 42-Year Medical Follow-Up of Manhattan Project Workers," *Health Physics*, Vol. 37 (1991).

H.R. Rep. No. 97-785, Part I, at 46 (1982). Moreover, radioactive elements in the wastes remain dangerous for millennia, FEIS-1-6, having "half-lives" (the time it takes a substance to decay to half of its initial radioactivity level) of up to 2 million years. FEIS-A-17. Some of these elements decay into other elements that become even more dangerous over time. *See* H.R. Rep. No. 97-785, Part I, at 46.

In addition, in the process of decay, the wastes produce heat so intense it can boil water out of desert rocks. FEIS at 2-9-2-11. As a result, spent fuel must be cooled three to five years in pools at reactor sites before it can be transported. H.R. Rep. 97-785, Part I, at 40. Originally, these pools provided storage for spent fuel. As they became filled to capacity, utilities began constructing above-ground storage facilities that can store fuel in casks that are continuously monitored and secured by armed guards. NRC, which licenses such "dry storage" facilities, has determined they can remain safe for at least 100 years, SA-022-3, though the industry has testified spent fuel "can be stored for centuries safely" at such facilities.[2] Utilities have already constructed 24 such facilities and are planning to build 21 more. SA-005-23-24. Utilities are also develop-

[2] Hearings on S.637, Senate Energy Committee (Pub. No. 97) and Senate Environment Committee, 97th Cong., 14 (1981) (Statement of Sherwood Smith, Chairman, American Nuclear Energy Council).

ing a dry storage facility in Utah that will hold nearly 87-percent of the industry's existing spent fuel inventory. FEIS-1-22.

Because spent fuel contains reusable uranium and plutonium, the government undertook for years to "reprocess" it to extract such materials. For years, a solution to the problem of spent fuel disposition was postponed because it was assumed spent fuel would be reprocessed, leaving liquid radioactive wastes which are far less volatile than spent fuel, and which are "vitrified," or immobilized, into solid glass logs that can be stored safely indefinitely. FEIS-1-7. In 1976, the government, for non-proliferation reasons, ended reprocessing in the U.S. FEIS-1-8.

In 1957, the National Academy of Sciences ("NAS") completed the nation's first comprehensive study of the management and disposal of nuclear waste. RR-1.0512. "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." *Id.* at 3.

Deep burial in a stable, isolating geologic setting was urged by NAS, particularly in salt deposits, since "no water can pass through salt" and its "fractures are self-sealing." *Id.* at 4. As NAS put it: "The question should not be phrased: 'How can we dispose of waste at X site?' but should be: 'Can or cannot waste be disposed of at X site?'" *Id.* at 6. NAS recommended "returning 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." *Id.* at 18.

The central recommendation of NAS for disposal, "deep geologic isolation," became the cornerstone of every repository program in the world. This scientific tenet strongly informed the government's practices and laws that led to the U.S. repository program.

In 1980, using the NAS recommendation to plan a strategy focused on geologic disposal, the President ordered DOE to prepare a full Environmental Impact Statement ("EIS") so as to recommend a preferred long-term alternative. FEIS at 1-9. DOE's 1980 EIS evaluated deep geologic isolation and every other conceivable method of disposal, including subseabed and ice-sheet disposal, deep-well injection, transmutation, and even disposal in outer space. RR-1.0312-1-1.16-1.20. In the end, the solution proposed by DOE for spent fuel was disposal "in mined repositories in geologic formations," *id.* at 1-3, which would be so effective that "it is extremely improbable that wastes in biologically important concentrations would *ever* reach the human environment." *Id.* at 1-3-4 (emphasis added).

The effectiveness of geologic isolation did not mean 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.

Id. at 5.1. DOE emphasized that "[m]ultiple barriers are intended to act independently to prevent waste migration and enhance isolation." *Id.* at 3-272. "The engineered components of the multi-barrier system would be of greatest importance in the short term and the repository medium and the surrounding geology would be the critical elements over the long term." *Id.* at 281.

To ensure long-term safety, DOE required any site to have "geologic," "hydrologic," and "geochemical" characteristics "compatible with waste isolation." *Id.* at 1-55. Echoing NAS, DOE concluded, "The 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 for the long term." *Id.* at 2-B.15.

DOE likewise evaluated the length of time the geologic setting should be capable of containing wastes to ensure long-term safety. DOE advocated an isolation target of *250,000 to 500,000 years* because of lethal long-lived isotopes like plutonium in spent fuel. *Id.* at 3-360-61.

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 enactment of the NWPA. Indeed, DOE later acknowledged that its decision in the 1980 EIS to pursue "mined geologic repositories as the preferred means" for disposal of nuclear waste "has since been supported by the [NWPA]." SA-039-31.

B. The Congressional Response

Congress first attempted to address nuclear waste disposal in 1980 with H.R. 7418, offered by the House Science Committee, and with S. 2189 in the Senate Energy Committee.

The House bill sought to establish a demonstration program that would facilitate development of repositories. H.R. Rep. No. 1156, Part 1, at 9 (1980). DOE was to nominate demonstration sites "using criteria based on the principle that the primary means of preventing the release of waste to the biosphere are engineered barriers. ... Primary reliance *on geology* which *can assure* that uncontained waste will be *completely isolated* from the biosphere is not required." *Id.* at 17-18 (emphasis in original).

That engineered barriers were sufficient for isolation reflected the contemporaneous presumption that *all* the wastes being buried would be reprocessed wastes from spent fuel, *not* the spent fuel itself. *Id.* at 25. The Committee pointed to "reduced geological requirements" for "repositories which are to be used only for reprocessed high-level wastes and which emphasize engineered barriers." *Id.* at 27.

DOE opposed the bill on grounds that it was inappropriate to place primary reliance 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.

Id. at 37.

Recognizing the nation's policy shift away from reprocessing, the Senate Energy Committee reported S. 2189, which proposed development of repositories for disposal of unreprocessed spent fuel. S.Rep. No. 548, at 11 (1980). In a separate bill, the Senate Environment Committee, at DOE's urging, emphasized both natural and engineered barriers, noting that:

> [i]n explaining this conservative, defense-in-depth approach to repository design, [DOE] states:
>
> "The multibarrier concept requires that the success of the system be protected against deficient barrier performance or failure by using a series of relatively independent and diverse barriers that would not be subject to a common mode of failure. Barrier multiplicity is required both as a hedge against unexpected occurrences or failures and to provide an appropriate means for protecting against a wide variety of potentially disruptive events. Acceptable system performance must not be contingent on the performance of any non-independent barrier combinations."

S.Rep. No. 96-871, at 3-4 (1980).

In summer 1980, the House Interior Committee reported a revised version of H.R. 7418. Recognizing DOE's opposition to its earlier bill, and the fact that "the option to reprocess spent nuclear fuel is presently foreclosed to the nuclear industry," the Committee concluded "it is necessary at this time to do preliminary planning on the basis of geologic disposal of spent fuel." H.R. Rep. No. 1156, Part 2, at 2 (1980). As the Committee explained:

> The form of the waste itself and engineered barriers will provide the first level of defense against release of radionu-

> clides. But locating appropriate rock formations, and gathering data to adequately confirm their ability to provide protection over very long periods of time, are crucial elements of the repository development program.

Id. at 29.

This dramatic turnaround was the result of Congressional recognition that disposal of unreprocessed spent fuel presented a far more dangerous and longer-term risk. The Committee noted, for example, that some isotopes would need "to be isolated for at least 245,000 years." *Id.* at 13.

> [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 groundwater.

Id. at 14. Underscoring this principle, the revised bill mandated site suitability requirements designed to ensure primary geologic isolation for spent fuel.

> All site characterization activities in the site selection process itself in both the preliminary and final stages are to be based upon the premise that the geologic media is to be the ultimate barrier which isolates the waste from the biosphere, and that engineered barriers are but intermediate and short-term forms of isolation.

Id. at 29.

In 1981, the Senate committees reported a new bill containing provisions for "deep geologic repositories capable of accommodating either high-level nuclear waste or spent fuel." S.Rep. No. 97-282, at 6-7 (1981). This meant geologic isolation would remain the primary requirement for site suitability, a position codified in the April 1982 House version of the nuclear waste bill, H.R. 3809. *See* H.R. Rep. No. 97-491, Part 1, at 4 ("Such Guidelines shall specify detailed geologic considerations that shall be primary criteria[3] for the selection of sites in various geologic media."), 50 (1982).[4] This exact language persisted through subsequent revisions of the proposed legislation and ultimately was incorporated into the NWPA.

Indeed, Congress was explicit about the "essential elements of the program" it was codifying in the NWPA:

> Commitment 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 main-

[3] DOE has consistently read "primary criteria" in this text to mean "*the* primary criteria." *See, e.g.*, 66 Fed. Reg. 57,298, 57,300 (Nov. 14, 2001) (emphasis added); 64 Fed. Reg. 67,054, 67,056 (Nov. 30, 1999).

[4] Identical language appeared in the House bill. H.R. Rep. No. 97-785, at 5, 45-48.

> tenance after an initial period of testing and subsequent closure of the repository.

Id. at 30. *See also* H.R. Rep. No. 97-785, Part I, at 48 (1982).

C. The NWPA: Primary Reliance on Geologic Isolation

In the NWPA, Congress prescribed a complex process for selecting one or more sites from among several "candidate sites" for detailed site characterization. The NWPA required DOE to hone in on a preferred repository location by conducting successive geologic and scientific studies. FEIS-1-9. Upon completion of such "site characterization," the Secretary was to make a recommendation to the President as to his choice of any site for development.

From the beginning, three agencies shared independent responsibilities for the assessment and potential development of the repository. Those responsibilities included site characterization and selection by DOE, establishing radiological and health standards by the Environmental Protection Agency ("EPA"), and licensing the construction and operation of the repository by NRC.

The NWPA prescribed a two-step process leading to repository development. First, DOE would determine site *suitability* under Sections 113 and 112, and second, NRC would determine overall *licensability* under authority given it in Section 114. Only then could a construction permit be granted by NRC. *See* RR-7.0004 at 9.

Reflecting its history and purpose, the NWPA defines "repository" as a system to be used for "permanent deep geologic disposal." NWPA §11(18). "Candidate sites" are defined as areas "within a geologic and hydrologic system" that undergo DOE site characterization, NWPA §11(4), which, in turn, means DOE activities "undertaken to establish the *geologic* condition" of a candidate site, NWPA §11(21), and which was to have been *completed* prior to any site recommendation. NWPA §114. Section 112(a) requires DOE to establish guidelines for the selection and recommendation of sites, which "shall specify detailed geologic considerations that shall be primary criteria" for site selection. 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...." *Id.*

D. Original Repository Rulemaking Activity

Pursuant to NWPA requirements, DOE, NRC, and EPA published rules intended to discharge their obligations. 10 C.F.R. Part 960 and 60, 40 C.F.R. Part 191, respectively. In publishing 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 to be specified by NWPA Section 112(a). 49 Fed. Reg. 47,714, 47,718 (Dec. 6, 1984). 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 the geologic media" during suitability evaluations. *Id.* at 47,719-20. EPA also warned DOE not to over-rely on engineered barriers. *Id.* at 47,727.

DOE's final rules accordingly provided that "engineered barriers shall not be used to compensate for an inadequate site; mask the innate 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." 10 C.F.R. § 960.3-1-5 (1984). Thus, while this geologic qualifying criterion formed the key requirement for comparative analysis of proposed sites, it was equally clearly a requirement for the absolute scientific evaluation of *any* site. DOE knew that establishing performance of the "total system" was not inconsistent with establishing performance of each part of that system.

As Section 112(a) requires, DOE also specified both qualifying and disqualifying conditions. Part 960 defined "disqualifying condition" as "a condition that, if present at a site, would eliminate that site from further consideration." 10 C.F.R. §960.2. A key disqualifying condition was that of groundwater travel time ("GWTT"). As DOE explained, "The most likely mechanism for the release of radionuclides from a repository to the accessible environment is transport by groundwater." 49 Fed. Reg. at 47,732. Accordingly, DOE specified that surface rainwater trickling through Yucca must take no less than 1000 years to descend from the repository through the dry, "unsaturated" zone and into the water table and the accessible environment:

> A site *shall be disqualified* if the pre-waste emplacement groundwater travel time from the disturbed zone [the underground waste area] to the accessible environment is expected to be less than 1000 years along *any* pathway of *likely and significant radionuclide travel.*

10 C.F.R. §960.4-2-1(d) (emphasis added). The Part 960 conditions were not intended to foster selection of a perfect or even superior site, but were "the *minimum* conditions for site qualification." RR-1.0315-6-2 (emphasis added).

E. <u>The 1987 NWPA Amendments Act ("NWPAA")</u>

In 1987, due to rising cost estimates for site characterization at three sites chosen by DOE, Congress amended the NWPA to provide that Yucca would be the only site characterized. Significantly, Congress did not prejudge the site's physical suitability but made clear that "[i]f the Secretary *at any time* determines the Yucca site to be *unsuitable for development as a repository*," he was to terminate all activities and notify Congress. NWPA §113(c)(3) (emphasis added). Moreover, the Secretary was in that circumstance to report to Congress with DOE's "recommendations for further action to assure the safe, permanent disposal of [waste], including the need for new legislative authority." *Id.*

In the NWPAA, Congress did nothing to change the physical siting requirements it had enacted in the NWPA in Section 112(a). Indeed, Section 113, which was amended to provide for characterization only of the *Yucca* "candidate site," still required DOE to develop "criteria to be used to determine the suitability of *such candidate site* for the location of a repository, *developed pursuant to Section 112(a)*." (Emphasis added).

In the NWPAA, Congress also created a limited exception to NEPA Section 102(C)(iii), which requires agencies planning major federal actions to consider reasonable alternatives to the proposed action. Congress created this exception with the understanding that the proposed disposal action would be mined *geologic* disposal in a repository at Yucca. Section 114(f)(6) provides that, in licensing Yucca, NRC must adopt, to the extent practicable, DOE's FEIS and need not consider "nongeologic alternatives to such site." Likewise, "compliance [by DOE] with the [NWPA] shall be deemed adequate consideration of ... all alternatives *to the isolation* of high-level radioactive waste and spent nuclear fuel in a repository." NWPA §114(f)(2) (emphasis added). DOE's FEIS need not "consider ... alternatives to geological disposal." NWPA §114(a)(1)(D).

F. <u>DOE's 1988 Site Characterization Plan</u>

As required by the NWPAA, DOE released a "Site Characterization Plan" ("SCP") in December 1988. In it, DOE acknowledged that the NWPAA did nothing to alter the NWPA's requirement that DOE must apply site suitability guidelines developed pursuant to the requirements of Section 112(a). RR-1.0316-I-8-9.

DOE described the physical character and basic design of the Yucca repository. Yucca's natural setting is composed largely of "tuff," a compacted form of glassy shards and rock crystals formed from volcanoes. SA-054-15. Just below the surface, an "unsaturated" zone in the tuff, presumed largely free of water, extends roughly 2000 feet to the underlying water table. The level of the water table begins what is called the "saturated zone," where the tuff is essentially saturated with water.

The repository area was to be hewn out of the mountain approximately halfway through the unsaturated zone, about 1000 feet deep.[5] SA-054-15, 41. Waste packages were to be placed into a number of half-mile-long "emplacement panels" dug out of the tuff, in which holes are bored for waste emplacement. *Id.* at 41.

The SCP stressed that repository safety is inextricably linked to its geologic and hydrologic setting. "Geologic conditions are intrinsic to the performance of a repository...." *Id.* at 16. Likewise, "[h]ydrologic conditions at the site are critical to the long-term performance of the repository because [they] may affect the behavior of the waste package and because the movement of ground water is the principal mechanism for transporting radionuclides to the accessible environment." *Id.* at 26.

Evidencing DOE's view in 1988 that Yucca would likely prove to have a suitable hydrogeologic setting, DOE said "[p]resent estimates of the time of ground-water travel from the proposed repository to the underlying water table range from about 9,000 to 80,000 years," long enough to pose no safety concern. *Id.* at 28. But DOE cautioned that "lit-

[5] No other high-level waste repository in the world is being considered above the water table. SA-033-19.

tle is known about the occurrence and movement of water deep within the unsaturated, fractured tuffs. . . ." *Id.* at 27. Therefore, extensive field investigations had "the highest priority in the program." GR-14-8.0-9.

DOE affirmed that site characterization could lead to the discovery of a "disqualifying" condition at Yucca. "The discovery and confirmation of such a flaw would bring site-characterization activities to a halt." SA-054-8.

G. <u>The 1992 Energy Policy Act ("EnPA")</u>

In EnPA, Congress resolved a longstanding battle over whether NRC or EPA had authority to set the primary radiological standards for waste emissions at Yucca by giving EPA the exclusive responsibility to promulgate such standards. EnPA §801(a)(1). But Congress did not alter in any way the provisions of NWPA Sections 112(a) or 113. Indeed, the House Committee which sponsored the legislation emphasized that "[t]he provisions of Section 801 address only the standards of the [EPA], and the comparable regulations of the [NRC], related to protection of the public from releases of radioactive materials. . . . The provisions of Section 801 are not intended to affect in any way the application of any other existing laws to activities at the Yucca Mountain site." SA-040-4466-67.

Later that year, DOE made clear it viewed EnPA as not having altered the NWPA siting guidelines codified in Part 960. SA-032 at 4-5. Thus, DOE's site study would continue to "include an evaluation of potential disqualifying features and conditions...." *Id.* at 5. Though DOE had begun to apply "total system performance assessment" models of the entire repository system, it confirmed that site suitability would be evaluated independently of, and simultaneously with, repository "system" performance. GR-19-ES-2.

In August 1994, DOE made the point again in a formal announcement that the Part 960 guidelines "as they currently exist" would continue to govern "the site suitability process" for Yucca. 59 Fed. Reg. at 29,766. DOE did acknowledge that, because the NWPAA eliminated all candidate sites but Yucca, "comparative evaluation is no longer relevant," and therefore that portion of the 960 guidelines would no longer be employed. *Id.*

In 1995, DOE again confirmed publicly that it viewed the Part 960 siting guidelines "as the primary criteria required by section 113(b) of the NWPA to be used to determine the suitability" of Yucca. 60 Fed. Reg. at 47,738. DOE rejected any notion that it needed to develop a new set of guidelines just for Yucca. *Id.* at 47,739; *see also* SA-010, SA-041.

H. DOE's 1994 "Program Approach" to Suitability

In 1994, DOE put even greater programmatic emphasis on determining "technical site suitability," refocusing on "data most important for evaluating the qualifying or disqualifying conditions...." SA-042-27; SA-031-A-1. DOE stated on numerous occasions that the effort was "an attempt to realign the program closer to the original intent of the legislative and regulatory framework." SA-043-2; SA-044-2; RR-5.0034-1-4; GR-26-II-8; RR-5.0035-1-3.

In what DOE called its "Program Approach," the agency set as its primary goal completion of seven "technical suitability reports" covering each of the Part 960 qualifying and disqualifying conditions. SA-044-9; SA-045-7. Of the seven, the hydrologic suitability finding (including GWTT) was regarded by DOE as "heads and shoulders above the others" in difficulty and importance. SA-046-65.

In late 1995, confirming the agency was working independently and simultaneously on repository "system" analysis *and* individual technical site suitability studies, DOE issued both its "Total System Performance Assessment-95" and the first of its seven planned technical site suitability reports. GR-30. But that technical report, concerning surface characteristics, pre-closure hydrology, and erosion, was determined by reviewers to be unsound. For example, an NAS panel concluded that the report "fails to establish credibility in the scientific basis" for numerical characterization of erosion. SA-047-65.

I. 1996: The "Perfect Storm"

DOE had not even started to rework the first of its seven suitability studies when it was hit in 1996 by the perfect storm.

First, Congress slashed the Yucca budget by forty-percent. SA-011-xi. In imposing what DOE called "draconian budget cuts" (SA-048-1) for fiscal 1996, the Appropriations Committee directed DOE to refocus *all* its efforts "to collect the scientific information needed to determine the suitability of the Yucca Mountain site" and to "defer preparation and filing of a license application for the repository ['system'] with the [NRC] until a later date." *See* GR-32-11.

Second, in *Indiana-Michigan Power Co. v. DOE*, 88 F.3d 1272, 1275 (D.C. Cir. 1996), this Court 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, according to the Nuclear Energy Institute. SA-009.[6] *See also Northern States Power Co. v. DOE,* 128 F.3d 754, 759 (D.C. Cir. 1997) (referring to "billions" of dollars of delay-related costs); *Alabama Power Co. v. DOE,* 307 F.3d 1300, 1302 (11th Cir. 2002) (referring to "tide of litigation arising out of this massive breach").

Third and worst of all, ominous results were pouring in from studies in a five-mile tunnel DOE had bored deep into the Yucca unsaturated zone. Geologists discovered Chlorine-36 in fractures found in the area where the repository was to be constructed. GR-41. The abundance of this rare isotope meant it had originated from fallout during atmospheric nuclear testing in the 1950s, suggesting it had migrated from surface rainwater through hundreds of feet of tuff in previously unsuspected "fast flow paths" of less than 50 years. GR-31-1; GR-34-381; GR-44-ES-9. Geologists confirmed the finding by evaluating the "age" of surprisingly large "perched" (or trapped) water pockets found in the "dry" unsaturated zone, some of which amounted to up to *a million cubic meters* of water. GR-34-267.

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[6] Indeed, there are presently pending in the Court of Federal Claims numerous lawsuits by utilities to recover damages against DOE. *See Maine Yankee Atomic Power Co. v. U.S.,* 225 F.3d 1336 (Fed. Cir. 2000).

After further studies, DOE's geologists confirmed "it has become increasingly evident 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.*" GR-34-384, 399 (emphasis added).[7] Clearly, the site would not meet Part 960's GWTT disqualifying condition and would fail what DOE knew was the litmus test of any repository. Far from "permanently" isolating waste, Yucca's geology could not prevent groundwater from carrying radionuclides into the water table far sooner than required to prevent its toxic effects from being visited on the human environment.

Faced with these insurmountable obstacles, DOE's Yucca program office took extreme measures. It laid off hundreds of contractor person-

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[7] For details of this dramatic discovery and DOE's response, *see* Affidavit of John W. Bartlett, former Director of DOE's Yucca Program. Dr. Bartlett confirms DOE's studies showed "rates of water infiltration into the mountain were on the order of 100 times higher than had been expected; that water flowed very rapidly through fracture pathways in some of the geologic layers (like flow through a pipe rather than dispersed flow through a medium like a bed of sand); and that there appeared to be unexpected 'fast pathways' for movement of radioactivity from the repository to the water table about 1000 feet beneath it." RR-7.0004-11-13. Thus, the Yucca site "cannot be shown to be capable of long-term geologic isolation of high-level radioactive waste during the regulatory time period...." RR-7.0004-2.

nel, SA-015-19, and then it did *precisely the opposite* of what Congressional appropriators had instructed it to do.[8] That is, instead of refocusing activities on an early determination of site suitability (step one in the statutory process) and deferring preparation of a license application (step two), DOE *cancelled* its suitability activities and placed all its efforts into developing a repository "system" design that could ostensibly meet NRC license requirements for a *construction permit* by relying almost totally on engineered barriers. SA-015-15; SA-016-406; SA-021-2; GR-32-19. By January 1996, DOE informed the Technical Review Board,[9] "We're not doing suitability process any more." SA-015-406. The new focus would be "on the predictive performance of the repository ... rather than on a comprehensive discourse on site characterization." SA-048-7.

Recognizing that this fundamental departure would require regulatory and legislative changes, DOE went to work on all fronts. By March 1996, DOE and its industry allies had lobbied the Senate Energy Committee to report a bill, S. 1271, which provided that DOE's site suitability

[8] Explaining this departure to DOE's technical auditors, DOE's acting Yucca Program Director said, "The Congress of the United States is an educated body. But Lord, they're ignorant right now." SA-015-24.

[9] The "TRB" is a board of scientists established by NWPA Title V that serves as a technical auditor of DOE's Yucca work.

guidelines in Part 960 "are annulled and revoked." The new standard proposed for disqualification of the Yucca site was not its physical unsuitability, but rather a mere determination of whether the repository "system" could potentially meet NRC construction permit requirements. S.1271, §205. The bill did not make it through Congress.[10]

On the regulatory front, DOE began intensively lobbying NRC and EPA to change their respective Yucca rules to focus on "system" performance analysis of the engineered barriers in the as-yet-uncharacterized natural setting and to require no independent qualifications related to site features. SA-021-6; SA-017-16; SA-023-11; SA-030-332; SA-019-42; SA-020-10; SA-014-6. Rather than assess the *site's* "suitability," the NWPA's first repository development requirement, DOE would instead assess the *repository's* "viability" to meet re-tailored, system-based NRC licensing requirements. SA-049-13; SA-021-5, 17; RR-5.0037-ES-1; SA-021-5, 17.

DOE cautioned 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...." SA-21-16; *See also* SA-

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[10] In 1999, another bill seeking to eliminate the Section 112(a) guidelines, the "Nuclear Waste Policy Act of 1999," H.R. 45, also failed to get enacted.

024-6. DOE now called its previous search for technical site suitability "a false target." SA-017-152.

In revising its Program Plan to accommodate this sea change, DOE emphasized that "[i]t became increasingly clear that many of the expectations embodied in the [NWPA] could not be met." GR-32-5. Now, "[w]e will concentrate our near-term design effort on the critical technology requirements of the engineered barriers." *Id.* at v. Accordingly, DOE noted that it had "cancelled [its] technical site suitability process." GR-32-19. *See also* SA-019-42; SA-030-325.

By December 1996, inverting reality, DOE announced in the *Federal Register* that it would be amending its guidelines because "Congress directed DOE in fiscal year 1996 to focus on only those activities necessary to assess the performance of a repository at the Yucca Mountain site." GR-48-1. Thus, new 10 C.F.R. Part 963 took flight.

By early 1997, having eliminated NWPA's first required step (determining site suitability) and having effectively replaced it with the NWPA's second step (licensing construction of the repository) DOE made an admitted effort to hide the fact it was focusing now on licensing. It created a new name for its core project directed at preparation of a license application, calling it the "Project Integrated Safety Assessment"

("PISA"). In May 1997 testimony before NRC's Advisory Committee on Nuclear Waste ("ACNW"), DOE's Licensing Manager explained the PISA:

> The way this came about was when we shut down our licensing activities that year [1996] that they [Congress] cut $85 million of our budget, we invented a PISA because *it was our stealth [License] Application.* We weren't allowed to work there. *So we invented a PISA so we could work on the side.*

SA-036-287 (emphasis added). *See also* SA-037-65-67. One Committee member responded, "I can see why Lake Barrett [DOE's Program Manager] was nervous." SA-036-289.

Barrett later admonished the TRB:

> The site suitability decision *need not and should not depend on individual attributes of the site* outside the context of an assessment of the performance of the proposed engineered repository.

SA-013- 3 (emphasis added).

By this time, DOE's rejection of geologic isolation was complete, and the goal now was to change the rules and attempt to design a waste package that alone might last for the 10,000-year duration of EPA's compliance period.

J. Groundwater Travel Time

By late 1998, after reviewing DOE's reports to the TRB, Nevada's Governor urged DOE to disqualify the Yucca site pursuant to the groundwater travel time requirements of DOE's 960 guidelines and the NWPA. SA-025-2. The Secretary wrote back, conceding DOE's analyses showed that *up to 20-percent* of all water moving through the repository would reach the water table in less than 1000 years. SA-026-Encl-1. However, "additional study is warranted," he said, calling a disqualification decision "premature" and noting that "most of the water" would take more than 1000 years. *Id.*

In January 1999, DOE presented to the TRB the results of its repository performance assessment. In one run, DOE had "removed" the engineered barriers from the repository so as to model the performance of the natural setting alone, simulating performance in the event of failure of the engineered barriers. DOE's analysis showed that, because of fast water flow, annual doses to humans at the site boundary would rise precipitously above the 15 millirem/year EPA dose limit in well under 2000 years, peaking at nearly 1000 millirem/year in about 3000 years. SA-051-15; SA-012-77-100. DOE also presented a chart showing that the geologic setting was able to contribute almost nothing to the repository system's total waste isolation capabilities (less than 0.3%). SA-051-18. In short, DOE's model of the repository "system" showed almost total reliance for its safety on engineered barriers, which had yet to be fully designed. *See* RR-7.0004-16. Equally important, the "base case" analysis, with all barriers and packages in place, showed that even then doses would rise sharply above the EPA limit after 10,000 years.[11]

In testimony to the TRB, DOE conceded that Yucca's natural barriers would be ineffective to protect against uncertainties in the performance of the engineered barrier system, and that "defense-in-depth" could only exist in the "system" by stacking one man-made barrier onto another, since geologic factors could make no significant contribution. SA-012-85-94. One TRB member concluded, "You can't even come close with the mountain...."[12] SA-012-100.

By 2000, DOE's performance analyses showed that, if the engineered barriers were presumed to fail, the flimsy natural barriers alone would permit a dose rate more than 666 times the EPA limit, or 10,000 millirem/year, within the first 10,000 years. RR-1.0291-E-11, Fig. E-1. This meant that any repository "system" at Yucca which did not have

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[11] Respondents will not dispute that *any* model of Yucca's performance will show the repository's failure to meet EPA dose limits during the longer periods (after 10,000 years) recommended for compliance by the NAS.

[12] *See also* SA-033-73 (International peer review by repository scientists concluding DOE's assessment of water flow lacks "realism"); RR 7.0001-17 (noting "water...dripping liberally from the ceiling" of a test tunnel deep inside Yucca and "[a] DOE explanatory sign confirming this").

perfectly operating engineered barriers would rapidly become unsafe and noncompliant with EPA dose limits.

In 2001, EPA produced an extensive history of the site suitability issue, confirming the projected noncompliance of the geologic setting and the inability of the site to meet Part 960's GWTT disqualifying criterion. EPA also confirmed that water in the saturated zone which in 1995 had been expected by DOE to be capable of diluting radioactive wastes by factors of 1,000 to 100,000 before they reached the site boundary were assumed four years later to be capable of actual dilution of only a factor of 10. SA-034-3-6, 3-22. In short, wastes emerging from the repository in water seeping through the mountain would become vastly more concentrated at the site boundary than previously believed possible.

The last time DOE presented a repository performance analysis showing the actual anticipated performance of the geologic setting occurred at an NRC/DOE Technical Exchange in January 2001. DOE showed that, if engineered barriers were to fail, the annual dose at the site boundary was projected to be 100 millirems/year – more than six times the EPA limit – at only 1000 years. By the 3000-year mark, the expected dose would rise to over 1000 millirems/year, or 67 times the EPA limit. SA-027-17.

K. DOE's Part 963 Tautology

Late in 1999, DOE published proposed amendments to Part 960, announcing a new Part 963 applicable only to Yucca. Part 960 was to be revised to limit its application only to *other potential* repository sites. GR-186-67055. New Part 963 would establish new "site suitability criteria" for *Yucca alone*, abandoning each of the geologic and hydrologic criteria of NWPA Section 112(a) 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. GR-186-67066-70.

Having lobbied NRC and EPA for three years to change their rules to a system-based regime that would obscure the distinctive roles of natural and engineered barriers, DOE now blamed the abandonment of 960 and the promulgation of 963 on the rule changes by those agencies.[13]

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[13] This is especially ironic given that EPA had earlier objected to DOE's abandonment of 960, saying the "major reason" for the move was DOE's discovery of "significantly faster water flow" than its regulations allowed. GR-134-2. "Overall," EPA said, "the waste isolation capability of the natural features of the Yucca Mountain site is at present highly uncertain and largely unassessed." GR-134-3. Moreover, the "system approach proposed by the DOE could be viewed as masking this uncer-

Id. at 67068-72; GR-201-3; GR-332-57299. The two agencies had finally relented on changes, largely on the premise that it was solely *DOE*'s statutory role to determine site suitability, not NRC's and EPA's. *See, e.g.*, SA-035-99 ("it is their call to make").

With the new rule, DOE perfected a regulatory tautology: DOE's change was to accommodate NRC's change that was necessary because of DOE's change. With Part 963, no longer was site suitability a matter of assessing the isolation capabilities of the geology. Rather, as explained by DOE to NRC, "Simplistically, the suitability evaluation ... is a DOE evaluation as to whether or not we feel we have enough information to have a credible License Application." SA-625-226. As DOE now viewed its job, its role was redundant to NRC's.

Part 963 (the "Guidelines") was issued in final form in November 2001.[14] GR-332.

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tainty and the potentially insufficient waste isolation capability of site features...." *Id.*

[14] Just prior to issuance of the new rule, the Senate Appropriations Committee admonished DOE *not* to jettison the specific geological requirements of Section 112(a), saying the NWPA gave DOE no such authority. SA-028-106.

L. The Site Recommendation

On February 14, 2002, barely two months after Part 963 became effective, the Secretary issued to the President a Site Recommendation for Yucca under NWPA Section 114(a)(1), saying the "site is scientifically and technically suitable for development of a repository." SA-052-1. The recommendation was accompanied by the Yucca FEIS but no Record of Decision. The FEIS, which had been privately circulated to select federal agencies, was not released to Nevada and the public until the date of decision.

One day later, the President, in a letter to Congress, approved the recommendation under NWPA Section 114(a)(2)(A). Sixty days later, Nevada's Governor submitted to Congress a Notice of Disapproval of the site designation pursuant to NWPA Section 116(b)(2). Pursuant to NWPA Section 115, Congress passed a joint resolution overriding the Notice of Disapproval, which the President signed on July 23, 2002.[15]

[15] Respondents have argued that Congress' override mooted Petitioners' challenges to the Guidelines, DOE's and the President's recommendations and the FEIS. The Court has deferred consideration of jurisdictional issues, and thus Petitioners will fully respond in their reply brief to any jurisdictional arguments raised by Respondents in their brief. We note here that Respondents' mootness argument rests on the unsupported proposition that in overriding Nevada's notice of disapproval pursuant to precisely-articulated and truncated NWPA procedures, Congress impliedly repealed the site suitability and the judicial review

With that, DOE was both entitled and required to submit a License Application to NRC within 90 days. NWPA §114(b). DOE failed to do so and now says it cannot submit an application until December 2004 at the earliest.

SUMMARY OF ARGUMENT

In the NWPA, Congress unambiguously mandated a "system" for the "permanent deep geologic disposal" of nuclear waste. Congress required that the "geologic medium" form the primary barrier keeping waste from people and the environment over the millennia.

DOE's new Guidelines instead assert that DOE can lawfully evaluate Yucca from the perspective of "total system performance," essentially abandoning NWPA's mandate that the site's geology form the primary isolation barrier. But because Congress has spoken to the precise question at issue, there is no occasion for this Court to accord deference to DOE's strained construction of the NWPA.

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provisions of the NWPA, while simultaneously authorizing abdication by DOE of traditional NEPA requirements. But all Congress really did, in classic legislative veto fashion, was follow NWPA procedures to the letter and cancel out Nevada's veto of the President's siting decision; it did not forever shield that decision, or the DOE decisions and actions on which it was based, from judicial review.

The NWPA explicitly defines a "repository" as a "system" for the "permanent deep geologic disposal" of radioactive material. NWPA § 2(18). Moreover, Sections 112 and 113 obligated DOE to issue guidelines governing the suitability determination and the recommendation of sites for repositories that both establish "detailed geologic considerations" to serve as "primary criteria" in site selection and specify the physical factors that would qualify or disqualify a site from development. Pertinent legislative history, from the initial efforts of Congress through the enactment of the NWPA and later amendments, shows a clear Congressional commitment to a repository deep underground, relying on multiple, independent barriers, including primarily the geology of the site.

Even if the NWPA left this point ambiguous, however, DOE's earlier consistent position, and its sharp break with that position in its new Guidelines, strongly argues against according DOE's new position any deference. Not only does the NWPA not delegate fundamental policymaking to DOE, it was intended to wrest such policymaking away from the Executive Branch.

DOE also failed to take key actions required by the NWPA. Although DOE had determined Yucca was unsuitable for development, DOE never took the actions required, including reporting to Congress, and recommended Yucca for development without first completing required site characterization.

In recommending Yucca, DOE also evaded its NEPA responsibilities, refusing against the advice of its own staff to prepare a Record of Decision supporting its final site recommendation, refusing to wait 30 days after EPA publication of notice of the FEIS's availability, and refusing to provide notice and an opportunity to comment to Nevada.

In its FEIS, DOE committed foundational errors that obfuscated the nature of the "proposed action" and invalidated its assessment of the comparative merits of the project versus the "no-project" alternative. DOE also defined the "proposed action" to leave critical aspects of the project unassessed; segmented out the transportation component for future analysis; failed to disclose statutory violations; and failed to evaluate realistically the consequences of terrorism in spent fuel transport.

ARGUMENT

I. Standard of Review

At issue here is a question of pure statutory construction, subject to *de novo* review. *See National Labor Relations Bd. Union v. FLRA*, 834 F.2d 191, 197-98 (D.C. Cir. 1987).

1. By refusing to give geologic considerations primacy, DOE exercised "its authority in a manner that is inconsistent with the administrative structure that Congress enacted into law." *FDA v. Brown & Williamson Tobacco Corp.* 529 U.S. 120, 125 (2000) (internal quotation omitted). The issue here does not "center[] on the wisdom of the agency's policy," but on whether it made "a reasonable choice within a gap left open by Congress." *Chevron v. NRDC*, 467 U.S. 837, 866 (1984). "Regardless of how serious the problem an administrative agency seeks to address, ... [a]nd although agencies are generally entitled to deference in the interpretation of statutes that they administer, a reviewing 'court, as well as the agency, must give effect to the unambiguously expressed intent of Congress.' " *Brown*, 529 U.S. at 126-27 (quoting *Chevron*, 467 U.S. at 842-43). Thus, in measuring whether the Guidelines pass muster under the NWPA, this Court should accord DOE's new position no deference.

The fact that Congress has "directly spoken to the precise question at issue" (*Chevron*, 467 U.S. at 842) is evident from numerous provisions of the NWPA. *See American Bankers Ass'n v. NCUA*, 271 F.3d 262, 267 (D.C. Cir. 2001). Especially important is the fact that among these passages are specific definitions of key terms, such as "repository," that strongly support Petitioners. As this Court has said, "In the face of a clear statutory definition, ... there is no occasion for deference." *Time Warner Entertainment Co. v. FCC*, 56 F.3d 151, 190 (D.C. Cir. 1995). *See also Board of Governors v. Dimension Fin. Corp.*, 474 U.S. 361, 368 (1986); *ACLU v. FCC*, 823 F.2d 1554, 1568 (D.C. Cir. 1987). Here, DOE's new rules would excise the NWPA's references to geologic considerations from the statute. Such revisions were not an option Congress gave DOE.

Furthermore, identification of the "unambiguously expressed intent of Congress" is not limited to statutory text, but involves "traditional tools of statutory construction," *NRDC v. Browner*, 57 F.3d 1122, 1125 (D.C. Cir. 1995) (quotation omitted), including examination of legislative history, *id.* at 1127, and the broader "context" of the relevant words, *American Bankers Ass'n*, 271 F.3d at 267, both of which strongly favor Petitioners.

Strikingly, when the NWPA was passed, DOE concluded it did *not* have authority to discard the primacy of geologic considerations. DOE maintained this position through enactment of the NWPAA and EnPA. Such an unvarying position by DOE, contemporaneous with enactment of the statute and amendments it must administer, is of great significance to the *Chevron*-One analysis. As the Supreme Court explained, "the want of assertion of power by those who presumably would be alert to exercise it, is ... significant in determining whether such power was actually conferred." *BankAmerica Corp. v. U.S.*, 462 U.S. 122, 131 (1983) (internal quotation omitted). *See also EEOC v. Associated Dry Goods Corp.*, 449 U.S. 590, 600 n.17 (1981); *Middle South Energy, Inc. v. FERC*, 747 F.2d 763, 769-70 (D.C. Cir. 1984).

A consistent, longstanding understanding by DOE of the meaning of its operative statute "bolsters" the conclusion that Congress required geologic considerations to have primacy in isolating wastes at DOE's chosen site. *See Brown*, 529 U.S. at 157. In short, from the evidence that should be considered in any *Chevron*-One analysis, it is clear Congress *did* speak to the precise question at issue, and thus no deference is due DOE's departure from that mandate.

2. Even if one were to conclude that the text, structure, and legislative history of the NWPA were ambiguous, under *Chevron* "Step Two," the consistency of DOE's earlier position, and its eleventh-hour break with that position in the new Guidelines, strongly argues against according the new view any deference. *See United States v. Mead Corp.*, 533 U.S. 218, 228 (2001) ("The fair measure of deference to an agency administering its own statute has been understood to vary with circumstances, and courts have looked to the degree of the agency's care, its

consistency, formality, and relative expertness, and to the persuasiveness of the agency's position."); *NLRB v. United Food & Commercial Workers Union*, 484 U.S. 112, 124 n.20 (1987).

Though this Court has noted that an agency's "self-interest alone gives rise to no automatic rebuttal of deference," *Independent Petroleum Ass'n v. DeWitt*, 279 F.3d 1036, 1040 (D.C. Cir. 2002), the circumstances under which DOE undertook its change here combine with other evidence of Congressional intent to discourage deference to DOE's position. *See Transohio Sav. Bank v. Director, OTS*, 967 F.2d 598, 614 (D.C. Cir. 1992) (observing danger of according deference to interpretation where it might "lead a court to endorse self-serving views" of agency). Here, DOE's change was influenced by its desire to minimize crushing liability to utilities for its past delays.

More important, none of the values that justify deference are implicated here. In particular, "an agency to which Congress has delegated policymaking responsibilities may, within the limits of that delegation, properly rely on the incumbent administration's views of wise policy to inform its judgments." *Chevron*, 467 U.S. at 865. In such a situation, an agency is indirectly accountable to the people (through the President) for "resolving the competing interests which Congress itself either inadvertently did not resolve, or intentionally left to be resolved by the agency." *Id.* at 865-66.

Not only does the NWPA not delegate fundamental policymaking to DOE, it was intended to wrest such policymaking away from the Executive Branch, in a calculated effort to restore Congressional leadership and control over the waste disposal problem. Indeed, Congress' work on the issue was provoked by perceived failures of the Executive Branch to address the problem. As one House Committee noted:

> The failure of the Federal government to have successfully demonstrated that it can dispose of high level radioactive materials after nearly four decades of allowing such materials to be generated and the recently announced proposal to delay the establishment of a repository for as much as two more decades, has resulted in the erosion of public confidence in the ability of the government to prove that it can dispose of these materials.

H.R. Rep. No. 96-1156, Part III, at 16 (1980). *See also* H.R. Rep. No. 96-1382, Part II, at 23 (1980) ("The decided emphasis of the Committee was on formulating a certain, Congressionally mandated pathway...."); S.Rep. No. 97-282, at 3 (1981). *See also* NWPA §111(a)(3), (b)(2). Thus, policymakers in Congress intended to resolve issues that policymakers in the Executive Branch had long failed to resolve. *See* H.R. Rep. No. 97-491, Part 1, at 29-30 (1982).

II. Respondent's Guidelines and Siting Decisions Violate the NWPA

It cannot be denied that nuclear waste disposal represents one of the most important policy issues facing America today, with implications for health, safety, and the environment for centuries to come. It is equally undeniable, however, that "[r]egardless of how serious the problem an administrative agency seeks to address, ... it may not exercise its authority in a manner that is inconsistent with the administrative structure that Congress enacted into law." *Brown*, 529 U.S. at 125 (citation and internal quotation omitted). *See also id.* at 161; *Wisconsin Elec. Power Co. v. DOE*, 778 F.2d 1, 8 (D.C. Cir. 1985).

Though DOE purports to rely on the NWPA as authority for Part 963, those rules are in no way grounded in the authority granted DOE by that statute. The rules are thus unlawful, and the site suitability and selection decisions by DOE and the President, based on those rules, are consequently invalid.

Part 963 reduces to an afterthought the hydrogeologic characteristics of the Yucca site. While Part 963 pays lip service to DOE's consideration of "criteria" that include these "properties" at Yucca, 10 C.F.R. §963.17(a)(1), such properties have no minimum requirements and become, in fact, unimportant in adjudging site suitability. The Guidelines specify no factors that would qualify or disqualify the Yucca *site* from development. Because Part 963 includes no requirement that the geologic setting independently provide waste isolation, the Guidelines effectively authorize DOE to find a "site" suitable solely through the use of man-made packages. If the package alone can contain wastes for 10,000 years, DOE's standard can presumably be met wherever that package resides, and any such site becomes "suitable."

The concerns raised by these features are not theoretical: It was these very features that authorized DOE to recommend Yucca to the President. These features authorized DOE to allow the purported (but speculative and untested) benefits of "engineered barriers" to completely mask Yucca's known geologic deficiencies. And Part 963's elimination of any disqualifying conditions allowed DOE to recommend the site notwithstanding the presence of at least one condition (GWTT) that disqualified it under the previous rules.

A. <u>The NWPA's Plain Language Requires Geologic Considerations to be Primary in Determining Site Suitability</u>

Numerous provisions of the NWPA make clear that geologic considerations are to be the primary factors considered by DOE in determining site suitability. At the heart of the statute, Congress defined "repository" as

> any system licensed by the [NRC] that is intended to be used for, or may be used for, the *permanent deep geologic disposal* of [waste]....

NWPA §2(18) (emphasis added).

To be sure, this definition does reflect Congress' intent that a "repository" constitutes a disposal "system," including natural and engineered barriers. It would be ludicrous to contend that Congress intended engineered barriers to play *no* role in isolating waste, such that it would be sufficient for DOE to simply throw loose waste into a hole in the ground. By the same token, this definition's reference to "permanent deep geologic disposal" makes clear that Congress intended a site's geology to itself play the primary and "permanent" role in isolating waste. By authorizing DOE to find Yucca suitable *irrespective* of whether its geologic properties are capable of isolating waste that will remain lethal long after engineered barriers can be expected to work, Part 963 unlawfully redefines "repository" to mean a non-permanent system of engineered barriers that just happens to be placed underground.

In addition, NWPA Section 112(a) required DOE to "issue general guidelines for the recommendation of sites for repositories," which were to "specify detailed geologic considerations that shall be primary criteria for the selection of sites in various geologic media." And Section 113 required DOE to prepare for Yucca "a general plan for site characterization activities ... which plan shall include ... *criteria to be used to determine the suitability of such candidate site for the location of a repository, developed pursuant to section 112(a).*" NWPA §113(b)(1)(A)(iv) (emphasis added). *See Nevada v. Watkins*, 914 F.2d 1545, 1562 (9th Cir. 1990) (Section 113(b) "makes clear [that] the guidelines developed by [DOE] pursuant to section [112(a)] are to be utilized to determine the suitability of Yucca."). Sections 112 and 113 highlight the central importance of a site's physical characteristics to determining its suitability. There is no way the Guidelines, which barely pay lip service to consideration of Yucca's geologic properties, and which authorize selection of Yucca regardless of how little (if at all) its natural barriers can successfully isolate waste, can be squared with these provisions.

The NWPA also leaves no doubt that DOE's rules must include qualifying and disqualifying conditions: Section 112(a) unambiguously provides that "[s]uch guidelines shall specify factors that qualify or disqualify any site from development ..., including factors pertaining to ... hydrology, geophysics, seismic activity...." DOE's original guidelines did specify such conditions, and for years DOE consistently and correctly maintained that those conditions would apply to and govern its Yucca suitability determination. But Part 963 contains *no* qualifying or disqualifying factors, let alone factors pertaining to the specific topics listed in Section 112(a).

Whether read in isolation or as a coherent whole, these and other[16] provisions of the NWPA underscore Congress' emphasis on the critical long-term role of natural barriers. *Cf. NRDC v. EPA*, 824 F.2d 1258, 1279 (1st Cir. 1987) ("Congress ordered that these highly dangerous wastes be placed underground with the intent that the surrounding geologic formations would be the major component of the containment mechanism."). DOE itself fully understood what Congress intended, and construed the NWPA and the NWPAA in a manner designed to effectuate Congress' intent, at least until 1996 — when, facing liability for its "massive breach" of its duty to begin waste disposal in 1998, *Alabama Power*, 307 F.3d at 1302, and after uncovering fatal deficiencies in the Yucca site, DOE abandoned its longstanding construction of the NWPA in favor if its current expedient "construction."

[16] *See* NWPA §§ 2(4), 2(21)(B), 113(b)(A)(ii), 114(a)(1)(D), 114(f)(6), 217(a)(6), 217(b)(3).

B. Legislative History Reaffirms Congress' Intent

Though there is no need to go further than the plain words of the statute, the legislative history of the NWPA leaves no doubt that Congress intended what it said. *See supra* at 12-17. To summarize, the legislative effort originated from the proposed action recommended by DOE in its 1980 EIS — deep geologic isolation — itself reaffirming a key NAS study recommending the same. Congress at first proposed not to mandate geologic isolation and sought to require primary reliance on engineered barriers, but explicitly reversed this approach, at DOE's urging, when it became clear that the nation would be burying long-lived spent fuel as well as less-volatile reprocessing wastes. This turnabout to primary reliance on geologic isolation provides unambiguous context to the meaning and intent of the NWPA provisions discussed above, which Congress left intact when revisiting the Act again in 1987 and 1992.

C. DOE's Justifications Dishonor the Congressional Mandate

DOE's justifications for adopting the Guidelines do not withstand scrutiny.

1. According to DOE, the guidelines mandated by Section 112(a) govern only "the process of selecting and comparing among potential sites to determine which sites are appropriate to proceed" to characteri-

zation, and nothing in the NWPA requires these guidelines to also "govern the process for determining site suitability and site recommendation under [S]ections 113 and 114." 66 Fed. Reg. at 57,312. DOE also contends that because Section 113 requires DOE to develop "criteria" and not "guidelines," and because the NWPA does not define "criteria," Congress did not mandate that there be any substantive relationship between the Section 112 "guidelines" and the Section 113 "criteria." *Id.*

These arguments all fail mightily. Section 112 does not limit the applicability of the guidelines it requires to the comparison of sites to determine which should be characterized, but provides that such guidelines are also to govern "the recommendation of sites for repositories," which includes DOE's recommendation of fully characterized sites. *Cf.* NWPA §114(a)(1). And Section 113(b)(1)(A)(iv) explicitly incorporates the salient aspects of DOE's Section 112(a) guidelines for the purpose of developing DOE's site suitability "criteria."

DOE's argument that Congress left "criteria" undefined ignores that Section 112 expressly equates "criteria" with "detailed geologic considerations." DOE elsewhere acknowledges that Section 112(a) "uses the term 'primary criteria' synonymously with the term 'detailed geologic considerations,'" and that "it seems likely that Congress used the word 'criteria' in [Sections 112 and 113] to have the same general meaning." 66 Fed. Reg. at 57,320. It is disingenuous for DOE to equate the meanings of "criteria" in both provisions when doing so suits its purposes, but then contend that Congress left the Section 113 "criteria" undefined when it came to the substantive content of DOE's siting guidelines.

DOE also contends that because Congress could have drafted Section 113 to refer to the Section 112(a) "guidelines" rather than "criteria," it is "unlikely that Congress intended to require the [Section 113] 'criteria' to be the [Section 112 guidelines] themselves." 66 Fed. Reg. at 57,312. This argument misapprehends the issue. Everyone agrees there is not a complete overlap between the purposes served by the Section 112 guidelines and the Section 113 criteria. Because Section 112 is concerned in part with the drawing of comparisons between sites while Section 113 is not, there would be no need for Congress to require a wholesale incorporation of the Section 112 guidelines into Section 113. It does not follow, however, that the content of the Section 113 criteria need bear no connection to the content of the Section 112 guidelines. DOE itself had previously recognized as much, noting on numerous occasions that in carrying out its duties under Section 113, it could apply only the provisions of the

1984 guidelines relevant to those duties. *See, e.g.*, 60 Fed. Reg. 47,737, 47,740 (Sept. 14, 1995).

DOE's claim that Section 113's explicit reference to the Section 112 guidelines only requires DOE to observe the "special procedural requirements of section 112(a)" in formulating the Section 113(b) "criteria," 66 Fed. Reg. at 57,312, is groundless. Congress *could* have easily so circumscribed Section 113's reference to Section 112 if that were its intent; it could, for example, have provided that the Section 113 criteria were to be "formulated pursuant to the procedures specified in section 112(a)." It did not, and DOE's argument is an attempt to re-write the statute. *See Watkins*, 914 F.2d at 1562.

Finally, DOE's position leads to absurd results. DOE necessarily contends that although Congress *required* geologic considerations to govern analyses of which sites to characterize, Congress did not care what role, if any, such considerations played in DOE's Section 113 analysis of whether a characterized site should actually be developed. But it would make no sense for Congress to require geologic considerations to play a critical (indeed, *disqualifying*) role in determinations that must be made *before* in-depth geologic information is available, but to be utterly indifferent to the role, if any, geology was to play in the far more critical decisions DOE was to make *after* it obtained such information.

2. DOE next argues that Congress redirected the waste program in a way that necessitated adoption of Part 963. Specifically, DOE contends that the NWPAA and EnPA directed that Yucca be the exclusive focus of the waste program, and that in 1996 and 1997 appropriations acts, Congress endorsed DOE's adoption of a "systems"-only approach. 66 Fed. Reg. at 57,312-13.

It is tellingly odd for DOE to suggest that the NWPAA or EnPA provided support for its actions, when DOE waited *nine years* after enactment of the NWPAA, and *four years* after enactment of EnPA, to even propose revising its guidelines. And DOE was not idle during this intervening period; on several occasions, extending as late as 1995, DOE gave serious consideration to the question of whether the NWPAA or EnPA required or justified amendment of the guidelines, and concluded they did *not*. It was only when DOE discovered that Yucca would not qualify for development that DOE confected the idea of using these later enactments to rationalize changing the rules. *See* Section I, *supra*.

To be sure, the NWPAA did direct DOE to characterize only Yucca. But, as DOE has itself insisted, the NWPA did not prejudge the issue of Yucca's suitability. *Cf. Watkins*, 914 F.2d at 1559. Moreover, neither the

NWPAA nor EnPA made any substantive changes to the provisions of Sections 112 and 113 specifying standards governing the site suitability/selection analysis, or to any of the other provisions of the NWPA, discussed above, emphasizing the role of natural barriers in that test. *Id.* at 1562. EnPA did not even purport to address, let alone alter, DOE's duties in connection with the waste program; rather, EnPA relates solely to the responsibilities of EPA and NRC.

DOE's argument ignores the "cardinal rule ... that repeals by implication are not favored," *Posadas v. National City Bank*, 296 U.S. 497, 503 (1936). *See also J.E.M. AG Supply v. Pioneer Hi-Bred Int'l*, 122 S. Ct. 593, 601 (2001). Because changes in the waste program effected by the NWPAA and EnPA are not at all inconsistent, let alone "irreconcilable," with the NWPA's emphasis on geologic isolation, there is no reason to conclude that these later enactments impliedly repealed the numerous geologic isolation features of the earlier enactment. *Cf. Morton v. Mancari*, 417 U.S. 535, 550 (1974).

DOE's attempt to rely on a 1997 appropriations act, and language in an earlier appropriations conference report, is even more suspect. The rule that repeals by implication are disfavored "applies with especial force when the provision advanced as the repealing measure was enacted in an appropriations bill," *U.S. v. Will*, 449 U.S. 200, 221-22 (1980), and there is *no* authority that would allow substantive law to be amended through language in a committee report. The fact that an appropriations committee approved of measures by DOE to perform a Yucca "viability assessment" is surely not inconsistent, let alone irreconcilable, with Congress' direction in the NWPA that the physical characteristics of a site offer primary isolation capability. After all, DOE had been performing "system" assessments for years, *see e.g.*, 66 Fed. Reg. at 57,305, and had never suggested they obviated the need for it to ensure the waste isolation capability of Yucca's natural barriers.

3. DOE next argues that because NRC's new regulations focus on the ability of the repository "system" to satisfy EPA standards, DOE too had to revise its Guidelines to conform to NRC's "total system approach." 66 Fed. Reg. at 57,313-14. Of course, the mere fact that EPA and NRC revised their regulations does not establish that those new regulations are lawful, or that DOE was justified in relying on them. Petitioners are challenging those regulations in separate actions pending before this Court. Furthermore, DOE's suggestion that it had little choice but to follow EPA and NRC is disingenuous, since those agencies adopted their regulations principally as a result of intense lobbying by DOE, which

needed an excuse to change its own rules. As discussed above, DOE adopted its new regulations over the strong *objection* of EPA. For DOE to hide behind EPA's and NRC's new regulations is like the child who kills his parents and pleads for mercy because he is an orphan.

In any event, even if EPA's and NRC's regulations are lawful, that would not legitimize Part 963. DOE, NRC, and EPA have independent duties under the NWPA, and the site suitability determination is entrusted, subject to statutory standards, to DOE. Neither EPA's nor NRC's regulations purported to dictate how DOE should make its determination.

DOE's contention that its suitability determination amounts to little more than a prediction regarding the site's "licensability" represents a complete reversal of DOE's previous, contemporaneous, and long-held views. DOE had consistently maintained that suitability and licensability were substantively distinct concepts.[17] *See* RR-7.0004-9. Of course there is a relationship between the two; a site can hardly be considered suitable if it yields no prospect of later satisfying requirements for a construction permit. It does not follow, however, that the converse is true – that a repository designed to secure a construction permit is necessarily sited in a

[17] Curiously, DOE elsewhere in its notice acknowledges this distinction between suitability and licensability. 66 Fed. Reg. at 57,322.

suitable setting. Thus, DOE's assertion that it would be "illogical" for it to maintain suitability criteria that NRC had removed from its licensing regulations, 66 Fed. Reg. at 57,314, is itself "illogical."

For similar reasons, the fact that NRC's new rules focus on a "total system" approach to licensing does not excuse DOE's abandonment of its own responsibility to ensure that Yucca's natural barriers can provide significant isolation capabilities. NRC's rules will come into play under the NWPA only if, among other things, DOE fulfills its statutory duties regarding the suitability determination. The fact that NRC regulations may presume DOE's compliance with its statutory duties cannot serve as a basis for DOE to shirk those same duties.

Moreover, there is nothing inconsistent between a "system" approach, properly conceived, and the statutory commitment to geologic isolation. As discussed, the NWPA contemplates that, at least for the initial period of repository operations, when it is possible to predict the performance of engineered barriers, the engineered and natural barriers will work together as a system to protect against harmful releases. But because no man-made barrier can be expected to work perfectly, or to last for the hundreds of thousands of years the wastes will remain lethal, Congress insisted that a site's natural barriers be themselves capable of isolating wastes. Congress' decision that NRC's licensing regulations "provide for the use of a system of multiple barriers," NWPA §121(b)(1)(B), thus fits comfortably with its insistence that a site's natural barriers themselves be independently (or "primarily") able to protect against releases. Only DOE's unlawful adoption and application of Guidelines that authorize selection of a site whose natural barriers contribute little or nothing to waste isolation conflicts with this "multiple barrier" or "system" approach.

D. The Secretary's and President's Repository Siting Decisions Accordingly Fail

For the reasons discussed, DOE's Guidelines are not "grounded in a valid grant of authority from Congress." *Brown*, 529 U.S. at 161. Because the Secretary premised his suitability determination and site recommendation on application of the unlawful Guidelines,[18] that determination and recommendation must be invalidated and set aside. *Cf. SEC v. Chenery Corp.*, 318 U.S. 80, 88 (1943); *Prill v. NLRB*, 755 F.2d 941, 948 (D.C. Cir. 1985).

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[18] SA-052-Encl-10 ("Using [DOE's] suitability Guidelines, I have concluded that Yucca Mountain is in fact suitable for a repository."); 10 C.F.R. §963.1(a).

Section 114(a)(3)(A) makes clear that "[t]he President may not recommend the approval of the Yucca Mountain site unless the Secretary has recommended to the President ... approval of such site." The unlawfulness of the Secretary's recommendation to the President also requires that the President's selection of Yucca be invalidated and set aside.

III. DOE Failed to Take Actions Required by the NWPA

The NWPA authorizes judicial review of alleged "failure[s] of the Secretary, [or] the President ... to make any decision, or take any action, required under this subtitle." NWPA §119(a)(1)(B). This provision provides an independent basis for the Court's intervention, as DOE has failed to take critical actions required by the NWPA.

A. Failure to Declare Site Unsuitable and Report to Congress

NWPA Section 113(c)(3) provides that "[i]f the Secretary at any time determines the Yucca Mountain site to be unsuitable for development as a repository, the Secretary shall" take several actions, including "terminat[ion of] all site characterization activities" and reporting to Congress with "recommendations for further action" to provide for alternate disposition, "including the need for new legislative authority." As discussed in Sections I and J, *supra*, DOE *in fact* made just such a determination when it concluded after years of analysis that Yucca's natural barriers could not sufficiently impede the flow of water through the repository to the accessible environment to meet the groundwater travel time requirement in Part 960. This finding, pertaining to the very disqualifying condition DOE believed was "heads and shoulders above the others" in importance, was confirmed and re-confirmed over five ensuing years, to the point were the agency lost hope of ever establishing significant, let alone "primary," geologic isolation in the natural setting.

This circumstance imposed a duty on the Secretary to declare the site unsuitable. The site's failure to isolate waste primarily by geologic means reflected a failure of the basic premise of a geologic repository, as reflected in the NWPA and the literal terms of DOE's own rules.

By 1998, as his letter to Nevada's Governor establishes, the Secretary had determined that up to 20-percent of all water moving through the repository would reach the water table in less than 1000 years. *See* Section J, *supra.* Part 960, in effect until December 2001 when the Secretary jettisoned its requirements and approved 963 just for Yucca, specified that a site "shall be disqualified" if GWTT is "less than 1000 years along *any* pathway of *likely and significant* radionuclide travel." 10 C.F.R. §960.4-2-1(d) (emphasis added). 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. GR-34-384, 399.

In his 1998 letter, the Secretary made unripe a threatened judicial challenge by Nevada for "failure to act" with his representation that DOE was still studying the GWTT situation. But as is clear from the record, DOE's subsequent studies produced nothing to suggest that its dire GWTT estimates had been erroneous. Indeed, later studies (*e.g.*, SA-027-17) confirmed the worst with respect to the ability of Yucca's natural setting to isolate the flow of contamination to the accessible environment, showing that, because of poor geologic isolation, failure of the engineered barriers would *guarantee* violation of the EPA dose limit well before the end of the 10,000-year compliance period. *See* Section J, *supra*.

Upon determining in fact that the Yucca site was unsuitable, DOE did not take *any* of the actions Section 113(c)(3) required. Instead, in November 2001 the Secretary signed an order eliminating Part 960 for Yucca and approving an *ultra vires* Part 963.

B. <u>Failure to Complete Site Characterization</u>

DOE also failed to take actions required under Section 114(a). That provision required DOE to "complet[e] [its] site characterization activities" before the Secretary could recommend Yucca to the President. As described in the Statement of the Facts at Section I, *supra*, DOE recommended Yucca without coming close to fulfilling its statutory obligation to complete site characterization. Indeed, DOE "cancelled" site characterization (GR-32-19) and completed only part of one of the seven separate analyses it and independent reviewers like TRB, NAS, and ACNW had deemed critical before site characterization could be considered finished.

IV. <u>DOE Substantively and Procedurally Conducted a Flawed Environmental Review</u>

A. <u>DOE's NEPA and NWPA Violations Are Not Entitled to Deference</u>

Faced with one of the most critical tasks in its history – the environmental review supporting its Yucca site recommendation – DOE committed foundational errors that irreparably damaged the comparisons in both the FEIS and the recommendation between the consequences of adopting the proposed project versus declining to do so. So fundamental were these errors that it is impossible for Petitioners, the public and other agencies to decipher the environmental consequences between the project and the "no project" alternative. DOE also refused to follow mandatory procedures designed to protect Petitioners' and the public's rights, despite the absence of any statutory excuse.

DOE's end run around the clear mandates of NEPA and related provisions of the NWPA constitutes the most glaring evasion of federal environmental review responsibilities in the 31 years since this Court's seminal decision in *Calvert Cliffs' Coordinating Committee v. AEC*, 449 F.2d 1109, 1115 (D.C. Cir. 1971). This Court "has repeatedly taken note of the sweeping scope of NEPA and the EIS requirement." *Environmental Def. Fund v. Massey*, 986 F.2d 528, 536 (D.C. Cir. 1993) (citing *Calvert Cliffs'*, 449 F.2d at 1122). *See also Idaho v. ICC*, 35 F.3d 585, 596 (D.C. Cir. 1994). NEPA requires agencies to "fully assess[] the possible environmental consequences" of activities "which have the potential for disturbing the environment." *Grand Canyon Trust v. FAA*, 290 F.3d 339, 342 (D.C. Cir. 2002) (internal quotations omitted).

Far from excusing DOE's performance under NEPA, NWPA Section 114 provides:

- The site recommendation *is* DOE's "major [f]ederal action significantly affecting the quality of the human environment" for purposes of NEPA compliance. NWPA §114(f)(1).

- An FEIS "prepared by the Secretary under [NEPA] shall accompany any recommendation to the President to approve a site for a repository." NWPA §§114(f)(1) and (a)(1)(D).

- With respect to three enumerated subjects, compliance with "the procedures and requirements" of the NWPA shall be deemed "adequate consideration" to satisfy the requirements of NEPA. NWPA §114(f)(2), (3). In all other respects, including those addressed here, neither Section 114 nor any other provision of the NWPA limits the Secretary's obligation to comply with NEPA.[19]

NEPA "ensures that the agency will not act on incomplete information, only to regret its decision after it is too late to correct." *Marsh v. Oregon Natural Resources Council,* 490 U.S. 360, 371 (1989).[20] NEPA Section 102, 42 U.S.C. §4332, directs agencies to comply to "the fullest extent possible." This mandate is "neither accidental nor hyperbolic," but

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[19] *See also* H.R. Rep. No. 97-785, at 37, 69 (1982) ("Although specific sections of NEPA are suspended at specific points in the repository development program, the spirit and intent of the evaluation process established by NEPA applies throughout the program....").

[20] NEPA procedures "must insure that environmental information is available to public officials and citizens *before* decisions are made and *before* actions are taken." 40 C.F.R. §1500.1(b) (emphasis added). *See also Grand Canyon,* 290 F.3d at 340; *Sierra Club v.Peterson,* 717 F.2d 1409, 1415 (D.C. Cir. 1983).

rather "a deliberate command that the duty NEPA imposes upon the agencies to consider environmental factors not be shunted aside in the bureaucratic shuffle." *Flint Ridge Dev. Co. v. Scenic Rivers Ass'n*, 426 U.S. 776, 787-88 (1976). This language is not an "escape hatch for footdragging agencies," but a mandate to enforce NEPA's procedural requirements "unless there is a clear conflict of *statutory* authority." *Calvert Cliffs'*, 449 F.2d at 1115 (emphasis in original).

In *Calvert Cliffs'*, this Court dismissed as a "paper tiger" the notion that compliance with NEPA's procedural requirements is "somehow discretionary," concluding that Congress established a "strict standard of compliance" and warning against "abdication" of the AEC's NEPA authority to other agencies. 449 F.2d at 1112-14, 1123. This Court posited that without rigorous consideration of all environmental factors at the time of the agency's final decision, its decision would become a "hollow exercise" failing the procedural mandates of NEPA. *Id.* at 1128. *See also Idaho*, 35 F.3d at 596 (deferral of review to future proceedings impermissible).

Like the AEC in *Calvert Cliffs'*, DOE's stubborn evasiveness here reveals a "thoroughgoing reluctance to meet the NEPA procedural obligations" in the agency review process. 449 F.2d at 1119. DOE's preliminary motion to dismiss displayed a novel view of its own FEIS as little more than an advisory report to Congress and the NRC that is simultaneously moot and unripe, rendering it impervious to judicial review. Since DOE relied on its "final" EIS to expedite a Congressional decision and facilitate its NRC license application, but disclaimed its finality for judicial accountability, its disrespect for the most basic NEPA requirements is unsurprising.

But DOE's NEPA evasions are not entitled to deference. Since "NEPA's mandate is addressed to all federal agencies," an agency claim that NEPA requirements are inapplicable "is not entitled to the deference the courts must accord to an agency's interpretation of its governing statute." *Citizens Against Rails-to-Trails v. Surface Transp. Bd.*, 267 F.3d 1144, 1150 (D.C. Cir. 2001). Likewise, "this court owes no deference" to agency interpretations of the Council on Environmental Quality's ("CEQ's") NEPA regulations. *Grand Canyon*, 290 F.3d at 342. An agency's claim to be exempt from NEPA requirements is "a question of law, subject to *de novo* review." *Citizens*, 267 F.3d at 1151. In such review, this Court's duty is to "see that important legislative purposes, heralded in the halls of Congress, are not lost or misdirected in the vast hallways of the federal bureaucracy." *Calvert Cliffs'*, 449 F.2d at 1111.

B. DOE Blatantly Violated Mandatory Procedural Requirements of NEPA and the NWPA

Under CEQ's regulations, "the agency *must file* with EPA the [FEIS], along with public comments received regarding the proposed statement, which are then published in the *Federal Register*. *See* 40 C.F.R. §§1506.9-10. ... An agency *must wait* at least 30 days following publication before taking any action...." *U.S. Ecology, Inc. v. Department of the Interior*, 231 F.3d 20, 22 (D.C. Cir. 2000) (emphasis added). *See* 40 C.F.R. §1506.10(b)(2). DOE's own NEPA regulations concur. 10 C.F.R. §1021.315(a). As DOE understood, SA-031-A6, neither the NWPA nor other laws exempt the Secretary from following these rules prior to his site recommendation. To the contrary, NEPA's 30-day rule coincides with the NWPA's requirement, Section 114(a)(1), that Nevada have 30 days to comment on the Secretary's recommendation before its submission to the President. NWPA §114(a)(1).

DOE issued its site recommendation the *same day* it published the FEIS, and never submitted it for EPA publication of a notice of availability. The Secretary's failure deprived other agencies of the opportunity to refer the FEIS to CEQ pursuant to 40 C.F.R. § 1504.1, and deprived Nevada and the public of the opportunity to argue, based on the defective FEIS, that the Secretary not make his recommendation.

CEQ NEPA regulations also provide that "at the time of its decision," a federal agency "shall prepare a concise public record of decision." 40 C.F.R. §1505.2; *see also U.S. Ecology*, 231 F.3d at 22. DOE's NEPA regulations concur. 10 C.F.R. §1021.315(b). DOE's NEPA staff recognized this black-letter requirement as early as 1994 for Yucca, concluding that "[i]f DOE decides to take action on a proposal covered by an EIS, a [ROD] is prepared and published in the *Federal Register*.... No action is taken until the decision has been made public." SA-031-A6.

The FEIS record repeatedly establishes that a ROD must precede any site recommendation, and that DOE understood this. *See* NR-1.00098-3; NR-1.01259-8, 9; NR-1.01318-5; NR-1.01258-13.

Nothing in the record explains why DOE abandoned its well-understood obligation to prepare a ROD supporting the site recommendation. Nevada was first informed of this abandonment in January 2001 by letter from DOE's Director of Institutional Affairs, who stated that DOE did not "presently anticipate" issuing a ROD because "the decision to approve the site rests not with the Secretary of Energy, but with the President."[21] SA-001. *See also* FEIS-CR1-49.

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[21] DOE's "deferral" to the Presidential stage does not cure the error, since Presidential approval came one day after the Secretary's decision and included no ROD.

This case does not come close to the "clear conflict of statutory authority" required to exempt DOE's site recommendation from the basic NEPA rule requiring a timely ROD. *Calvert Cliffs'*, 449 F.2d at 1115.[22] Indeed, the Secretary's recommendation apparently marks the first time that an agency took final agency action under the CEQ's regulations and described in an EIS without first issuing the required ROD.

Finally, NWPA Section 114(a)(1)(F) required the recommendation to include "the views and comments of the Governor and legislature of any State ... together with the response of the Secretary to such views." This requirement served central purposes of the NWPA "to define the relationship between the Federal Government and the State governments with respect to the disposal...," NWPA §111(b)(3), and to "promote public confidence in the safety of disposal...." NWPA §111(a)(6). *See also* 40 C.F.R. §1508.27.

Betraying this federal/state comity, DOE withheld the FEIS from Nevada, other states, the public, and some key federal agencies for more than a month after completing it, while allowing several other federal

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[22] *See also Committee for Nuclear Responsibility v. Seaborg*, 463 F.2d 783 (D.C. Cir. 1971) (subsequent appropriations bill created no conflict); *Izaak Walton League v. Marsh*, 655 F.2d 346 (D.C. Cir.), *cert. denied*, 454 U.S. 1092 (1981) (subsequent legislation created no conflict).

agencies secretly to review and submit comments on it.[23] Nevada, as well as other states and federal agencies that had submitted comments critical of the proposed action received no such opportunity. Nevada never even saw the FEIS for Yucca prior to the site recommendation.

C. DOE's Faulty Definition of the "No-Action" Alternative Precluded Comparative Assessment of the Site Recommended Versus the Site's Disapproval

CEQ's NEPA regulations require an FEIS to analyze "the alternative of no action." 40 C.F.R. §1502.14(c). The no-action alternative serves a distinct role in NEPA analysis from that of project alternatives, since it "provides a benchmark, enabling decision-makers to compare the magnitude of environmental effects of the action alternatives." CEQ, *Forty Most Asked Questions Concerning CEQ's NEPA Regulations*, Question 3, 46 Fed. Reg. 18,026, 18,027 (Mar. 23, 1981).[24]

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[23] CEQ's January 9, 2002 letter to the Secretary, attached to his final site recommendation, noted it had completed preliminary review of the *"January 4, 2002"* FEIS. (Emphasis added). CEQ's letter recognized Nevada had not yet been notified, and that CEQ's "detailed" review would follow in the 30 days after notification to Nevada. Although Nevada was notified on January 10 of the Secretary's intent to approve Yucca, Nevada was not provided a copy of the FEIS and was unaware of its existence until the site recommendation.

[24] *See also Grand Canyon*, 290 F.3d at 346; *Alaska Wilderness Recreation & Tourism Ass'n v. Morrison*, 67 F.3d 723, 729-30 (9th Cir. 1995).

Without this benchmark, the FEIS could not fulfill NEPA's objective to adequately inform Congress, the public and the President of significant impacts of the proposed action. 46 Fed. Reg. at 18,027; *see* 40 C.F.R. §1500.1(a). NEPA regulations "require the analysis of the no action alternative even if the agency is under a court order or legislative command to act." 46 Fed. Reg. at 18,027. DOE is therefore required, as it has long recognized, *see* NR-1.01196-2, to assess the no-action alternative to Yucca. That duty remains even though the NWPA suspends the ordinary consideration of *action* alternatives with respect to *disposal* at Yucca.[25] The fact that Congress in the NWPA mandated an "up or down" decision on Yucca made it even more critical that the FEIS adopt a proper "no-action" benchmark to frame its assessment of the proposed action.

DOE's no-action analysis is audaciously contrived, against the advice of DOE's own staff and Program Manager, to direct decision-makers to the proposed action, and it ignores the logical and predictable consequences of what would happen if the project is cancelled or fails to re-

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[25] DOE "shall not be required" to consider the need for the repository, alternatives to geologic disposal, and sites other than Yucca. NWPA §114(a)(1)(D).

ceive an NRC license.[26] Under DOE's no-action scenario, utilities and DOE sites would continue to store wastes where they now are indefinitely. FEIS-S-29. The FEIS concludes that, "[b]ecause it would be highly speculative to attempt to predict future events, DOE decided to illustrate one set of possibilities by focusing ... on the potential impacts of two scenarios." *Id.* DOE recognizes, however, "that neither scenario would be likely" if Yucca is not developed. *Id.*

Scenario One assumes the waste would remain where it is "under institutional control for at least 10,000 years." *Id.* Scenario Two likewise "assumes that the wastes would remain at the 77 sites in perpetuity, but under institutional control for only 100 years." *Id.* In both scenarios, there would be no waste movement to centralized storage sites, and "no construction for onsite storage." NR-1.01196-4, 7; NR-1.01289-2. In Scenario Two, civilization as we know it would essentially cease to exist at waste sites, but would continue unabated elsewhere, except where radioactivity oozing from degrading sites made living conditions unacceptable. *See* NR-2.00142-26; FEIS-K; NR-1.01289-3.

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[26] NRC regulations require DOE's FEIS to include consideration of what would happen in the event of license denial. NR-1.01196-2; 10 C.F.R. §51.67(A).

DOE received hundreds of comments critical of its no-action approach, *see, e.g.*, FEIS-CR-5, but declined to change direction. Using its concededly unreal assumptions, DOE concluded that the proposed action is less costly and safer than taking no action. But that assessment is fatally flawed.

First, the record extensively details the fanciful, result-driven nature of DOE's no-action assessment:

- DOE's FEIS Management Council conceded at the outset that selection by DOE of the no-action alternative would surely be an "unlikely event." NR-1.01196-8.

- Management Council member Lichtman reported in 1999 that "[t]he EIS appears contrived to favor the Proposed Action ... by comparing disposal at [Yucca] only to the worst possible result of not proceeding...." NR-1.03341.

- DOE's Environmental Safety division proposed that the FEIS should analyze a more realistic scenario involving transfer to a few centralized sites for interim storage. Lichtman noted this scenario "eliminates [the] appearance of bias" and "better conforms to [CEQ] guidance."

Id.[27] But he conceded the political risks of NEPA compliance given the Secretary's opposition to storage. *Id.*

- Though above-ground storage options were expediently taboo,[28] DOE's General Counsel sought in 1997 to ensure that transport analyses in the FEIS nevertheless were "sufficiently flexible to allow the inclusion of interim storage, if necessary in the future." NR-1.01290-3; *see also* NR-1.01287-2.

Second, DOE's assumption of "no spent fuel storage construction" ignores the certainty of such storage recognized elsewhere in the FEIS. Though its figures are low, the FEIS notes utilities have already constructed 18 dry storage facilities, and are planning to build an additional 15. FEIS-A-13; 1-22, 2-64, 8-89 (describing "reasonably foreseeable" large-

[27] He concluded "the transfer scenario is at least as 'predictable' as continued *in situ* storage." *Id.* Other reviewers concurred, including the TRB. NR-1.01624-6. *See also* NR-1.01353.

[28] DOE was nervous that even analyzing the no-action alternative could be "alarming" to the public around its own sites and could "generate further unnecessary ill will with the commercial utilities." NR-1.101628-2; NR-1.01529; NR-2.00143. Construction of any storage facility, it was noted, "suggests there is no near-term need for a repository" and "may result in re-opening the decision process regarding alternatives to geologic disposal and set the program back 20 years." NR-1.01254-13. In 1998, FEIS preparers were instructed to avoid even using the words "storage facility" or "interim storage." NR-1.01624-1. *See also* NR-1.02011-6 ("Don't want to go there!").

scale Utah storage facility). These facilities are or will be built regardless of whether Yucca proceeds, yielding dramatic economies-of-scale and enhanced safety in spent fuel containment. NR-1.01289-12 (noting minimal health/safety impacts of storage).

Third, the premise that institutional control would be suddenly lost after 100 years is hardly a credible "bounding" assumption. In 1997, the Director of DOE's Yucca Program, in reviewing the planned no-action approach, insisted that the FEIS should make clear this scenario "is irresponsible and *will not happen*." NR-1.01263-2 (emphasis added). By 1998, however, the "bounding" approach had become entrenched in the EIS bureaucracy.

Fourth, DOE relied on faulty legal advice to support its approach. DOE's FEIS Project Manager opined that analysis of interim storage would constitute an "action" alternative proscribed by the NWPA. NR-1.01624-1. From this profoundly misguided legal analysis,[29] DOE

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[29] The NWPA contains elaborate provisions to promote and license interim storage at a monitored facility, and it requires NRC to establish a licensing regime for storage facilities built by utilities. *See* NWPA §133 and Subtitles B and C. NRC routinely licenses these sites under 10 C.F.R. Part 72. DOE and NRC are required by NWPA Section 132 to "take such actions as such officials consider necessary to encourage and expedite the effective use of available storage, and necessary additional storage...."

avoided even the simplest study of what it knew would happen without Yucca. Even DOE's EIS contractor objected that "incremental storage costs of additional [storage] at reactors is estimated to be ... less than a fraction of 1% of nuclear power generation costs. ... It is expected that the cost impacts of extended spent fuel storage at reactors are not great enough to change the economic competitiveness of nuclear power." NR-1.03301. Nevertheless, DOE instructed its NEPA team to ignore this realistic, economical and predictable no-action scenario. NR-1.08514-2.

Fifth, DOE considered the alleged no-action impacts "of the continued storage of *the entire inventory* of DOE and commercial [waste]," NR-1.01522-2-3 (emphasis added), against the impacts arising only from the 77,000-ton statutory limit of waste slated for Yucca. This mismatch radically understated the impacts of the proposed action by ignoring the impacts that would continue to accrue at waste sites for the balance of the waste not able to fit into Yucca. *See also* NR-1.003325.

Ironically, DOE's EIS Management Council fully recognized what would really happen with "no-action." In 1998 the Management Council met

> to recognize (qualitatively) that in all likelihood shutdown of the Repository program (selection of no action) would include a combination of the following: (1) the accumulation of fuel at the reactor sites, (2) the need for new dry storage fa-

> cilities and periodic maintenance of existing and new facilities, (3) an increase in the likelihood that an interim storage facility(ies) would be constructed pending ultimate disposition, (4) the consolidation of fuel among utilities to maintain operational status of the reactors, (5) and the identification of other potential options until such time as the Nation decided how to proceed with the ultimate disposition of SNF and HLW.

NR-1.08640. Unfortunately, DOE made certain this no-action scenario would never be analyzed.

Finally, and most egregiously, DOE's no-action assessment conspicuously omits DOE's own watershed deal in July 2000 with PECO Energy to implement the one illustration of the no-action alternative that it later shunned in the FEIS. DOE would take title to the utility's spent fuel on the reactor site, and manage that fuel indefinitely in dry storage casks at a safe interim dry storage facility built by the utility and financed by DOE. SA-006.

In 1999 Senate testimony, DOE recognized this approach as "a "practical option" for DOE and utilities that would be "relatively easy to implement." In July 2000, DOE's Secretary hailed the first of these arrangements as a "precedent" for all utilities. SA-007; *Alabama Power*, 307 F.3d at 1306 (DOE "will use the [deal] as a settlement model on an industry-wide basis"). But because DOE chose to pay for the deal by allowing PECO to offset payments to the utilities' NWPA Nuclear Waste Fund, several utilities sued to block that part of the arrangement. The Eleventh Circuit in *Alabama Power* invalidated this element, but *not* its underlying terms. *See* NR-1.01196-2

Thus, a proper analysis of the impact of not proceeding with Yucca would compare the *incremental* costs and impacts of simply storing and managing wastes for a longer period than will be the case *even if Yucca proceeds.*[30]

It is not necessary to prove here that the PECO alternative, implemented on an industry-wide basis, would be superior to proceeding with Yucca. Decision-makers clearly lacked sufficient information to make that determination. The important point is that DOE neglected to evaluate the very no-action scenario it had already begun to implement.

D. DOE's Distorted and Inconsistent Definition of the "Proposed Action" Masks Substantive Statutory Violations

Under NEPA, a stable and accurate definition of the "proposed action" is an indispensable threshold requirement, without which an agency cannot fulfill its obligation to take a "hard look" at environmental

[30] The only outstanding question is storage duration. Even if Yucca proceeds, such storage would necessarily occur for decades, since filling the repository to its statutory capacity will take until at least 2034. FEIS-S-20. According to nuclear industry testimony, such storage could safely go on for centuries. *See* Footnote 2, *supra*.

consequences. Federal agencies "shall make sure the proposal which is the subject of an environmental impact statement is properly defined." 40 C.F.R. §1502.4(a); *see also id.* §§1502.4, 1502.14, 1502.24. Adequate project definition is necessary to "allow those removed from the initial process to evaluate and balance factors on their own." *Calvert Cliffs'*, 449 F.2d at 1114. A defective project description is an "obvious deficiency" preventing NEPA compliance, making an EIS "insufficient on its face." *Montgomery v. Ellis*, 364 F.Supp. 517, 521 (N.D. Ala. 1973) (applying *Calvert Cliffs*).

1. The FEIS's "Project" is an Unlawful Non-Geologic Repository

The FEIS fails on the most fundamental level, positing that DOE's "proposed action" is one to "construct, operate and monitor, and eventually close a geologic repository…." FEIS-S-9, 1-3. However, as discussed above, the repository referenced in the site recommendation relies almost entirely on engineered barriers, not geologic containment. The representation that the project is for "permanent geologic disposal," FEIS-1-9, is a distortion of the facts.

The project description of geologic containment is not only wrong, but inconsistent. Addressing safety concerns, DOE attributes to Yucca the *geologic* disposal promised in the NWPA. *See, e.g.*, FEIS-CR 1-1 to 1-4.

Elsewhere, DOE responds to concerns about the *lack* of geologic isolation by recasting its project as a hybrid "system" of "natural and engineered" barriers. See FEIS-CR 2-1. The FEIS never quantifies the relative contributions of these barriers, *id.* at 2-2, S-9, or discloses the wealth of data, discussed above, showing the minimal contribution of geology.

The Secretary's site recommendation relied on the FEIS, but described the project merely as "an underground repository," abandoning the word "geologic." SA-052-Encl-6. His selection of an *ultra vires* disposal alternative is foreclosed by the NWPA and thus violates NEPA. 40 C.F.R. §1508.27.

2. <u>The "Proposed Action" Does Not Match the Action "Recommended" by the Secretary and the President</u>

The site recommendation described a project involving wastes "currently stored at over 131 sites in 39 states." SA-052-3. But the FEIS only "analyzes the potential impacts of transporting [waste] to the Yucca Mountain site from 77 sites across the United States," FEIS-1-3, in 37 states. FEIS-6.1-6.2; App. J (Fig. 2-22a). This divergence between the "recommended" final agency action and the "proposed action" in the FEIS renders the latter "insufficient on its face." *Montgomery*, 364 F. Supp. at 521.

3. The FEIS Fails to Define the Basic Project Design of the "Proposed Action"

DOE published its FEIS so prematurely that it had yet to choose the rudimentary design of the repository and the fundamental aspects of the repository program. Instead, DOE seeks to apply a learn-as-you-go process over the next 50 to 300 years, conceding that, in the proposed action "DOE *would* design the repository." FEIS-2-14. The FEIS proposed only an opaque and ever-evolving *concept,* left for future definition and refinement, euphemistically termed "flexible design."

> This [flexible design] represents the current state of the ongoing process that identifies and develops ideas through conceptual, then preliminary, then more detailed designs to produce a design that DOE *would use for purposes of the [Secretary's] determination* of whether to recommend approval ... to the President....

FEIS-2-61 (emphasis added).

This concept, which even as described appears to have been truncated prior to the recommendation, is code for DOE's abrogation of the core NEPA principle requiring disclosure of environmental information *before* agency action is taken. *Grand Canyon,* 290 F.3d at 340; *Peterson,* 717 F.2d at 1415; 40 C.F.R. §1500.1(b). The FEIS, therefore, fails to specify such key matters as:[31]

[31] *See generally,* NR-1.02694-2.

(a) Whether the repository will be designed, built, and operated in a "low-temperature" or "high-temperature" mode (i.e., below or above the boiling point of water). FEIS-2-8-2-12.

(b) Whether the repository will have a massive above-ground staging area for the aging of fuel for 50 years prior to its emplacement underground. *Id.* at 2-24.

(c) Whether vast facilities for ventilation of underground heat from decaying waste will be required, the type of such facilities, and the duration of ventilation (100 or 300 years). *Id* at 2-12, 2-25, 2-31-2-32.

(d) The amount of real estate needed for the repository, the volume of excavated material, and the basic spacing between waste packages.[32]

(e) The composition of the waste packages, and the number, type or design of those packages.[33]

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[32] DOE's design "options" could change the habitat disturbed by 80 to 800 acres. NR-1.02512. Waste package spacing is anywhere from 0.1 meter to 6 meters (a factor of 60). SA-053-3. Yucca's underground area could be 4.7 to 10.1 square kilometers. FEIS-2-9. Excavated volume could be 4.4 to 8.8 million cubic meters. *Id.*

[33] DOE does not know whether fuel slated for Yucca would be mostly "canistered" or mostly "uncanistered." FEIS-2-7-2-8. If canistered, DOE does not know if wastes will be packaged in disposable or dual-purpose

(f) When closure of the repository would occur, or if it would be closed at all.[34]

(g) Whether repository design and development will occur in modular, or "staged" fashion or as a discrete project, and whether a modular approach can even presumptively meet NRC's regulations.[35]

(h) The actual inventory mix of spent fuel and high-level waste types.[36]

To account for the preliminary nature and uncertainties of its analysis, the FEIS claims to have performed various "bounding analyses." FEIS-2-5. But these violate DOE's own understanding of NEPA.[37] DOE concedes its FEIS provides only "a representational range of poten-

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(storage/transport) canisters. *Id.* The number of waste packages could be anywhere from 11,000 to 17,000. FEIS-2-9.

[34] Closure could occur anywhere from 50 to 324 years. FEIS-2-19. "Future generations" would decide whether it should be closed. FEIS-4-3.

[35] FEIS-2-61-2-63.

[36] FEIS-A. DOE recognized that "changes in the inventory numbers for SNF and HLW have a dramatic effect on design ... [and] EIS impacts...." NR-1.02386-5.

[37] In its official guidance for EIS preparers, DOE warns that "[i]t is never appropriate to 'bound' the environmental impacts of potential future actions (not yet proposed) and argue later that additional NEPA analysis is unnecessary because the impacts have been bounded by the original analysis." SA-002.

tial environmental impacts the Proposed Action would cause." FEIS-2-14. By limiting analysis of impacts to a "representational range" of general conceptual options, DOE consciously avoided the "hard look" and "full and fair discussion" NEPA requires. *See NRDC v. Hodel*, 865 F.2d 288, 294 (D.C. Cir. 1988); 40 C.F.R. §1502.1.

4. <u>The FEIS Unlawfully Segments Out Assessment of Yucca's Transportation Component</u>

The FEIS identifies "the transportation of [waste] from commercial and DOE sites to the Yucca Mountain site" as an integral component of the proposed action. FEIS-S-9, 1-3. Yet remarkably, the very nature of the transportation program and its potential impacts remained a cipher at the time of the Secretary's final decision. DOE's refusal to define this critical program component prior to its final action runs afoul of well-established NEPA principles preventing segmentation of interrelated components. *See, e.g., Foundation of Economic Trends v. Heckler*, 756 F.2d 143, 159 (D.C. Cir. 1985); *Fund for Animals v. Clark*, 27 F.Supp.2d 8 (D.D.C. 1998).[38] Nor could post-hoc definition cure this error. *See Thomas v. Peterson*, 753 F.2d 754, 760 (9th Cir. 1985) (NEPA's purposes "cannot be

[38] *See also* 40 C.F.R. §1502.4(a); 40 C.F.R. §1508.25(a).

fully served" if assessment of successive steps "is delayed until the first step has already been taken.").

The FEIS reveals classic symptoms of NEPA segmentation:

- It does not disclose how many shipments will occur to Yucca, what mode of transport (truck, rail, or barge) these shipments will take, and over what routes. The number of shipments is perhaps less than 1000, or perhaps more than 100,000. FEIS-J.

- It announces DOE's intention to postpone any ROD selecting a mode, or any specific route through Nevada or elsewhere, until *after* the Secretary's final action. FEIS-S-2, 1-3, 2-2.

- It identifies DOE's preference for "mostly rail," but concedes it "would use both legal-weight truck and rail transportation, and would determine the number of shipments by either mode as part of future transportation planning efforts." *Id.* at 2-3; 2-46.

- If rail is ultimately chosen for Nevada, it is unclear where it would go, and how and when it would or could legally be built, and at what cost and impact to Nevadans. *See* FEIS-C. [39] "At this time, [DOE] has not

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[39] This new line could be several hundred miles long, and would itself require a major new EIS and comprehensive involvement by the federal Surface Transportation Board, whom DOE apparently did not consult.

identified a preference among the five potential rail corridors" in Nevada. *Id.* DOE conceded many necessary transport studies have not yet been commenced, *including "[NEPA]* reviews." *Id.* at 1-3-1-4 (emphasis in original).

- DOE's "preferred mode" of rail transport is currently *unavailable* in Nevada and at more than 24 of the proposed sites DOE intends to ship from, without the added use of barges and heavy-haul trucks, *id.* at J-11, which will necessitate upgrading of public highways – also not evaluated in the FEIS. *Id.* at S-23.

Lastly, DOE failed even to follow its own official guidance to EIS preparers on how to avoid illegal segmentation, which recommends that necessary "transportation activities" should be evaluated "as part of the proposed action ...." SA-003.

5. <u>The FEIS Unlawfully Includes an "Aging Facility" Component Prohibited by the NWPA</u>

The FEIS proposes that as much as two-thirds of all commercial spent fuel slated for the repository would, in one of two preferred repository operating modes, be "aged" in a surface storage facility near Yucca for 50 years. FEIS-2-12. This "aging facility" is to be located somewhere "north and east" of the repository. *Id.* at 2-24 and Fig. 2-10. The FEIS lacks any description of this massive new facility, drawn by DOE to an approximate size of 4,250,000 square feet, which would make it the largest spent fuel storage facility in the world. *Id.*

The FEIS does not disclose that this Nevada-based aging facility would violate the NWPA. The facility would be both an "Independent Spent Fuel Storage Installation" ("ISFSI") as defined by NRC in 10 C.F.R. §72.3, and, because it is to be built and operated by DOE, a "Monitored Retrievable Storage" installation ("MRS") as also defined in 10 C.F.R. §72.3 and in NWPA Subtitle C. NWPA Section 145(g) expressly provides that "[n]o [MRS] authorized pursuant to Section 142(b) may be constructed in the State of Nevada." In designating a proposed site for the aging facility, the Secretary also unlawfully failed to follow the site selection criteria for a proposed MRS in NWPA Sections 145 through 149.

Assuming *arguendo* that the facility was not an MRS, it would nevertheless be an ISFSI, which would require a separate NRC license under 10 C.F.R. Part 72. Part 72 also requires completion of a stand-alone EIS for ISFSI construction. DOE's failure to provide this mandatory evaluation in the FEIS is a material departure from the requirements of both the NWPA and NEPA. 42 U.S.C. § 4332(c); 40 C.F.R. §1508.27.[40]

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[40] DOE understood such an "interim storage facility" could be constructed at Yucca only "if the NWPA were changed." NR-1.01412-4; NR-1.02409-2.

6. The "Proposed Action" Unlawfully Contemplates Disposal of Wastes Prohibited by the NWPA

The NWPA authorizes disposal in a repository of "high-level radioactive waste" ("HLW") and "spent nuclear fuel" ("SNF"). *See* NWPA §§2(18), 111(a)(4)-a(7), 113(b)(1)(A)(ii) and (b)(1)(B), and 123. "HLW" is defined as

> (A) The highly radioactive material resulting from the reprocessing of [SNF]...; and
>
> (B) Other highly radioactive material that [NRC], consistent with existing law, determines by rule requires permanent isolation.

NWPA §2(12). "SNF" is defined as "fuel that has been withdrawn from a nuclear reactor following irradiation...." NWPA §2(23). *See also* 10 C.F.R. §§60.2, 63.2, and 72.3; DOE Order 435.1.

The proposed action would include, in the inventory of materials slated for disposal, "surplus weapons-usable plutonium as spent mixed-oxide fuel or immobilized plutonium." FEIS-2-2. Immobilized plutonium does not meet the definitions above and is therefore not statutorily eligible for disposal. Though it is highly toxic, plutonium in its weapons-useable form is not a "highly radioactive material," and NRC has promulgated no rule requiring its permanent isolation (it continues to be used in U.S. nuclear warheads). As proposed in the FEIS, about one-third of the nation's surplus weapons-usable plutonium would be *mixed with* high-level radioactive waste. FEIS-A-50; NR-1.00186-1. But mixing a non-eligible waste with an eligible waste does not make the combination legally eligible. If that were the case, DOE could mix *any* substance (*e.g.*, nerve gas) with high-level waste and dispose of it at Yucca.

In 1996 and again in 1997, DOE recognized that surplus fissile materials such as plutonium "are *not* SNF/HLW." NR-1.01146-21; NR-1.01287-1(emphasis added). Therefore, DOE reasoned, if such materials were proposed for disposal at Yucca, DOE would require "law changes" or would need the materials "reclassified by NRC," neither of which have occurred. *Id.* DOE proposed to address such disposal "in supplemental analysis under NEPA," which also has not occurred. *Id.* *See also*, NR-1.01285-4, 13.

7. <u>The FEIS Ignored the Requirement to Obtain Nevada RCRA Permits</u>

Missing from the FEIS's list of "Statutory and Other Applicable Requirements," Table 11-1, is any mention of the Resource Conservation and Recovery Act ("RCRA"), 42 U.S.C. §§6901 *et seq.*, administered in Nevada by the Division of Environmental Protection ("DEP"). FEIS-11-14. But numerous records evidence views by DOE attorneys, FEIS preparers, and public commenters (FEIS-CR-4) that waste slated for Yucca will contain several listed hazardous materials under RCRA, many of which are toxic and soluble in water. *See, e.g.*, FEIS-I-52.

The FEIS notes that the repository's engineered barriers alone will include 190,000,000 pounds of "Alloy-22" containing 22.5% chromium, 57.2%nickel, and 0.35%vanadium. FEIS-5-7. They will also include 310,000,000 pounds of stainless steel containing 17% chromium and 12% nickel. Each of these is a listed hazardous waste under RCRA. 40 C.F.R. §261 App. VIII and §261.24. FEIS Tables A-15 and A-16 show that spent fuel slated for Yucca also contains metals and elements formally listed as "hazardous" under RCRA, including barium. *See also* FEIS Table A-22, at A-34; FEIS Table I-8.

RCRA covers "solid waste" that, in this case, is not excluded as "source, byproduct, or special nuclear" material as defined in the Atomic Energy Act, 42 U.S.C. §1004(27). As DOE itself recognized, "irradiated reactor fuel" is defined by NRC's licensing rule, 10 C.F.R. §63.2, as "high-level radioactive waste," a definition consistent with DOE's intent to "dispose" of the material and not reprocess it. NR-1.01146-13. DOE also recognized that the "source, byproduct, and special nuclear" material exemption could not be invoked for metallic spent fuel assemblies and underground waste packages, but only for the actual radionuclides suspended in the waste substance making up spent fuel. NR-1.01146-14, citing 52 Fed. Reg. 15,937 (May 1, 1987) and 53 Fed. Reg. 37,045 (Sept. 23, 1988).

As was frequently noted in the record, if either spent fuel assemblies or Yucca waste packages contain hazardous substances, the project will require either a RCRA disposal permit from Nevada or, alternatively, a "de-listing" of waste constituents from cognizant EPA and Nevada authorities and state authorities with jurisdiction over particular generators. *See* 40 C.F.R. §260.22. Neither possibility, nor its consequences, was analyzed in the FEIS.

Instead, the FEIS concludes without evaluation that, under DOE requirements, "DOE could not accept hazardous waste for disposal at Yucca," and thus it "does not expect to need a [RCRA] permit for its activities at the proposed repository." FEIS-11-13-14.

In 1996, DOE's Yucca Program Director conceded that "we do not know what materials the State of Nevada may determine are RCRA wastes." NR-1.01159-2. In 1997, he concluded that "disposal *could not proceed* if DOE had to obtain a RCRA permit to operate the facility from the state of Nevada." *Id.* (emphasis added). *See also,* NR-1.01287-3; NR-1.01290-4. DOE's NEPA Management Council recognized in 1998 that "delisting" RCRA wastes for burial in Yucca would probably require legislative changes. NR-1.08764-2. Recognizing that resolution would itself require a major NEPA analysis, DOE's General Counsel "noted that, if necessary, future supplemental EISs could be prepared." *Id.* But DOE's deferral of that assessment until *after* its final agency action is irreconcilable with NEPA. *See* 40 C.F.R. §1502.4; n. 20, *supra.*

8. <u>The FEIS Conducted a Flawed Assessment of Sabotage Risks in Spent Fuel Transport</u>

In the aftermath of 9/11, the FEIS failed to address realistic sabotage scenarios involving spent fuel transport and thus vastly understated the risks and consequences of undertaking thousands of such shipments if Yucca proceeds, contrary to the "hard look" NEPA requires.

The sole terrorist scenario analyzed by DOE, in a study conducted in *the late 1970s,* consisted of a single shot with an anti-tank missile at a traveling cask. FEIS-6-51-52, and referenced studies. DOE's own terrorism consultant recognized this analysis was outdated. NR-1.01483. DOE assumed sabotage would occur with a now-obsolete missile instead of a state-of-the-art "TOW" missile, of which over 500,000 exist in 36 countries.[41] DOE therefore assumed the missile would penetrate only one cask wall instead of both, leaving a small hole. DOE assumed no water would enter the hole, and that fire would not be co-located with it, despite the exploding warhead. Accordingly, the FEIS assumed the attack would cause only 9 to 48 early fatalities, and it made no estimate of cleanup costs from resulting contamination. FEIS-6-52.

DOE did not consider the risk that a warhead exploding inside a spent fuel container could cause fissile nuclear material inside to create a nuclear chain reaction, or "criticality, "whose consequences would catastrophically exceed the postulated consequences of the relatively tame event described in the FEIS. *See* RR-1.0333 at 4-406-4-416; FEIS-5-38.

Ironically, DOE acknowledged the danger of criticality events in connection with the mere *storage* of these same casks in the "no action" alternative. See, e.g., NR-1.03317-6-7 (rainwater seepage may induce criticality); NR-1.03338-2 (fire near casks may induce criticality). Yet, DOE's assessment of the "proposed action" ignored the far more realistic risks of criticality occurring in a sabotage event, where, for example, an exploding TOW missile might shred the front and back hulls of a cask

[41] *See* Military Analysis Network (February 2000) www.FAS.org/man/dod-101/sys/land/tow.htm.

moving through a city, exposing spent fuel to rain, fire, or firefighters' spray, inducing criticality. Most significant, the fact that such a cask might be one containing fissile weapons-grade plutonium from dismantled warheads, as the FEIS contemplates, was not analyzed.

Indeed, for a terrorist with a four-mile range TOW mounted on a pickup truck, such a scenario would seem to involve the ultimate, readily available "dirty bomb." DOE's failure to examine a sabotage criticality scenario, while nevertheless imposing its evaluation in the far less dangerous circumstances of the "no-action" alternative, exemplifies bias and is arbitrary, capricious, and contrary to NEPA.

CONCLUSION

For the foregoing reasons, the Court should (1) declare unlawful and set aside DOE's Guidelines, DOE's Yucca site recommendation to the President, and the President's selection of that site for development; (2) declare that DOE has failed to take actions required under Sections 113 and 114 of the NWPA; (3) declare that DOE's FEIS is inconsistent with NEPA, closely related provisions of the NWPA, and NEPA regulations; (4) declare that DOE failed to act in accordance with NEPA, closely related provisions of the NWPA, and other applicable laws and regulations, as described herein; and (5) remand this matter to DOE for further proceedings in conformity herewith.

Respectfully submitted,

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CERTIFICATE OF COMPLIANCE

Pursuant to FRAP 32(a)(7)(C), I hereby certify that this brief complies with the type-volume limitation of FRAP 32(a)(7)(B) and Circuit Rule 32(a)(2), as modified by this Court's order of September 20, 2002, which authorized Petitioners to file an opening brief of not greater than 20,000 words. In reliance on the word count of the word-processing system used to prepare this brief, I hereby certify that the portions of this brief subject to the type-volume limitation contain 19,953 words.

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CERTIFICATE OF SERVICE

I hereby certify that two true and correct copies of the foregoing document were served on the individuals listed below on this 2nd day of December 2002 by First Class Mail, postage prepaid.

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UNITED STATES COURT OF APPEALS
FOR THE DISTRICT OF COLUMBIA CIRCUIT

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NUCLEAR ENERGY INSTITUTE INC., :

Petitioner, :

v. : No. 01-1258, et al.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, :

Respondent. :

- - - - - - - - - - - - - - - - - -x

Wednesday, January 14, 2004

Washington, D.C.

The above-entitled matter came on for oral argument pursuant to notice.

BEFORE:

CIRCUIT JUDGES EDWARDS, HENDERSON, AND TATEL

APPEARANCES:

EPA CASES, NEVADA/NRDC ISSUES:

ON BEHALF OF ENVIRONMENTAL PETITIONERS:

GEOFFREY H. FETTUS, ESQ.

ON BEHALF OF PETITIONER STATE OF NEVADA:

ANTONIO ROSSMAN, ESQ.

ON BEHALF OF THE RESPONDENT:

CHRISTOPHER S. VADEN, ESQ.

It's five kilometers in every direction but in the direction that the groundwater flows. And what they've essentially done is far from forming part of the isolation barrier, this controlled area serves as a conduit to carry the radionuclides away. It flies in the face of the very precedent that sustained EPA's application of a controlled area. That's why NRDC is back in this Court today. And I seem to have run out of time, and I don't want --

JUDGE EDWARDS: Your time is up, counsel. Okay. Thank you.

MR. FETTUS: Thank you, Your Honors.

ORAL ARGUMENT OF ANTONIO ROSSMAN, ESQ.

ON BEHALF OF THE PETITIONER

STATE OF NEVADA

May it please the Court. Good morning, Your Honors. I am Antonio Rossman of San Francisco representing the State of Nevada. May I introduce one additional member of our team, the Attorney General of Nevada, Brian Sandoval.

Your Honor, we are in a Washington venue and appropriately so, because it was here that the decisions were made. But we ask the Court to keep in mind that the land is western land, the water is western water. And let me second what Mr. Fettus said. We ask the Court in addressing these cases to remember the wisdom of our fellow Westerner John Muir: When we try to pick out anything by itself, we find it hitched to everything else in the universe.

EPA's irrational rejection of the National Academy's determination that restricting the time of compliance to 10,000 years has no scientific basis is hitched to the overriding error of our Government's unfortunate and irrational response to the Congressional mandate that the geology of the site shall provide the permanent isolation for all generations, as Congress commanded in the Nuclear Waste Policy Act.

The facts are uncontroverted. It is EPA's response that cannot withstand review. Congress established a substantive standard: protection of the public. There is no countervailing standard, there is no balancing here, as if perhaps in an EPA bubble rule. And it must be health-based, and it must be for all generations, and that's what the National Academy of Sciences did under its Congressional delegation. The National Academy determined that there is no scientific basis for confining the period to 10,000 years, because we can determine and enforce a standard that will go many times that amount, and especially so because the facts are equally uncontroverted that the greatest radiation risk does not even begin to arise until long after 10,000 years.

JUDGE TATEL: Well, EPA relies on this language in the National Academy report, which acknowledges that there are policy considerations that it has not taken into account.

MR. ROSSMAN: Yes, sir.

JUDGE TATEL: One of which is the exact one that the EPA seems to have relied on, which is to have standards which are similar to the ones they use for other long-lived hazardous materials.

MR. ROSSMAN: Yes, sir. That is one of their justifications, and it does not stand up. In fact, in order --

JUDGE TATEL: Why not?

MR. ROSSMAN: And if may address that, Your Honor. These are the words that EPA used in their final rule. They started by severely misquoting what the National Academy said. The National Academy said that EPA might want to establish consistent policies to deal with both non-nuclear and nuclear waste. But here is how EPA turned those words around: The NAS says, quote, we might select an alternative more consistent with previous agency policy. That is not what the National Academy said, but the National Academy was suggesting that perhaps EPA might want to set a unique standard as Congress commanded for Yucca Mountain and then consider whether the rest of its standards ought to rise to that level. And that is why we say, I mean, the fact that EPA had to mischaracterize the National Academy in order to pretend to respond to it, EPA itself recognized that its existing standard, which was, for example, addressing the Waste Isolation Pilot Project or so-called WIPP, that what we're dealing with here at Yucca Mountain is indeed unprecedented, and the EPA itself recognized in response to citizen comment that this was a far greater radiation and that it lasted far longer into the future than anything else it dealt with.

JUDGE EDWARDS: Counsel, what are we talking about precisely in terms of the redress that you're seeking? The legal argument is pretty straightforward. You're saying they violated 801 because NAS said something quite contrary to what they concluded.

MR. ROSSMAN: Yes, sir.

JUDGE EDWARDS: That the result of that is what in your view in terms of breaches?

MR. ROSSMAN: The result --

JUDGE EDWARDS: What are you talking about? NAS talks about the standard should be measured at the time of peak risk.

MR. ROSSMAN: That's right.

JUDGE EDWARDS: All right. And they said 10,000, at least --

MR. ROSSMAN: They --

JUDGE EDWARDS: -- and one reading of theirs doesn't work. But what does that mean in terms of redress? What are we talking about?

MR. ROSSMAN: That the rule must be set aside because EPA failed to carry out the Congressional mandate of being consistent.

JUDGE EDWARDS: Which is what?

MR. ROSSMAN: To be --

JUDGE EDWARDS: What I'm asking, understand what I'm asking. What is consistency in your view? If you followed NAS, what would that have produced in what EPA wrote?

MR. ROSSMAN: It would have produced a standard of more than 10,000 years, a standard that addressed the period of maximum does, which is 100,000 years into the future, unless EPA could articulate a rational reason for departing from the National Academy's determination. And seeing that I'm getting into my rebuttal time, Your Honors, I just want to suggest that the answer will be found in four pages of the administrative record, EPA's response on this issue, beginning at page 32097 of the Federal

Register. And when the Court scrutinizes that language that EPA has used to respond on all of these claims, international standards, the record shows there is no international consensus. In fact, if there's any --

JUDGE TATEL: But let me, let me, excuse me, let me just pursue Judge Edwards's question a little bit, because I understand what you want us to do. You want us to say that the EPA has violated the requirement that its rules be consistent with National Academy standards.

MR. ROSSMAN: And beyond that, Your Honor, it violated the --

JUDGE EDWARDS: Let him ask the question here. Wait a minute.

JUDGE TATEL: Let me finish. The question both of us are asking is what are the consequences of that for the EPA's revised regulation? What will it do differently than this one, since everybody seems to concede that at these periods of time, whether it's 10,000 years or 100,000 years or 200,000 years, our predictive abilities, except for geological questions, are pretty difficult?

MR. ROSSMAN: Well, the geology is predictable and --

JUDGE TATEL: No, I understand the geology. I understand what the Academy said. Let's assume peak dose periods are, let's assume that everybody agrees they are

300,000 years, okay?

MR. ROSSMAN: Yes, sir.

JUDGE TATEL: How will the regulation look any different?

MR. ROSSMAN: The regulation could look, and it's not up to this Court to write the regulation, it's up to this Court to --

JUDGE TATEL: I understand that, but it would help us to know --

JUDGE EDWARDS: Counsel, no, wait, understand what we're asking.

JUDGE TATEL: Right.

JUDGE EDWARDS: If you're talking about something that's unimaginable, we're not interested.

MR. ROSSMAN: Yes, sir.

JUDGE EDWARDS: So you have to explain to us what are you talking about. We understand the legal disjunction that you referred to. It's pretty easy. But we do go the next step. So what are you talking about?

MR. ROSSMAN: That EPA would have to, unless it could come up for a rational reason for doing otherwise, adopt a standard that applied through the period of maximum dose.

JUDGE TATEL: We understand that.

JUDGE EDWARDS: We know that.

JUDGE TATEL: But how would it be different? Where would it change?

JUDGE EDWARDS: If you don't know, tell us.

JUDGE TATEL: Yes, that's okay.

JUDGE EDWARDS: But what are you talking about?

MR. ROSSMAN: Well, what we're talking about is looking at -- the other thing that we know in addition to geology is radioactive decay, and we see that that maximum peak dosage is reached sometime around 300,000 years out, and it remains constant at that point. So one possible answer to the Court's question would be a standard that would be applicable for 300,000 years.

JUDGE TATEL: But we have a standard that's now applicable for 10,000 years.

MR. ROSSMAN: Yes, sir.

JUDGE TATEL: I mean, how, in terms of our predictive ability, anybody's predictive ability, what's the difference between 10,000 and 300,000 years? Aren't they equally unpredictable?

MR. ROSSMAN: They are not, Your Honor.

JUDGE TATEL: Except for the geological considerations.

MR. ROSSMAN: Geological and radiological, sir.

JUDGE TATEL: Well, does this -- no, I understand the business about the half-life, but does this relate to the engineered barriers? Is that what this is all about?

JUDGE EDWARDS: Is this the backdoor way to say the focus should be on geology, because the engineered barriers are going to fail at 10,000 years?

MR. ROSSMAN: It's not backdoor, sir, it's our front door.

JUDGE EDWARDS: Front door.

MR. ROSSMAN: Yes, sir.

JUDGE EDWARDS: All right, whatever.

MR. ROSSMAN: I mean, that is the ultimate command from Congress was to find a permanent --

JUDGE EDWARDS: Forget all of that, okay?

MR. ROSSMAN: Yes, sir.

JUDGE EDWARDS: We're trying to get to the point, because your time is short. Is that what you're really arguing?

MR. ROSSMAN: Yes, sir.

JUDGE EDWARDS: Okay, fine.

MR. ROSSMAN: We are arguing that, but I do want to make the point that I think Judge Tatel was in the same place Congress --

JUDGE EDWARDS: Tatel.

MR. ROSSMAN: Tatel, excuse me, Your Honor, was in the same place where Congress was when they wrote EnPA. Nobody knew the answers, and so they asked our institutional experts, our disinterested experts, to give us some sense of reality, and the National Academy came back and said yes, you can meaningfully regulate to that period of time.

JUDGE TATEL: We understand that. What we're trying to understand is what are the consequences of agreeing with you in terms of rule-making here and Yucca Mountain.

MR. ROSSMAN: Yes, sir.

JUDGE TATEL: That's what we don't understand, and I have to say, I still don't get it. I don't understand, and your answer may be you don't need to understand to reverse. But humor us for a minute and help us try to understand.

MR. ROSSMAN: Yes, sir.

JUDGE TATEL: Let me put it to you this way: Suppose we didn't agree with you that this was inconsistent with the National Academy standard. You have an argument also that it's just arbitrary and capricious that they, to have picked 10,000 years, right?

MR. ROSSMAN: Yes, sir.

JUDGE TATEL: Well, why is that any more or less arbitrary and capricious than picking 300,000 years? How do we know?

MR. ROSSMAN: Well, we have to measure, I mean, this is an administrative record case.

JUDGE TATEL: Remember, this is a Court that defers to an agency's judgment, so as difficult as it is for the agency to distinguish between protecting human beings for 10,000 versus 300,000 years, we have a deferential standard of review, so our standards are even more amorphous.

MR. ROSSMAN: Yes, sir. But even under that deferential standard of review, the Court still has to find that there was a rational explanation by EPA for not following the National Academy.

JUDGE TATEL: No, no, no, I asked you, my hypothetical was assume we don't agree with you that the -- assume we ultimately conclude that the Academy's recommendation was not sufficiently clear to have bound the EPA.

MR. ROSSMAN: Yes, sir. And then I think the Court can look to the other factors such as that we're dealing with an unprecedented by known risk that maximizes at 300,000 years. We are dealing with a Congressional mandate.

JUDGE TATEL: How would I write a sentence which says it was arbitrary and capricious for the agency to pick 10,000 years instead of 300,000 years?

MR. ROSSMAN: Because the record shows that the maximum risk arises in 300,000 years. Congress mandated public health and safety for this and for future generations, and it is possible for us to meaningfully regulate that far. And it is irrational in the international community to cut off a period of compliance while the dose is increasing and the risk is increasing.

JUDGE EDWARDS: Let me ask you one last question, your time is up, to see if I understand the design of your strategy, if that's what's going on here.

MR. ROSSMAN: Yes, sir.

JUDGE EDWARDS: If you go beyond 10,000 years to something that you claim the NAS endorsed well beyond 10,000 years, the focus is going to be on geology, as you've already acknowledged, and that is a way to get to that. If the focus is on geology, implicit and maybe explicit in some of our arguments is the geology in Yucca Mountain won't work, and so your grand strategy is the end result is it's not going to be in this mountain.

MR. ROSSMAN: It has been our contention, as others --

JUDGE EDWARDS: Is that what's really going on?

MR. ROSSMAN: That is the ultimate --

JUDGE EDWARDS: They're not going to be able to do it?

MR. ROSSMAN: Yes, sir. And it's not because of us, it's because of the --

JUDGE EDWARDS: I'm not saying that this is mischievous.

MR. ROSSMAN: Right.

JUDGE EDWARDS: I'm just trying to understand.

MR. ROSSMAN: Yes, sir.

JUDGE EDWARDS: Okay. That's, okay, your time is up. I understand you.

MR. ROSSMAN: Okay.

JUDGE EDWARDS: You'll get, you know, you'll get a little time on rebuttal.

MR. ROSSMAN: Yes, sir. Thank you.

JUDGE EDWARDS: Thank you.

ORAL ARGUMENT OF CHRISTOPHER S. VADEN, ESQ.
ON BEHALF OF THE RESPONDENT
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

May it please the Court. I am Christopher Vaden with the Department of Justice. With me at counsel table this morning are Keith Matthews from EPA's Office of General Counsel and Michele Walter, also from the Department of Justice. Ms. Walter's going to address the issues raised by the Nuclear Energy Institute, and I'm going to address the issues we've just heard from Nevada and NRDC.

EPA developed the Yucca Mountain standards through a notice-and-comment rule-making process in which all of the issues that these Petitioners have raised were considered, and analyzed thoroughly and methodically. Applying its policy judgment to the scientific evidence and to NAS's expert scientific advice, EPA established a reasonable regulation that deserves this Court's deference under the arbitrary and capricious standard.

JUDGE TATEL: Well, before you get to policy, the Academy says, quote, there is no scientific basis for limiting the time period to 10,000 years. The difference between our recommendation, this is the Academy, and the 191 regulations, we have specified that the basis for the standard should be the peak risk, whenever it occurs, right?

MR. VADEN: Right.

JUDGE TATEL: And then the EPA says we believe that such an approach is not practical. I mean, Congress said the EPA's regulation has to be consistent with the Academy. The Academy said peak dose periods, they're beyond 10,000 years. Our recommendation is different from the generic 191 regulations. And EPA essentially follows its old regulations. What could be more inconsistent with the Academy's recommendations?

MR. VADEN: Well, Judge Tatel, as you noted in questioning Mr. Rossman, the Academy specifically noted that there were things they didn't consider, and I'll quote from the Academy's report at page 56. They said that although the selection of a time period of applicability has scientific elements, it also has policy aspects that we have not addressed. And I submit to the Court --

JUDGE TATEL: What are the policy aspects that led EPA to decide to assure human safety at 10,000 years rather that at the peak dose period?

MR. VADEN: I think the agency gave a number of reasons for that decision, probably -- I've got a list of about five. One of the most significant ones was that even though NAS said that the uncertainties could be bounded or were boundable out to the period of peak dose --

JUDGE TATEL: Well, but that's the scientific judgment that Congress wanted the EPA to defer to. In fact, EPA is actually pretty candid: Quote, despite the NAS recommendation, we conclude that there is still relative uncertainty as to current modeling capability. I thought that was the judgment that Congress wanted the EPA to defer to. That's a scientific judgment.

MR. VADEN: Certainly Congress wanted EPA to defer to the scientific judgment, and I guess what I'm suggesting is that there is a regulatory judgment that has to be made at the time of licensing that requires more certainty than it takes for a scientist to simply project a range of outcomes 500,000 or a million years in the future. The farther you project in the future, the more divergent the possible outcomes become. And it was EPA's judgment as --

JUDGE TATEL: Between 10,000 and 300,000?

MR. VADEN: Yes. And it was EPA's judgment that even though the range was boundable, you could sort of, you know, have an upper limit and a lower limit on it, that once you get way out into the hundreds of thousands of years, it becomes too uncertain to place a burden of proof on DOE now --

JUDGE EDWARDS: Where does NAS say that?

MR. VADEN: Where does NAS say that it's --

JUDGE EDWARDS: Where do they say that?

MR. VADEN: Well, they say that the uncertainty is boundable.

JUDGE EDWARDS: See, all you've done is to turn the statutes on its head. The statute doesn't say to follow NAS unless you think as a matter of policy that what they're suggesting is too burdensome. That's not what the statute says. It says the standards will be based upon and consistent with the findings and recommendations of NAS, period.

MR. VADEN: Based on and consistent, and Your Honor asked --

JUDGE EDWARDS: And it's not consistent. NAS in its summary, I mean, in their summary, I went back and looked at it, and it's really kind of astonishing what the agency did as compared to what NAS said. Compliance standard should be measured at the time of peak risk whenever it occurs, and they go on to say the standard in 191 applies for 10,000 years. Based on performance assessment calculations provided to us, it appears that the peak risk might occur tens to hundreds of thousands of years or ever farther into the future. They're very clear in saying 10,000 years is wrong.

MR. VADEN: Your Honor asked earlier what does consistency mean, and I believe Mr. Rossman acknowledged that it's sufficient for EPA to articulate a rational reason for departing from the NAS recommendation based on the policy, regulatory policy considerations that Congress left to EPA.

JUDGE EDWARDS: But you're not stating any that make any sense, assuming that's true. Because all you're really saying is, oh, that sounds difficult. Or that's hard to measure. All of this is hard to measure.

MR. VADEN: All of it is --

JUDGE EDWARDS: But NAS didn't seem to have the slightest problem in saying and concluding that 10,000 years is wrong.

MR. VADEN: They said there's --

JUDGE EDWARDS: So it seems to me, let me tell you my concern in reading this. The statute is clear: You must look to NAS, so that's our job, whether you did or not. NAS is absolutely clear, in my view, that 10,000 years is incorrect. So if indeed you're right that the agency could say, well, but we have other things we might want to think about, you have a heck of a high burden to meet to be able to point to policy considerations to overcome an NAS determination that 10,000 is flat wrong.

MR. VADEN: Well, they said --

JUDGE EDWARDS: Because they say that.

MR. VADEN: They said there's no scientific basis to cut it off then, but they recognized --

JUDGE EDWARDS: They say that 10,000 years, no matter how you read their language in that executive summary, doesn't work. It doesn't make sense. Their executive summary is very clear.

MR. VADEN: But they recognized that there were policy factors that were outside their purview that they didn't even consider, and I submit --

JUDGE EDWARDS: They didn't even begin to specify what they might be.

MR. VADEN: Well, that's right, because they're for EPA --

JUDGE EDWARDS: Right. So now I'm saying to you it seems to me, and it isn't within their competence to know whether or not as a legal matter that matters. They just say in passing there may be policy matters, because what they might have been saying is Congress might want to rewrite the law. So I don't know what they meant to say, but it doesn't matter, because our job is to decide whether you're consistent with their scientific judgment.

MR. VADEN: Well, I suggest it does matter, because Congress delegated the rule-making authority to EPA, not NAS. NAS didn't conduct a public notice-and-comment process.

JUDGE EDWARDS: But your rule-making authority is confined by reference to the statute --

MR. VADEN: It's --

JUDGE EDWARDS: -- and the statute says you have to look to NAS.

MR. VADEN: But I submit that strict identicality with NAS is more than what is required.

JUDGE TATEL: Well, see, you could have come, I mean, I think this might have been very different if the agency had come back with a regulation which says, okay, they say use peak dosage periods, and they think it's a couple of hundred thousand years. We think maybe, you know, that's pretty far out, and maybe the best we can do is 100,000 or 200,000 or something like that, but what's odd about this is that the generic regulations that had been issued earlier by EPA were 10,000 years, right?

MR. VADEN: That's right.

JUDGE TATEL: Okay, so subsequent to that, Congress says develop Yucca's specific regulations, get the Academy's view, contract with them, make sure your procedures are consistent with what they recommend. They reject the 10,000-year limit, and that's what EPA comes back with. So why did Congress go through all, why did Congress require the agency to go through this if it felt you were free to simply re-adopt the generic 10,000-year rule?

MR. VADEN: They wanted the best, impartial, scientific advice --

JUDGE TATEL: And they got it from the Academy, which said 10,000 is wrong.

JUDGE EDWARDS: And the agency says despite, they ignore it, and frankly, the policy reasons that you're talking about, I re-read them. They don't make any sense to me.

MR. VADEN: Well, EPA certainly put a lot of weight on the Academy's advice, and in fact that's why they required that DOE do projections out to time of peak dose as part of the EIS. So, and I think that's part of what makes the ultimate rule consistent with the NAS recommendation, but it's a different matter --

JUDGE TATEL: You have language in the preamble that says despite the NAS's recommendation --

JUDGE EDWARDS: Right.

JUDGE TATEL: -- we conclude. They're rejecting the NAS recommendation. They're not making their standard consistent with it.

MR. VADEN: But I guess I would pose the question, what does it mean to be consistent with a recommendation that specifically says we have not considered all of the relevant factors?

JUDGE EDWARDS: No, they didn't say that. They said we don't know whether there are policy considerations.

MR. VADEN: But we haven't considered them.

JUDGE EDWARDS: But it doesn't matter, because you're assuming something that we're not necessarily agreeing with, that is, that you can look to policy considerations to overcome that which Congress says. I'm not at this point prepared to accept that argument merely because you state it.

MR. VADEN: I think that it's implicit in

Congress having delegated the rule-making authority to EPA rather than the Academy.

JUDGE EDWARDS: No, we go through -- that we do know about. We do this all the time. Yucca Mountain's no different for us. An agency does not have the authority to do whatever it wants to do merely because it has rule-making authority. Now, we know agencies often argue that, but that's nonsense. The agencies are limited to their delegated authority. Within that framework, you can adopt rules that we defer to. So we ought to get past that one. You do not have the authority to do what you want to do merely because you have rule-making authority. That's an old argument, and you lose.

MR. VADEN: Well, we certainly think that the ultimate result was consistent with the NAS recommendations insofar as the projections out to time of peak dose are required to be performed and submitted in the EIS. I think it's fair to say that consistent with does not mean identical. It means sort of generally congruent with. EPA placed a lot of weight on the NAS recommendations and did not disagree with NAS on scientific issues, but decided that as a regulator it was not realistic to establish a present burden of proof on the license applicant to demonstrate a reasonable expectation of compliance out at times when the scientific studies simply grew more and more uncertain.

I would also address the Court's questions to Mr. Rossman about what relief you would have the Court frame. I think as part of the Petitioners' obligation to show standing to raise the specific issues they raise, they have to show that the relief they're requesting would redress whatever harm or injury they say they've suffered as a result of this rule, and I therefore submit that in addition to answering the Court's question about what the relief should look like --

JUDGE TATEL: Well, NRDC, the environmental groups have members who live here, right?

MR. VADEN: Yes, in Amargosa Valley.

JUDGE TATEL: So doesn't it clearly have standing to raise this question?

MR. VADEN: Certainly that's sort of the prototype person you would expect to have standing, but they're not challenging the standard.

JUDGE TATEL: You're certainly not going to tell us that they don't have standing because it isn't imminent, are you?

MR. VADEN: It's, well, I don't think they --

JUDGE TATEL: You don't want to go there, do you? I mean, we're talking about 100,000 years, so.

MR. VADEN: I don't think, but I don't think they

Science and Engineering Ethics (2005) 11, XX-XX

Comment

Mortgaging the Future: Dumping Ethics with Nuclear Waste

Kristin Shrader-Frechette
University of Notre Dame, Indiana, USA

Keywords: atomic, dose, energy, nuclear, public health, radiation, regulation, waste, Yucca Mountain

ABSTRACT: *On August 22, 2005 the U.S. Environmental Protection Agency issued proposed new regulations for radiation releases from the planned permanent U.S. nuclear-waste repository in Yucca Mountain, Nevada. The goal of the new standards is to provide public-health protection for the next million years – even though everyone admits that the radioactive wastes will leak. Regulations now guarantee individual and equal protection against all radiation exposures above the legal limit. Instead E.P.A. recommended different radiation exposure-limits for different time periods. It also recommended using only the arithmetic mean of the dose distribution, to assess regulatory compliance during one time period, but using only the median dose to assess compliance during another period. This piece argues that these two changes – in exposure-limits and in methods of assessing regulatory compliance – have at least four disturbing consequences. The changes would threaten equal protection, ignore the needs of the most vulnerable, allow many fatal exposures, and sanction scientifically flawed dose calculations.*

On August 22 ,2005 the U.S. Environmental Protection Agency (E.P.A.) issued its long awaited regulations for radiation releases from the proposed U.S. nuclear-waste repository in Yucca Mountain, Nevada.[1] E.P.A. recommended a dramatic reversal of international and U.S. health standards. Current regulations guarantee individual and equal protection against all radiation exposures above the legal limit. The proposed regulations remove these guarantees for Yucca Mountain. Instead E.P.A. recommends changes both in the exposure-limits and in how they are measured and enforced.

Because radioactive leaks will increase over time, E.P.A. proposes one radiation exposure-limit for the near future (the next 10,000 years) and another limit – 2300

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percent higher – for the distant future (the period beyond 10,000 years). For the near future, this annual standard is 15 millrems. For the distant future, it is 350 millirems. To assess compliance with these limits, E.P.A. proposes using the arithmetic mean of the dose distribution during the near future, and using the median dose during the distant future.

By setting different exposure limits for different time periods, E.P.A.'s first proposal fails to give all citizens equal protection. The agency defends this double radiation standard by saying that even the more lenient exposure-limit allows a dose only slightly higher than what is already received from natural-background radiation.[2]

How dangerous a dose is that? According to the United Nations Scientific Committee on Effects of Ionizing Radiation (U.N.S.C.E.A.R.), the International Atomic Energy Agency (I.A.E.A.), and other scientific groups, natural-background radiation causes about 3 percent of fatal cancers – roughly 18,000 annual U.S. deaths.[3] As the U.S. National Academy of Sciences reaffirmed in June, no dose of ionizing radiation is completely safe, no matter how small or how natural.[4]

What would happen if all polluters followed E.P.A.'s reasoning about natural-background radiation? They could save money by avoiding pollution control. They could increase profits at the expense of the public but claim that victims' health risks were acceptable merely because they were no worse than what some natural event had caused. Neither fairness, polluter responsibility, compensating victims, nor obtaining their consent would be relevant.

E.P.A.'s double radiation standards for different generations also suggest that we merit more protection than our descendants. Yet we, not they, profit from nuclear power plants that produce the radioactive waste.

What about E.P.A.'s second proposal, to use mean dose to assess near-future compliance with regulations, and to use median dose to assess distant-future compliance? Neither mean nor median exposure-limits protect against fatal doses at the tail of the distribution. Neither protects the medically vulnerable 25 percent of the population – including children, pregnant women, and those with allergies.

To see what could happen when one uses mean-exposure standards for assessing regulatory compliance, suppose that in the near future 715 residents of a small town received radiation doses from Yucca Mountain. If a baby received a fatal dose of 10,000 millirems but all other residents each received 1 millirem, the mean dose would be under 15 millirems. Although such dose distributions might be unlikely, nevertheless this situation would be allowed by the mean-exposure standard. That is one reason all nations require keeping individual radiation exposures "as low as reasonably achievable" (ALARA). All nations rely on individual dose limits and keeping individual doses ALARA, not just keeping mean exposures ALARA.[5]

Imagine the consequences if all regulatory compliance were based only on mean or average protection. Even serious harms caused by negligence or unfairness could be sanctioned if the rate of harm were below the mean. For instance, if a city's murder rate were below the U.S. mean – 7 deaths per 100,000 – police might say protection was adequate and stop pursuing suspects.[6]

Even mean radiation exposure from Yucca Mountain would be high in the distant future. Because E.P.A. recognizes this, it recommends assessing distant-future regulatory compliance by using median, not mean, exposure-limits. By definition, median limits would allow nearly half of exposures to exceed any standard. Consider what could happen if E.P.A.'s 350-millirems median standard were applied to the earlier town of 715 people. If doses were ranked lowest to highest, the middle or median dose would be received by person 358. Provided her dose were below 350 millirems, this median standard could legally allow 357 people to receive fatal doses. Whether or not such an exposure distribution actually would occur, the case illustrates that any median standard provides only minimal protection because nearly half of the exposures could exceed it.

Apart from these two policy reversals, E.P.A.'s proposals rely on poor science, as the 2001 peer review by the International Atomic Energy Agency warned. The I.A.E.A. said the government's own Yucca Mountain studies show its projected radiation doses have uncertainties between 8 and 12 orders of magnitude.[7] This means projected Yucca radiation exposures to the public could be a trillion times too low or too high. Yet if doses were only 29 times higher than the distant-future limit, they could immediately kill human embryos. Doses only 750 times higher could immediately kill half the adults exposed.[8]

Whether or not people agree with E.P.A.'s changing radiation-exposure limits and regulatory-compliance standards, people likely agree that pollution regulations should protect everyone individually and equally. These new regulations do not appear to do so. They mortgage the lives of people in the distant future.

REFERENCES

1. Environmental Protection Agency (2005) *Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada, 40 CFR Part 197, OAR-2005-0083;FRL, U.S. Government Printing Office, Washington, D.C.*
2. E.P.A., pp. 98-109.
3. See, for instance, United Nations Scientific Committee on Effects of Atomic Radiation, U.N.S.C.E.A.R. (1994) *Sources, Effects, and Risks of Ionizing Radiation*, U.N., New York.
4. U.S. National Research Council (2005) *Health Effects from Exposure to Low Levels of Ionizing Radiation*, National Academy Press, Washington, D.C.
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8. U.N.S.C.E.A.R., I.C.R.P.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JAN 27 2005

OFFICE OF
AIR AND RADIATION

Charles Fitzpatrick
Egan, Fitzpatrick, Malsch & Cynkar, PLLC
1777 N.E. Loop 410
Suite 600
San Antonio, TX 78217

Re: FOIA Request HQ-RIN-00375-05

Dear Mr. Fitzpatrick:

This letter is in response to the Freedom of Information Act (FOIA) request dated November 30, 2004, in which you requested documents related to interactions between the Environmental Protection Agency (EPA) and either the Nuclear Regulatory Commission (NRC), Department of Energy (DOE), or National Academy of Sciences (NAS), regarding the July 2004 U.S. Court of Appeals decision remanding portions of EPA's public health and environmental radiation protection standards for Yucca Mountain, Nevada (40 CFR part 197).

We have identified the documents described below as falling within the scope of your request. Portions of the responsive documents are being withheld pursuant to Exemption 5 of the FOIA. Exemption 5 protects inter- and -intragency communications protected by the deliberative process privilege and the attorney-client privilege. Non-responsive information has also been withheld from several calendar entries. All other reasonably segregable nonexempt information has been released.

DATE	DESCRIPTION (OTHER INVOLVED PARTIES)
7-9-2004	Email (DOE)
7-12-2004	Calendar entry (DOE, NAS)
7-13-2004	Calendar entry (NAS)
7-14-2004	Calendar entry, meeting notes (NRC, DOE)
7-16-2004	Calendar entry (NAS)
7-23-2004	Meeting notes (NRC)
8-02-2004	Calendar entries, meeting notes (DOE)
8-17-2004	Calendar entry (NAS)
8-23-2004	Emails (NAS)
8-24-2004	Calendar entry (DOE), Email (NAS)
8-30-2004	Calendar entry (NAS, DOE, NRC)

8-31-2004	Calendar entry (NRC, DOE), Email (DOE)
9-7-2004	Calendar entry (NAS)
9-10-2004	Email (NAS)
9-17-2004	Email (NAS)
9-20-2004	Calendar entry, agenda, notes from NAS public meeting
10-14-2004	Calendar entry (NRC)
10-22-2004	Calendar entry (NRC)
11-8-2004	Calendar entry (DOE)
11-9-2004	Calendar entry (DOE, NRC)
11-10-2004	Calendar entry, meeting notes (NRC)
11-16-2004	Calendar entry (NAS)
11-17-2004	Calendar entry, meeting notes (DOE)
11-18-2004	Calendar entry (DOE)
11-24-2004	Calendar entry, meeting notes (DOE)

You may file an appeal of this determination with the Headquarters Freedom of Information Staff (2822T); Office of Environmental Information, United States Environmental Protection Agency; 1200 Pennsylvania Avenue, N.W.; Washington, DC 20460. The appeal must be made in writing and must be submitted to the above address no later than 30 calendar days from the date of this letter. The Agency will not consider appeals received after the 30-day limit. The appeal may include as much or as little related information as you wish, as long as it clearly identifies the determination being appealed (including the assigned FOIA request number, referenced on the subject line of this letter). For quickest possible handling, the appeal letter and its envelope should be marked "Freedom of Information Act Appeal."

If you have questions or need further information, please call Betsy Forinash, Director of the Center for Federal Regulation, at (202) 343-9233.

Sincerely,

Bonnie Gitlin

Bonnie C. Gitlin, Acting Director
Radiation Protection Division
Office of Radiation and Indoor Air

(3)

8/02

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5

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11/24/2004 DOE - Yucca 2/3

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04/11/2005 01:45 PM

To robert_andrews@YMP.gov, mapted@monitorsci.com, jack_bailey@YMP.gov, barnard@nwtrb.gov, hbarron@duke-energy.com, mab@nei.org, rmbernero@aol.com, A.Bonne@iaea.org, william_boyle@YMP.gov, dbullen@exponent.com, Ray Clark/DC/USEPA/US@EPA, Thomas.Cotton@rw.DOE.gov, Croffag@att.net, kcrowley@nas.edu, diodato@nwtrb.gov, russ_dyer@YMP.gov, matt.eyre@exeloncorp.com, MVF@NRC.GOV, Betsy Forinash/DC/USEPA/US@EPA, bjgarrick@aol.com, garrish@rw.DOE.gov, April_Gil@YMP.gov, Arnaud.Grevoz@andra.fr, bima@insightbb.com, alan.hooper@nirex.co.uk, gmh3k@unix.mail.virginia.edu, cristina.ionescu@pgnmail.com, issacs2@llnl.gov, ajennetta@innuco.com, mikael.jensen@ssi.se, dcjones@duke-energy.com, jpk@NRC.GOV, christopher.kouts@rw.DOE.gov, spk@nei.org, rod.krich@exeloncorp.com, mpl@NRC.GOV, mlevenso@nas.edu, adam.levin@exeloncorp.com, rloux@govmail.state.nv.us, "Machiels, Albert" <AMACHIEL@epri.com>, tjm3@NRC.GOV, Charles.McCombie@arius-world.org, rxm@nei.org, P.E.Metcalf@iaea.org, iln@co.clark.nv.us, claudia_newbury@YMP.gov, northworks@mindspring.com, okrent@seas.ucla.edu, bpastina@nas.edu, pescatore@nea.fr, Mark_Peters@YMP.gov, peterson@nuc.Berkeley.EDU, pigford@nuc.Berkeley.EDU, cbr@NRC.GOV, reiter@nwtrb.gov, Reid Rosnick/DC/USEPA/US@EPA, HPEditor@csuniv.edu, bsagar@swri.org, Trevor@sam-ltd.com, wct1@erols.com, ctv@csn.es, abe_vanluik@YMP.gov, evt@co.clark.nv.us, cwhipple@environcorp.com, Jean_Younker@YMP.gov, joseph_ziegler@YMP.gov, zuidema@nagra.ch, "Beall, Robert" <robert.h.beall@constellation.com>, "Brookmire, Tom" <tom_brookmire@dom.com>, "Brown, Michael" <jbrown@ameren.com>, "Burger, A.R." <aburger@firstenergycorp.com>, "Canavan, Ken" <kcanavan@epri.com>, "Chapot, Jorge" <chapot@eletronuclear.gov.br>, "Coss, Bill" <bcoss1@txu.com>, "Franklin, Charles" <cfrankl@entergy.com>, "Gras, Jean-Marie" <jean-marie.gras@edf.fr>, "Hansen, Brian" <bjhansen@apsc.com>, "Hayashi, Toshiaki" <Hayashi.Toshiaki@tepco.co.jp>, "Hill, Lee" <lee_o_hill@dom.com>, "Hoppes, David" <dfhoppes@stpegs.com>, "Hsieh, Simon" <hsieht@dteenergy.com>, "Kato, Kazuyuki" <Kato.Kazuyuki@tepco.co.jp>, "King, Frank" <frank.king@opg.com>, "Kunita, Robert" <robert.kunita@pgnmail.com>, "Leblang, Suzanne" <suzanne.leblang@nmcco.com>, "Loftin, Richard" <raloftin@southernco.com>, "Martin, Zita" <zimartin@tva.gov>, "Myers, Paul" <myerspd@songs.sce.com>, "Nagasawa, Kazuyuki" <k.nagasawa@tepco.co.jp>, "Patton, Bruce" <bhp1@pge.com>, "Phy, Kenneth" <kphy@entergy.com>, "Pickard, Rodney" <rgpickard@aep.com>, "Rahn, Frank" <FRAHN@epri.com>, "Scofield, Frederic" <fscofield@oppd.com>, "Swantz, William" <wlswant@nppd.com>, "Tripputi, Ivo" <tripputi@sogin.it>, "Williams, Darrell" <dwill17@entergy.com>, "Hagan, Joe" <jhagan@firstenergycorp.com>, "Long, Louis" <lblong@southernco.com>, "Naughton, Bill" <william.naughton@exeloncorp.com>, "Pardee, Chip" <charles.pardee@exeloncorp.com>, "Rosanski, Ken" <ken.rosanski@opc.com>, "Saccone, Robert" <rasaccone@pplweb.com>, "Stall, Art" <art_stall@fpl.com>

cc

1

bcc

Subject EPRI report on Yucca Mountain standard licensing options for very long time frames

Dear Addressee:

Attached is a link to an interim report EPRI has just published that discusses technical issues and potential options for a revised licensing standard for the candidate spent nuclear fuel and high-level radioactive waste repository at Yucca Mountain, Nevada.

http://www.epriweb.com/public/000000000001011754.pdf

The purpose of this report is to consider technical implications and options associated with regulatory compliance periods in excess of 10,000 years that:

Are consistent with the July 9, 2004 US Court of Appeals ruling;
Result in a "meaningful" standard that protects public health and safety in a constructive and equitable manner; and
Would be "reasonable" and implementable in a regulatory environment.

This report does not revisit issues settled in the Court of Appeals ruling. Rather, the report addresses potential regulatory approaches for implementing the ruling that are based upon and consistent with the recommendations made by the National Academy of Sciences panel on the Technical Bases for Yucca Mountain Standard in its 1995 report.

This report provides arguments that some components of the Yucca Mountain system, particularly future climate at the site, will need to be treated fundamentally differently if the time period of compliance is extended beyond 10,000 years. This is because uncertainties related to the estimate of peak health risk (dose risk) grow with time out to roughly the time of peak risk. For example, uncertainties in future climate states (magnitude and rate of change) increase in the future, but especially so for time periods beyond the order of 10^4 years.

The recommendations made in this report are summarized as follows:

Because the court rejected all challenges to the existing regulations governing the first 10,000 years, EPA should take a surgical approach to revising its standard: specifying beyond 10,000 year requirements as separate, stand-alone, provisions that do not alter what is required regarding the first 10,000 years;

2

A change of approach to the regulation and its implementation should be adopted for those provisions of the regulation that will address time frames beyond 10,000 years if the regulation, as a whole, is to remain implementable;

The use of a "stylized" approach for scenario identification and level of rigor in the models should be established by the NRC for time periods beyond 10,000 years;

Future climate states should be fixed by rulemaking to one or, at most, two: present-day "interglacial" and "glacial;" if a "glacial" climate state is specified, the regulation should also specify a set of assumptions to govern human behavior that is consistent with the way humans would be expected to live in such a climate. However, it is preferable to simply assume the present-day interglacial climate state continues for the entire compliance period since it is likely to be reasonably bounding and the most implementable;

No additional FEPs screening is required for the time period beyond 10,000 years. This is because the current FEPs screening criterion (FEPs with a probability lower than approximately 10^{-8} per year can be screened out) is already overly inclusive compared to the approach recommended by the TYMS panel. If additional FEPs screening beyond 10,000 years is required by EPA, the concept of negligible incremental dose should be used as a screening tool; and

A two-tiered dose limit should be specified: one level for the first 10,000 years; and a second, higher level consistent with the increased uncertainty should be used for the period beyond 10,000 years.

EPRI seeks feedback from all interested parties on the content and recommendations made in this interim report. Please feel free to contact me at the coordinates below.

Sincerely,
jhk

PS: If you wish to receive a paper copy of the above report, please call EPRI's Report Distribution Center 1-800-313-3774 and ask for report number 1011754.

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(4)

Atomic Energy Agency

Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management

Notes: The Convention, pursuant to Article 40.1, entered into force on 18 June 2001, i.e. on the ninetieth day after the day 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.

Parties: 35
Signatories: 42

Last change of status: 04 October 2005

Country/Organization	Signature	Instrument	Date of deposit	Declaration etc.	/ Withdrawal	Entry into force
[1] Argentina	19 Dec 1997	ratification	14 Nov 2000	☐	☐	18 Jun 2001
Australia	13 Nov 1998	ratification	05 Aug 2003	☐	☐	03 Nov 2003
Austria	17 Sep 1998	ratification	13 Jun 2001	☐	☐	11 Sep 2001
Belarus	13 Oct 1999	ratification	26 Nov 2002	☐	☐	24 Feb 2003
[1] Belgium	08 Dec 1997	ratification	05 Sep 2002	☐	☐	04 Dec 2002
[1] Brazil	31 Oct 1997			☐	☐	
[1] Bulgaria	22 Sep 1998	ratification	21 Jun 2000	☐	☐	18 Jun 2001
[1] Canada	07 May 1998	ratification	07 May 1998	☐	☐	18 Jun 2001
Croatia	09 Apr 1998	ratification	10 May 1999	☐	☐	18 Jun 2001
[1] Czech Republic	30 Sep 1997	approval	25 Mar 1999	☐	☐	18 Jun 2001
Denmark	09 Feb 1998	acceptance	03 Sep 1999	☑	☐	18 Jun 2001
Estonia	05 Jan 2001			☐	☐	
[1] Finland	02 Oct 1997	acceptance	10 Feb 2000	☐	☐	18 Jun 2001
[1] France	29 Sep 1997	approval	27 Apr 2000	☐	☐	18 Jun 2001
[1] Germany	01 Oct 1997	ratification	13 Oct 1998	☐	☐	18 Jun 2001
Greece	09 Feb 1998	ratification	18 Jul 2000	☐	☐	18 Jun 2001
[1] Hungary	29 Sep 1997	ratification	02 Jun 1998	☐	☐	18 Jun 2001
Indonesia	06 Oct 1997			☐	☐	
Ireland	01 Oct 1997	ratification	20 Mar 2001	☐	☐	18 Jun 2001
Italy	26 Jan 1998			☐	☐	
[1] Japan		accession	26 Aug 2003	☑	☐	24 Nov 2003
[1] Kazakhstan	29 Sep 1997			☐	☐	
[1] Korea, Republic of	29 Sep 1997	ratification	16 Sep 2002	☐	☐	15 Dec 2002
Latvia	27 Mar 2000	acceptance	27 Mar 2000	☐	☐	18 Jun 2001
Lebanon	30 Sep 1997			☐	☐	
[1] Lithuania	30 Sep 1997	ratification	16 Mar 2004	☐	☐	14 Jun 2004
Luxembourg	01 Oct 1997	ratification	21 Aug 2001	☐	☐	19 Nov 2001
Morocco	29 Sep 1997	ratification	23 Jul 1999	☐	☐	18 Jun 2001

Country/Organization	Signature	Instrument	Date of deposit	Declaration etc. / Withdrawal	Entry into force
[1,2] Netherlands	10 Mar 1999	acceptance	26 Apr 2000	☐ ☐	18 Jun 2001
Norway	29 Sep 1997	ratification	12 Jan 1998	☐ ☐	18 Jun 2001
Peru	04 Jun 1998			☐ ☐	
Philippines	10 Mar 1998			☐ ☐	
Poland	03 Oct 1997	ratification	05 May 2000	☐ ☐	18 Jun 2001
[1] Romania	30 Sep 1997	ratification	06 Sep 1999	☐ ☐	18 Jun 2001
[1] Russian Federation	27 Jan 1999			☐ ☐	
[1] Slovakia	30 Sep 1997	ratification	06 Oct 1998	☐ ☐	18 Jun 2001
[1] Slovenia	29 Sep 1997	ratification	25 Feb 1999	☐ ☐	18 Jun 2001
[1] Spain	30 Jun 1998	ratification	11 May 1999	☐ ☐	18 Jun 2001
[1] Sweden	29 Sep 1997	ratification	29 Jul 1999	☐ ☐	18 Jun 2001
[1] Switzerland	29 Sep 1997	ratification	05 Apr 2000	☐ ☐	18 Jun 2001
[1] Ukraine	29 Sep 1997	ratification	24 Jul 2000	☐ ☐	18 Jun 2001
[1] United Kingdom	29 Sep 1997	ratification	12 Mar 2001	☐ ☐	18 Jun 2001
[1] United States of America	29 Sep 1997	ratification	15 Apr 2003	☐ ☐	14 Jul 2003
EURATOM		accession	04 Oct 2005	☑ ☐	02 Jan 2006

1 Indicates that the State has at least one operational nuclear power plant.

2 for the Kingdom in Europe

Radon Home

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Radon and Real Estate
Updated Radon Risk Assessment
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EPA Map of Radon Zones
Radon in Drinking Water
State Indoor Radon Grants (SIRG)

Radon Frequent Questions

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Definitions

Radon
Radon is a gaseous radioactive element having the symbol Rn, the atomic number 86, an atomic weight of 222, a melting point of -71°C, a boiling point of -62°C, and (depending on the source, there are between 20 and 25 isotopes of radon - 20 cited in the chemical summary, 25 listed in the table of isotopes); it is an extremely toxic, colorless gas; it can be condensed to a transparent liquid and to an opaque, glowing solid; it is derived from the radioactive decay of radium and is used in cancer treatment, as a tracer in leak detection, and in radiography. (From the word *radium,* the substance from which it is derived.) Sources: *Condensed Chemical Dictionary*, and *Handbook of Chemistry and Physics*, 69th ed., CRC Press, Boca Raton, FL, 1988.

EPA's Integrated Risk Information System profile on Radon 222 [CASRN 14859-67-7] is located at: epa.gov/iris/subst/0275.htm

Conversion Factors for Radon Units (PDF, 1 page, 346KB About

PDF)
Radon Decay Series Chart (PDF, 1 page, 244KB About PDF)

Sources of Radon

Earth and rock beneath home; well water; building materials.

What are the Health Effects From Exposure to Radon

No immediate symptoms. Based on an updated Assessment of Risk for Radon in Homes, radon in indoor air is estimated to cause about 21,000 lung cancer deaths each year in the United States. Smokers are at higher risk of developing Radon-induced lung cancer. Lung cancer is the only health effect which has been definitively linked with radon exposure. Lung cancer would usually occur years (5-25) after exposure. There is no evidence that other respiratory diseases, such as asthma, are caused by radon exposure and there is no evidence that children are at any greater risk of radon induced lung cancer than adults.

What is the Average Level of Radon Found in a Home?

Based on a national residential radon survey completed in 1991, the average indoor radon level is 1.3 picocuries per liter (pCi/L) in the United States. The average outdoor level is about 0.4 pCi/L.

What's the Debate on Radon?

There is no debate about radon being a lung carcinogen in humans. All major national and international organizations that have examined the health risks of radon agree that it is a lung carcinogen. The scientific community continues to conduct research to refine our understanding of the precise number of deaths attributable to radon. The National Academy of Sciences BEIR VI Report has estimated that radon causes about 15,000 to 22,000 lung cancer deaths annually based on their two-preferred models.

A few scientists have questioned whether low radon levels, such as those found in residences, increase the risk of lung cancer because some small studies of radon and lung cancer in residences have produced varied results. Some have shown a relationship between radon and lung cancer, some have not. However, the national and international scientific communities are in agreement that all of these residential studies have been too small to provide conclusive information about radon health risks. Major scientific organizations continue to believe that approximately 12% of lung cancers annually in the United States are attributable to radon.

How do we know radon is a carcinogen?

The World Health Organization (WHO), the National Academy of Sciences, the US Department of Health and Human Services, as well as EPA, have classified radon as a known human carcinogen, because of the wealth of biological and epidemiological evidence and data showing the connection between exposure to radon and lung cancer in humans.