INSTITUTE FOR ENERGY AND
ENVIRONMENTAL RESEARCH

6935 Laurel Avenue, Suite 201
Takoma Park, MD 20912

Phone: (301) 270-5500
FAX: (301) 270-3029
e-mail: ieer@ieer.org
http://www.ieer.org

Comments of the Institute for Energy and Environmental Research on the U.S. Nuclear Regulatory Commission's Proposed Waste Confidence Rule Update and Proposed Rule Regarding Environmental Impacts of Temporary Spent Fuel Storage[1]

Arjun Makhijani, Ph.D.
President, Institute for Energy and Environmental Research
6 February 2009

The following are the comments of the Institute for Energy and Environmental Research (IEER) on the Nuclear Regulatory Commission's (NRC's) proposed Waste Confidence Decision Update[2] and the associated Consideration of Environmental Impacts of Temporary Storage of Spent Fuel after Cessation of Reactor Operation.[3]

The proposed Waste Confidence Decision warrants careful examination, because it serves as the underpinning to several key safety and environmental findings regarding the operation of nuclear power plants and the disposal of the wastes that they generate.

- First, the Waste Confidence Decision presents a safety finding, under the Atomic Energy Act, that the NRC has reasonable assurance that disposal of spent fuel will not pose an undue risk to public health and safety. It does so via the finding that disposal is technically feasible and can be done in conformity with the assumption of zero releases in Table S-3 at 10 CFR 51.51, which specifies the environmental impacts associated with nuclear reactor operation, including those associated with nuclear wastes and emissions.
- Second, the Waste Confidence Decision provides the basis for a key assumption in the uranium fuel cycle rule that spent fuel can be isolated in a repository, with no radioactive releases. That finding, in turn, is key to the NRC's conclusion that the environmental impacts of the entire uranium fuel cycle are insignificant.[4]

---

[1] These comments were prepared at the request of Texans for a Sound Energy Policy.
[2] NRC 2008
[3] NRC 2008b
[4] 10 CFR 51.51 2008 and its Table S-3 2008

- Finally, the Waste Confidence Decision provides the basis for the NRC's Finding of No Significant Impact (FONSI) regarding the environmental impacts of temporary spent fuel storage pending its disposal in a repository.

As discussed below, IEER believes that the NRC lacks adequate support for the Waste Confidence Decision's first and second proposed findings. The NRC has simply failed to address currently available information which shows that the NRC currently does not have an adequate technical basis for a reasonable level of confidence that spent fuel can and will be isolated in a geological repository.

The NRC's lack of support for Findings 1 and 2 of the Waste Confidence Decision also fatally undermines the viability of the uranium fuel cycle rule promulgated in 1979.[5] In that rule, the NRC declared that the environmental impacts of the entire uranium fuel cycle would be negligible. The finding was based in part on the assumption that spent fuel would have no radioactive releases after it was placed in a repository. That assumption was based in turn on two other assumptions: (i) that disposal of spent fuel or reprocessing high-level waste would be in a salt repository, and (ii) that releases of radioactivity from that repository would be zero. In its draft Waste Confidence Decision, the NRC has acknowledged that salt is not a suitable medium for spent fuel disposal. Investigations of Yucca Mountain and other non-salt repositories have concluded that there are likely to be some releases of radioactivity due to spent fuel disposal. This invalidates the basis of the uranium fuel cycle rule and the Waste Confidence Decision that is associated with it. Other assumptions and findings contained in the 30-year-old uranium fuel cycle rule are also demonstrably invalid today, such as the assumption that greater than class C (GTCC) waste and depleted uranium (DU) tails can be disposed of in a shallow land burial as low-level radioactive waste (LLRW) under present rules. On the contrary, special permitting processes, including environmental impact evaluations will be necessary to dispose of these wastes. The NRC must re-evaluate all of these assumptions and findings in light of new information which shows that they are incorrect. And the NRC must re-evaluate its overall conclusion that the health impacts of the uranium fuel cycle are negligible.

In addition, the NRC's lack of an adequate basis for Findings 1 and 2 undermines the NRC's basis for a finding that spent fuel can be safely stored on reactor sites pending the opening of a repository. The NRC must conduct a new environmental analysis that examines the impacts of onsite spent fuel storage for a much longer period than 50 to 60 years after the cessation of reactor operations. This must include considerations relating to the potential deterioration of onsite storage canisters and the potential for transfers to new onsite storage canisters.

Finally, taken together, the Waste Confidence Decision, the uranium fuel cycle rule, and the NRC's environmental analysis of the impacts of temporary fuel storage completely fail to address one of the key environmental questions raised by the proposed licensing and re-licensing of nuclear plants: what does it cost to manage and dispose of the radioactive waste generated in the process of operating nuclear plants, and is the cost

[5] NRC 1979

justifiable in comparison to renewable energy alternatives such as wind and solar power? The lack of a credible cost analysis for waste means that alternatives to nuclear power cannot be fairly evaluated as required by NEPA.

A. Comments on Finding 1

The NRC proposes to reaffirm Finding 1 unchanged from 1990. Finding 1 reads as follows:

> Finding 1: The Commission Finds Reasonable Assurance That Safe Disposal of High-Level Radioactive Waste and Spent Fuel in a Mined Geologic Repository Is Technically Feasible.[6]

Three terms in Finding 1 are critical:

- "reasonable assurance"
- "safe disposal", and
- "technically feasible"

The term "safe disposal" involves (i) the safety of building the repository, putting the waste in it, and backfilling and sealing it, and (ii) the performance relative to health and environmental protection standards for a long period after the repository is sealed. It should be noted that the requirements of showing that there is "reasonable assurance" that "safe disposal" of "high-level waste and spent fuel" is "technically feasible" are much greater than would be the case if the problem were simply to show that it is possible to dig a deep mine, put spent fuel in it, and backfill it. That would be nothing more than dumping. In the case of a geologic repository system, it is essential to show a reasonable basis for confidence that the public and the environment far into the future will be adequately protected from the effects of disposal at a specific site and a specific engineered system built there.

A scientific explanation of the term "reasonable assurance" requires either physical proof that such a facility exists and has operated within expected performance rules or a statistically valid argument based on real-world data that would show (i) that all the elements for a repository system exist and (ii) that they would work together as designed, as estimated by validated models. The evidence must be sufficient to provide a reasonable basis to conclude that the durability of the isolation arrangements would be sufficient to meet health and environmental standards for long periods of time – hundreds of thousands of years with a high degree of assurance, or in other words, with a high probability. In statistical terms, this means that the upper bound estimate of health and environmental damage should be below the maximum allowable limit with a high level of confidence. At present these uncertainties are very large, which means that it is reasonable to conclude that under some circumstances the damage could be higher than the norms of radiation protection. See below for examples.

---

[6] NRC 2008, p. 59553.

The task of determining whether there is an adequate basis for a reasonable assurance of technical feasibility is very difficult. A large part of the difficulty so far as assessing long-term integrity and performance arises from the fact that three elements of a mined system that is highly perturbed thermally, chemically, and mechanically from its original geologic state must be shown to work together to provide "safe disposal" – that is to provide disposal that will conform to an agreed and settled radiation protection standard for the public and that will also protect workers during the construction period of the repository according to prevailing norms for worker protection. The three elements are:

- The waste and the waste encapsulation system.
- The backfill and sealant system.
- The near- and far-field perturbed geologic environment.

We will show that it is a very difficult and complex task to assess the performance of each of these elements under the conditions of spent fuel disposal in a repository and that a wide range of radiation doses can be estimated from the same general repository type and location, including doses that are above regulatory limits.

1. Lack of realistic demonstration of the technical feasibility of a thermally perturbed, sealed repository system

To date, no large-scale demonstration of a system that has been thermally perturbed by spent fuel and then back-filled and sealed has been carried out even for a limited period of time. Much less has there been a demonstration over a few decades that a highly thermally perturbed and sealed system with large amounts of spent fuel would function in the long-term as estimated on paper or via the results of limited experiments. Moreover, many of the experiments that have been proposed, even in highly regarded repository programs, are simply inadequate or inappropriate for estimating performance. For instance, an expert team of geologists put together by IEER[7] concluded that both the thermal and mechanical aspects of the research designed to study the suitability of the French repository location were deficient in essential respects, despite the fact that the program had many strong points:

> A crucial problem for research is that the model must estimate performance not of the natural setting but of a geologic system that has been considerably disturbed by a large excavation, which may induce fractures not originally present, by the introduction of (thermally) hot wastes, and by the addition of various backfill materials and seals. *Hence, the system being modeled is no longer the original geologic system, but a profoundly perturbed system.* …. Estimation of performance of a system under these conditions with some confidence poses challenges that are, in many ways, unparalleled in scientific research.
>
> In the specific case of the Bure site, the host rock is argillite, a hard rock consisting of clayey minerals, carbonates (mainly calcites), and quartz. The in-tact rock is not very porous, leading to expectation of diffusive flow in the

[7] See Attachment B for the Curriculum Vitae of the team members.

> absence of fractures and in the absence of disturbance by mining. Such flow would be very slow and the expected travel time of radionuclides released from waste packages could be very long.
>
> However, the IEER team's evaluation of (i) the documents, (ii) argillite rock properties under conditions of heat and humidity, and (iii) the research done to model the site performance indicated that the actual conditions prevailing in an actual repository could be very different from diffusive flow. Failure of certain components, notably repository seals, could result in rapid (in geological terms) transport of radionuclides to the human environment.
>
> ANDRA's own estimate of dose under conditions of seal failure was higher than the allowable limit of 0.25 millisieverts (25 millirem) per year. In this context, IEER concluded that ANDRA's scenario for human exposure was not necessarily conservative, in that doses to an autarchic farmer family (also called "subsistence farmer family") using groundwater in certain locations could be even higher than the dose at the surface water outcrop estimated by ANDRA.[8]

Note that as of the date of the IEER report on the Bure site in France, ANDRA's own estimate of dose exceeded its regulations in the event of seal failure. In this context, research on characterizing the long-term integrity of seals becomes critically important. And IEER found ANDRA's research program in this very area to be deficient. One of its principal conclusions about the research on seals was that it seemed to of "marginal value" and was far from adequate to enable a sound determination of repository performance:

> One crucial problem is that the simulated slot sealing test in the underground laboratory may be of marginal value and utility. The test is planned to be done very early on after excavation and only over a very short period of time relative to the duration of performance requirements and even relative to the time lapse over which the actual EDZ [Excavated Damaged Zone] will develop, prior to seal installation. This is neither convincing nor satisfactory. It is difficult to see how and why increasing the stress component parallel to the gallery walls will reduce the permeability in that direction or how a flatjack can simulate a bentonite seal, except in the most crude of approaches.[9]

Similarly, there has been considerable skepticism about the DOE's proposed disposal configuration for Yucca Mountain. DOE proposes disposal in the unsaturated zone in a configuration in which boiling of water is expected for "the first few hundred years after closure…in the drift vicinity."[10] The DOE expects the effects to be as follows:

---

[8] Makhijani and Makhijani 2006. Italics in the original. This article is based on the full report, which is in French: *Examen critique du programme de recherche de l'ANDRA pour déterminer l'aptitude du site de Bure au confinement géologique des déchets à haute activité et à vie longue : Rapport Final*. Hereafter cited as IEER 2005. The qualifications of the team members are found in Attachment C.

[9] IEER 2005, p. 59, in Chapter 2. Retranslated from the final French report by Annie Makhijani.

[10] DOE 2008 p. 2.3.3-58 in Chapter 2

> Thermal expansion of the rock matrix induces thermal stresses and associated changes in flow properties near emplacement drifts…. Thermally-driven effects also cause dissolution and precipitation of minerals, which may affect flow properties (thermal-hydrologic-chemical effects). [11]

While the DOE believes that these processes will not prevent satisfactory repository performance, Dr. Don Shettel, an expert geochemist and consultant for the State of Nevada, has concluded that a hot temperature design is "fatally flawed."[12] This was extensively discussed at the May 18, 2004, meeting of the U.S. Nuclear Waste Technical Review Board (NWTRB):

> We've talked about thermal concentration of brines and boiling point elevation. We can get fingering of concentrated solutions in fractures, thereby increasing the probability and percentage of thermal seepage waters that might reach the drift on the EBS [Engineered Barrier System]. We have mixed salt deliquescence [absorption of water vapor by solid salts so as to dissolve them], not so much from the dust that's on the canisters, but from the increased amount of thermal seepage water that we believe can reach the EBS. And, if these evaporated or concentrated solutions can reach the EBS before the thermal peak, then they can become, even after the thermal peak, get hydrated salts with thermal decomposition, with the evolution of acidic solutions and vapors. And, **one of the most important aspects of this model is the wet-dry cycling or intermittent seepage**. If you get some seepage on the canisters, and it evaporates to some extent, dries out, the addition of water to that can generate acid.
>
> ….We believe that the **high temperature design for the repository is fatally flawed** for the number of reasons that I've discussed, and that **emplacement in the saturated zone would be much better, because that's essentially where DOE has tested their metals at.** And, the saturated zone is also the much less complicated in terms of processes and modeling.[13]

It is clear from the above, that there are scientists who have carefully studied the problem who believe that DOE has tested the metals mainly in an environment [saturated] that is fundamentally different than the proposed disposal environment [unsaturated]. According to them the proposed DOE design is "fatally flawed" and the Yucca Mountain repository site is "not adequate." Dr. Shettel also stated that an entirely different disposal concept in the saturated zone would be "much better."[14]

Testing, experiments, and models that seem to bypass essential questions were a problem that the IEER team discovered in relation to sealants, as quoted above (proposed tests were "neither convincing nor satisfactory"). Moreover, the problem of wet-dry cycling and inadequate modeling was also cited by the IEER team as a significant problem in the French repository research program:

[11] DOE 2008 p. 2.3.3-58 in Chapter 2
[12] Don Shettel is Chairman and Geochemist, Geoscience Management Institute, Inc.
[13] Shettel 2004. Emphasis added.
[14] Also see below for further discussion of the corrosion problem.

> No evidence is found for any model evolution from simple, scoping, or conceptual models into design base models that result in conceptual design and site evaluation. Model evaluation potentials against direct, experimental results have been omitted. The simple models described in the documents do not seem to be adequate for the evaluation/verification of thermophysical site properties.
>
> It is not clear why one-dimension model results are included in the inverse modeling of in situ experiments; the heat flow is not remotely a linear, one-dimensional problem. Even the two-dimensional, analytical model result for an infinite heater length is a very poor model for the arrangement involving a 2 m-long heater only. The large difference between the two-dimensional, analytical, and three-dimensional, numerical models disqualifies the other models. It is even questionable whether the model condition of a three-dimensional domain assuming homogeneous and isotropic material/physical properties is adequate, since the stratigraphy of the Bure site is layered with different properties in different directions.
>
> The thermal conductivity, one of the most important thermophysical site characteristic, has not been adequately established. The standard deviation of this parameter is unusually high, leaving a large margin of uncertainty in the heat-rejecting capacity of the site. The number of samples used for establishing thermophysical site properties based on laboratory samples appears to be low, especially considering the potential spatial variation of these properties over the proposed storage area.
>
> Although the temperature regime according to the baseline design is below-boiling, above-boiling operation is not impossible. A bi-stable system, involving either below boiling or above boiling conditions in the emplacement area, is quite possible under some circumstances. A steam cycle therefore is possible under certain heat load conditions, namely, if the backfill buffer material cannot saturate and the damaged zone cannot re-saturate due to vapor-phase water loss caused by the condensing zones of the emplacement area.
>
> Since above-boiling point temperatures are expected in the Type C and spent fuel modules for long periods of time in the preferred design selection, these modules may develop continuous steam cycles within the emplacement area for centuries.[15]

There is experimental evidence that result of wet-dry cycling at Yucca Mountain could result in very rapid corrosion of the C-22 alloy containers. While the DOE believes the contrary, Dr. Roger Staehle, who worked as a consultant for the State of Nevada with a research team including other experts and Catholic University of America faculty, made a presentation to the NWTRB during which he went through the team's experimental findings for the NWTRB; he concluded with a set of stark "warnings":

[15] IEER 2005, pp. 101-102, Chapter 3. Retranslated from the final French report by Annie Makhijani.

Warnings

1. There is an abundance of warnings as well as solid quantitative data that demonstrate that corrosion of the C-22 alloy is *inevitable and rapid.*

2. A good paradigm for the warnings about C-22 can be found with Alloy 600 that was widely used in the nuclear industry as tubing in steam generators and as structural components. Alloy 600 has broadly failed in these applications, and present failures could easily have been predicted from past occurrences.

3. There are now *abundant warnings that that C-22 alloy is not adequate nor is the present design of the repository adequate*. Such warnings are founded on warnings, some of which are 15 years old.

4. Further, there is abundant evidence that the YM site itself is not adequate.

5. The analogies of warnings from the present nuclear industry are abundant and apply directly to whether the present design at YM is adequate. *The answer is that it is not.*

6. Some of the warnings from experience of the water cooled nuclear reactor industry apply directly to the design and development of the Yucca Mountain facility. These should be carefully assessed, e.g. as they apply to heated surfaces.

7. Finally, the incapacity to inspect the YM containers requires assurances of reliable performance that are higher than those of normal industrial expectations.[16]

The problem of adequacy of the research program or lack thereof points up the critical need to have confidence in each of the three elements of geologic disposal. In the above examples, we have shown that in the case of Yucca Mountain the behavior of the containers as well as the rest of the Engineered Barrier System has not been characterized to the point that independent scientists could agree that Yucca Mountain is a suitable disposal site, even though the DOE believes it is. On the contrary, there is quite a bit of evidence that Yucca Mountain is not a suitable site, and may even be "fatally flawed," since the containers are essentially the only effective barrier preventing radionuclide releases to the environment.

The Nuclear Waste Technical Review Board considered the question of the potential for severe corrosion due to deliquescence at length following the May 2004 meeting from which the above presentation is drawn. While the twists and turns that the issue took are technically interesting and illustrate the uncertainties, the most important point to note here is that, in the end, the DOE decided to entirely ignore the issue because it believes it to be "insignificant":

> Although deliquescence of salts on the waste package surface is expected to occur, this process has been excluded from TSPA [Total System Performance Assessment] because the effects of such deliquescence have been determined to be insignificant to performance (Table 2.2-5, FEP 2.1.09.28.0A, Localized corrosion on waste package outer surface due to deliquescence). The physiochemical characteristics of brines produced through deliquescence of minerals in deposited dusts are not expected to generate an environment favorable for the initiation of localized corrosion and

[16] Staehle 2004. Italics added.

> propagation for Alloy 22 (UNS N06022) waste packages. In addition, at elevated temperatures (greater than 120°C), only small quantities of brine will form from the available dust, and brine volume will limit the extent of localized corrosion damage should it initiate.[17]

And again:

> Modeling of evaporative evolution of potential seepage waters shows that corrosive calcium and magnesium-chloride brines are not expected to form. As noted above, although deliquescence-induced brine formation is expected to occur, this process has been excluded from TSPA because the effects of such deliquescence have been determined to be insignificant to performance.[18]

The Nuclear Waste Technical Review Board, the expert oversight body appointed by Congress to oversee the Yucca Mountain program, came to a somewhat different conclusion regarding whether deliquescence-induced corrosion should be excluded from DOE's license application:

The NWTRB's report was sent to Congress with a letter dated August 2008, two months after the DOE had submitted its license application concluding that deliquescence-induced corrosion could be ignored in performance assessment because it was judged to be insignificant. For this very reason, the report is worth quoting at length:

> The Board's January 12, 2007, letter [to the DOE Office of Civilian Radioactive Waste Management] and its attached report contained the following additional findings:
>
> - *Cumulative damage due to the combined effects of deliquescence-induced localized corrosion and seepage-based localized corrosion merits some analysis.*
> - *Including seepage-based localized corrosion in TSPA-LA while excluding deliquescence-induced localized corrosion is incongruous because the process (localized corrosion) is the same in both cases.*
> - *Deliquescence-induced general corrosion of Alloy 22 should be included in TSPA-LA.*
> - Anomalies among recent experiments at high temperatures, such as unexpectedly high general corrosion rates and a maximum of general corrosion rate with respect to temperature, require explanation.
> - Effects of waste package surface condition on the corrosion of the waste package surface may need more investigation.
> - *Including deliquescence-induced localized corrosion in TSPA-LA would add to its completeness, robustness, and credibility.*
>
> In a follow-up letter to OCRWM dated July 10, 2007 (Garrick 2007c), the Board pointed out that the dust settling on waste package surfaces during ventilation would contain significant amounts of organic materials and that reactions between these materials and nitrate in the dust could affect the amount of nitrate, which inhibits

---

[17] DOE 2008, p. 2.3.5-10
[18] DOE 2008, p. 2.3.5-12

> localized corrosion if present in large enough quantities relative to chloride. The Board stated that the Project should analyze the effects of the full range of factors (e.g., organics in dust, acid-gas devolatilization, and radiolysis) that could influence whether inhibitive nitrate-to-chloride ratios persist under repository conditions.
>
> OCRWM responded to the Board's January 12, 2007, and July 10, 2007, letters in a November 20, 2007, letter (Sproat 2007c). Although the Board agrees with some of the points mentioned in the letter, **in several instances OCRWM did not address points brought up by the Board. For example, in its January 12 letter, the Board addressed the apparent incongruity of excluding deliquescence-induced localized corrosion while including seepage-based localized corrosion despite the fact that both are the same process, i.e., localized corrosion**. In its November 20, 2007, letter, the Project reiterated the differences in the environments between deliquescence-induced and seepage based localized corrosion. The Board concurs that the environments are quite different, but the processes are not. **Regardless of whether NRC regulations allow a process to be split in two and one part to be discarded, doing so still remains incongruous.**
>
> In addition, the Project refers to components of the dust deposited on waste package surfaces as "reactants" or "limited reactants" in several places in its November 20 letter. Although the Board agrees that many components in the dust could be reactants, it seems that the principal reactants in general or localized corrosion would be either the water component of deliquescent brines or oxygen dissolved in the brines. Both water and oxygen are essentially limitless in supply. If they are consumed by the brine in corrosion reactions, they simply will be replenished rapidly by dissolution or deliquescence. The Board would welcome additional information from the Project about what other components of the dust undergo reactions. **Finally, although OCRWM claimed that it had addressed Board concerns about the effects of organic materials on the nitrate-to-chloride ratio in the November 20 letter, the basis for this claim is unclear.**
>
> **In sum, despite the workshop in September 2006 and the exchange of letters in 2007, the issue of deliquescence-induced localized corrosion, although apparently tractable, remains open.**[19]

In other words, on perhaps the most critical scientific uncertainty for the entire Yucca Mountain program, the DOE has

- failed to follow the advice of the Congressionally mandated Technical Review Board
- submitted a license application that dismisses as "insignificant" the very process that the NWRTB asked it to include and address further and that has led some scientists with considerable expertise to conclude that Yucca Mountain is not an adequate site or that the design is "fatally flawed."

There is no evidence in the draft Waste Confidence Decision that the NRC has taken any of this information and analysis into account in reiterating Finding 1 that there is "Reasonable Assurance That Safe Disposal of High-Level Radioactive Waste and Spent Fuel in a Mined Geologic Repository Is Technically Feasible." Further, the NRC draft

---

[19] NWTRB 2008, pp. 27-28, italics and bold emphasis added.

Decision also notes that salt repositories are unsuitable for disposal of spent fuel (see below).

2. Uncertainty in performance results and the question of technical feasibility

The technical feasibility of "safe disposal" of waste in a geologic disposal system with "reasonable assurance" must be judged according to technically sound and legally valid performance criteria. There are two issues that relate to "technical feasibility" in this context

a. What is the nature of the performance standards that must be met? This relates to the radiation protection standard set to protect the health and environment of future generations from the effects of waste disposal.
b. Is there reasonable assurance that the performance standard can be met and that other safety goals, such as worker safety during constructing, waste emplacement, and sealing, can also be met? This relates to a reasonable level of scientific and statistical confidence that the performance standard in terms of health and environmental protection will be met in practice.

a. Nature of the Performance Standard

The history of the process of specifying the standards of performance, such as maximum allowable dose, the pathways via which that dose must be assessed, and the period over which performance must be evaluated, in the United States undermines the NRC's claim of technical feasibility. The claim is also undermined by estimates of performance that cover a wide range and include at the upper limit large exceedance of the current EPA radiation dose requirement.

EPA standards for disposal of spent fuel, high-level waste, and transuranic waste were first promulgated in 1985 and amended later on to include drinking water protection.[20] The rule specified a period of protection of 10,000 years. Yet the National Research Council study done for the DOE in 1983[21] had already criticized the EPA proposal before its finalization and advocated extending the period of performance for all time, judging compliance for the proposed period of 10,000 years to be "rather easy."[22] The National Research Council also advocated a maximum individual dose approach rather than a population dose approach.

The EPA essentially ignored the National Research Council's advice and adopted the 10,000 year limit and limits on total releases of certain radionuclides including carbon-14. The EPA standard was to be the fundamental performance criterion for public health and environmental protection for spent fuel, high-level waste, and transuranic waste disposal.

[20] The regulation is 40 CFR 191, and can be found on the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/40cfr191_08.html.
[21] NAS-NRC 1983 Chapter 8.
[22] NAS-NRC 1983 p. 236.

Further study showed that the National Research Council's conclusion that a 10,000 year limit would make compliance "rather easy" to be incorrect with respect to unsaturated repositories like Yucca Mountain with respect to the specific standard adopted by the EPA. Specifically, the EPA set a limit of carbon-14 emissions of 100 curies per 1,000 metric tons of heavy metal in spent fuel or equivalent high-level waste.

An EPA panel was convened to examine the question of carbon-14 releases from unsaturated repositories like Yucca Mountain. In 1993, the Science Advisory Board of the EPA cast considerable doubt on whether Yucca Mountain, a proposed unsaturated repository, could meet the carbon-14 emission limit in the EPA standard:

> …[I]t is not possible on the basis of presently available information to predict with reasonable confidence whether releases from an unsaturated repository would be less than or greater than the Table 1 (40 CFR 191) release limits. (The Table 1 release limit is one-tenth of the inventory.)[23]

Instead of looking for a new repository that might meet the standard, Congress mandated special standards for Yucca Mountain, which may, in light of the process, be fairly called a double-standard-standard. The scientific basis of these standards was to be provided by the National Academy of Sciences.

The National Research Council of the National Academies issued a report in 1995 advocating a period of performance extending to the peak dose and a rather complex method of estimating the peak dose.[24] The latter itself generated sufficient controversy that one of the panel members, Professor Thomas Pigford, one of the most prominent nuclear engineers in the United States (and one of the authors of the 1983 National Research Council report), wrote a dissent. He concluded that the methods of dose calculation "in Appendix C are not mathematically valid."[25] He concluded that the method adopted

> would introduce unjustified and unprecedented leniency in public health protection from radioactive waste.

and that

> probabilistic exposure scenario [in Appendix C of the National Research Council's 1995 report] will be perceived by many as a disguised means of reducing the calculated individual doses below the high values (ca. 10 rem per year) that were presented to the committee. **Better repository design is the proper means of obtaining low doses, not by nonscientific policy fixes**. **Policy makers must reject pressures for short-term expediency and economy, lest, by enacting policy that compromises scientific**

[23] Loehr, Nygaard, and Watson 1993
[24] NAS-NRC 1995, Appendix C.
[25] NAS-NRC 1995, Appendix E, p. 177.

> **validity and credibility, it undermines public confidence** and puts and end to all further nuclear development and research.[26]

In 2001, the EPA proposed a new standard that applied only to Yucca Mountain. Contrary to the advice of the National Research Council report of 1995, it limited the period of performance to 10,000 years.[27] This was invalidated in court and then the EPA proposed a revised draft standard in 2005.[28] That proposed standard was far more lax for the period from 10,000 to 1 million years than any radiation protection standard protecting today's population. At 350 millirem per year, the lifetime risk of fatal cancer to women would be as high as 1 in 62. Higher doses to some people were permitted. For a small minority, doses as high as 2 rem would be permitted leading to a lifetime fatal cancer risk of 1 in 10.[29]

The EPA published its final rule in 2008. It limits doses in the first 10,000 years to 15 millirem per year committed effective dose equivalent, and to 100 millirem per year in the 10,000 to 1 million year period.[30]

The State of Nevada has sued the EPA over these final standards.[31] It should be noted in this context that the courts have twice before invalidated EPA "final" rules in regard to deep geologic repositories. Further the NRC has also changed its rules. In the early stages, following the 1980 DOE EIS on geologic disposal it was assumed that the containers would be the main barrier for an initial period, such as 1,000 years, but that the geologic setting would perform the main job of preventing long-lived radionuclides from reaching the human environment.

In sum, after more than a quarter of a century of trying to come up with a standard that would apply to spent fuel disposal at a proposed repository (40 CFR 191 applies to spent fuel disposal but no repository is proposed to which it might apply and it does not apply to the only one that is proposed), the matter of a final standard is still unsettled in that it is under litigation. Without a final standard that is clear of court challenges, performance assessment must necessarily rest on guesses about what it might be; this is not a basis on which "reasonable assurance" of the technical feasibility of "safe disposal" can be given, for the simple reason that there is no accepted definition of safe in relation to Yucca Mountain as yet. This is the current situation even if it could be shown that Yucca Mountain could conform to postulated rather than actual settled dose limits.

And, as it happens, there is no reasonable assurance as yet that Yucca Mountain can meet the final standard that the EPA has now in place at 40 CFR 197.

---

[26] Pigford 1995, emphasis added.
[27] EPA 2001.
[28] EPA 2005
[29] Makhijani and Smith 2005. The original standard 40 CFR 191 has no specified public health protection beyond 10,000 years.
[30] EPA 2008
[31] Nevada v. EPA 2008 (State of Nevada v. Environmental Protection Agency (D.C. Cir., No. 08-1327, consolidated with No. 08-1345))

b. Evaluating performance

We will assume for the purpose of this section that the EPA standard for Yucca Mountain at 40 CFR 197 is the one against which "safe disposal" is to be judged as it concerns protection of future generations. In this limited context, a reasonable assurance of the technical feasibility of safe disposal at Yucca Mountain must show that there is a high probability that the standard will be met. This requires that the performance assessment that estimates the dose be generally accepted in the scientific community and that reasonable technical questions raised by experts on critical issues have been resolved. This is not the case with Yucca Mountain.

Analysis provided to the Nuclear Waste Technical Review Board indicates that the geologic setting of Yucca Mountain contributes essentially nothing to the performance of the site. This can be seen from the set of DOE graphs in Attachment A, which is a part of these comments. Specifically, Graph A, the first one in Attachment A, shows that in the absence of the container, a dose limit of 15 millirem would be greatly exceeded in much less than 10,000 years. Graph A shows that a 25 millirem per year dose limit, which was the norm against which the DOE was assessing compliance at the time, would be exceeded as soon as 2,000 years after closure and the peak dose would be on the order of 1,000 millirem well before 10,000 years. This is more than 60 times the EPA dose limit for the period less than 10,000 years. All of the other graphs show that if the container stays intact, the failure of another part of the overall system would not affect doses much in the first 10,000 years. (The peak dose beyond 10,000 years exceeds the limit in 40 CFR 197 in all cases in this set of DOE graphs – see below).

This puts a premium on the integrity of the container because it is the one element that would ensure compliance (according to the DOE model) in the period less than 10,000 years. This DOE conclusion that the container is practically the only barrier to the release of radioactivity has also been expressed before the Nuclear Waste Technical Review Board by an independent expert, Roger Staehle (also quoted above):

> The central question that we're all considering here is really the integrity of the container. So, whatever we're thinking about has to be directed toward the integrity of the container, because that's **the primary or virtually the only barrier to release of radioactivity**. [32]

As we have noted above, the question of whether the containers will endure for very long is, at best, an open one. There is clear evidence that they may corrode quickly relative to time scales required for assessing performance.

If they do corrode quickly, then the situation described in Graph A of Attachment A, that is, doses tens of times greater than the present final EPA standard prior to 10,000 years will prevail. The DOE itself has calculated doses for the repository that vary widely, indeed, wildly. For instance, the most recent estimate, in DOE's license application for the Yucca Mountain repository shows peak doses that would be more than 100 times

---

[32] Staehle 2004 p. 241.

lower than the final EPA standard of 100 millirem per year (beyond 10,000 years) discussed above.[33] But the peak doses shown in Attachment A (base case), prepared by the DOE for the NWTRB, are about an order of magnitude higher than the 100 millirem standard – that is, they are a thousand times bigger than the estimate in the DOE license applications. As another example, the DOE had estimated doses as high as 10 rem in a presentation to the National Research Council, or ten thousand times higher than the estimate in the license application (see Dr. Pigford's quote above). Finally, DOE's peak dose estimates in its 2002 Final Environmental Impact Statement for Yucca Mountain are also much higher than the 100 millirem per year dose to the maximally exposed individual. The Table below is reproduced from DOE's Final EIS for Yucca Mountain. Even the mean dose to the "reasonably maximally exposed person (RMEI)" is greater than 100 millirem. The 95 percentile dose for the "reasonably maximally exposed person" is far higher – 510 millirem. Should the population 18 kilometers from Yucca Mountain be in the thousands, many individuals would be expected to have doses considerably in excess of 500 millirem, since this value is a 95[th] percentile estimate. We note that even 30 kilometers away, where people live today, the 95 percentile peak dose is much greater than 100 millirem per year.

Table 5-12. Impacts for an individual from groundwater releases of radionuclides during 1 million years after repository closure for the lower-temperature repository operating mode.

Individual	Mean		95th-percentile	
	Peak annual individual dose (millirem)	Time of peak (years)	Peak annual individual dose (millirem)	Time of peak (years)
At RMEI location[a]	120[b]	480,000	510[c]	410,000
At 30 kilometers[d]	83[e]	NC[f]	350[e]	NC
At discharge location[g]	48[e]	NC	240[e]	NC

a. The RMEI location is approximately 18 kilometers (11 miles) downgradient from the repository.
b. Based on 300 simulations of total system performance, each using random samples of uncertain parameters.
c. Represents a value for which 285 out of the 300 simulations yielded a smaller value.
d. 30 kilometers = 19 miles.
e. Estimated using scale factors as described in Section 5.4.1.
f. NC = not calculated (peak time would be greater than time given for the RMEI location).
g. 60 kilometers (37 miles) at Franklin Lake Playa.

Source: "Chapter 5: Environmental Consequences of Long-Term Repository Performance," p. 5-29, in Volume I of *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, DOE/EIS-0250 (U.S. Department of Energy, February 2002), on the Web at http://www.ocrwm.doe.gov/documents/feis_a/vol_1/eis05_bm.pdf.

In sum, at the present juncture, it is impossible to say with any reasonable assurance what the radiation doses to the public from a Yucca Mountain repository would be. The DOE itself has in the last few years calculated doses that are different by a factor of 1,000, ranging from compliance to non-compliance. The DOE has dismissed the potential for severe corrosion due to deliquescence as insignificant. But that possibility cannot be ruled out on the basis of present scientific evidence. As discussed above, the DOE chose to disregard the advice of the NWTRB on this matter.

[33] DOE 2008, Table 2.4-2, p. 2.4-357.

This demonstrates that there is not enough scientific basis for "reasonable assurance" that waste can be disposed of at Yucca Mountain safely for the durations envisaged. On the contrary, the uncertainties continue to be high and the possibility that Yucca Mountain could suffer a complete failure (be "fatally flawed") cannot be reasonably excluded. The NRC does not assume that Yucca Mountain will be licensed. But its draft Finding 1 has not taken into account the data and analysis that indicate the potential that it may not meet EPA's standard and therefore cannot be any part of the basis for its Finding.

Another example throws considerable light on the issue. For decades it was assumed that salt was a suitable medium for high-level waste and spent fuel disposal. Salt sites were part of the DOE's first round set under the Nuclear Waste Policy Act (NWPA). Over the decades DOE has investigated several sites in salt formations. One of the top three sites that DOE selected for characterization for spent fuel disposal was a salt site (in Texas); the others were on federally controlled land in Washington State (the basalt site at Hanford) and Nevada (the volcanic tuff site at Yucca Mountain).[34] But now the NRC itself considers salt as unsuitable for spent fuel disposal. According to the draft waste confidence rule:

> Salt formations currently are being considered as hosts only for reprocessed nuclear materials because heat-generating waste, like spent nuclear fuel, exacerbates a process by which salt can rapidly deform. This process could potentially cause problems for keeping drifts stable and open during the operating period of a repository.[35]

The problem of salt being an inappropriate medium for spent fuel disposal is linked to a larger problem of waste confidence as it relates to assessment of the environmental impact from the licensing of reactors. This issue concerns the obsolescence and incorrectness of the governing regulation for reactor licensing, 10 CFR 51, which sets forth "environmental protection regulations applicable to NRC's domestic licensing and related regulatory functions."[36] It is connected to the Waste Confidence Rule and is discussed in Section C below.

The NRC also did not consider the third geologic formation that was in the DOE's top three: the basalt formation at the Hanford Washington site. Many serious defects of the site, including very serious problems in safety, were noted by one of the leading geologist in the United States, Donald E. White, who was a member of the National Research Council panel that wrote a report for the DOE on geologic isolation. In regard to safety Dr. White noted three "threatening effects" including "rock bursting," "costly and troublesome drainage problems" and the following:

> Construction of the repository at very high in-site temperatures, estimated by Rockwell to be 57°C but possibly considerably higher. Refrigeration on a scale seldom if ever attempted in world mining may be necessary. **The costs in time, money, energy, and lives of men are likely to be very high.**

---

[34] See Nevada timeline 1999
[35] NRC 2008, p. 59555.
[36] 10 CFR 51.1 2008

> **Even if each of the above [threatening effects] is individually tractable, all in combination may be intolerable.** More satisfactory alternatives probably can be found elsewhere.[37]

The DOE ignored this 1983 analysis and went ahead and selected basalt at Hanford as one of the top three sites it would characterize.

In the case of granite, the medium in which DOE hoped to find second repository locations for characterization, the DOE proceeded with a screening program that was so technically deficient that the ranking results were not credible. Essentially, the scoring system adopted by the DOE in its Delphi consultation gave zero weight to criteria for which no information was available. This made them equivalent to criteria which were "unimportant" or "judged to be poorly measured." In other words, if the DOE did not know anything about it then it could be ignored. As a result, the sites for which the least was known would tend be ranked higher than those about which there were more data and adverse as well as positive or partly positive characteristics could be evaluated. In other words, the DOE essentially used an "ignorance is bliss" approach to site ranking in order to determine which sites it would characterize."[38] The second repository program was abandoned in 1986.

We may also cite the example of France in regard to performance, which has the second largest number of reactors of any country in the world (after the United States) and which has a repository program that has been attempting to characterize a site. We have already noted that the program's research in regard to seals and thermal effects is deficient in certain critical aspects. We note here than ANDRA, the French agency charged with repository characterization and development, itself had found that doses would be greatly exceeded in the event of a seal failure. Calculated peak doses in that scenario due to chlorine-36 in Class B waste (the approximate equivalent of U.S. Greater Than Class C waste) would be 300 millirem per year and those from due to iodine-129 in spent fuel would be 1,500 millirem per year.[39] Both of these are greatly in excess of the French limit of 25 millirem per year and even of the more lax U.S. final EPA standard for Yucca Mountain of 100 millirem per year beyond 10,000 years.

These examples illustrate that it is essential to take into account the specific aspects of repository research that are important to assessing whether a given disposal system can perform to specified standards for health and environmental protection.

With the exception of salt sites, which the NRC itself rejects for spent fuel, the NRC has failed to take the specific scientific evidence about the U.S. repository program and the potential for it to meet performance, safety, and health criteria for protecting public health, worker safety, and the environment into account. By failing to examine the available evidence in regard to the elements of a repository system relevant to the United

[37] White 1983, p. 25, reprinted as an appendix to Makhijani and Tucker 1984, emphasis added.
[38] See Makhijani 1986
[39] ANDRA 2001, p. 139.

States, the NRC has not met the minimal requirements of a scientifically based analysis that is necessary to arrive at a conclusion that there is "reasonable assurance" that safe disposal of spent fuel in a repository is technically feasible.

We are not persuaded by the NRC appeal to the fact that 24 countries have repository programs..[40] The fact that all countries with nuclear power programs have to deal with the intractable problem of nuclear waste and have chosen to believe that disposing it of in deep underground will solve the problem is not a scientific demonstration of technical feasibility of safe disposal of nuclear spent fuel in a geologic repository. In its Waste Confidence Decision Update, the NRC has used information from other countries to argue the unexceptionable point that social and political factors are important. The fact remains that no country has a repository for spent fuel or even high-level waste disposal. Further, the NRC has not presented technical evidence from the many repository programs to show that there are enough data for each of the three elements described above – the waste and waste packages, the back fill and sealing system, and the near- and far-field environment – in these programs to come to a reasonable conclusion that each is sound and that they will function together as modeled with reasonable assurance. Nor has it presented any scientific analysis of how these programs are technically relevant to the specific conditions in the United States in terms of assisting the NRC's ability to buttress Finding 1 in regard to the three elements and the modeling of their functioning together.

By contrast, we have shown that the U.S. Yucca Mountain site may well not meet established radiation protection norms and may even be fatally flawed. The geologic setting is not likely to play a significant role in containment of radionuclides, even according to the DOE's own assessment. Among other things, the basalt site at Hanford presents severe safety issues, which the NRC did not address. The second round repository investigation for granite sites in the United States was a failure, for a variety of reasons.

IEER's detailed review of the French repository program research indicated that the research was significantly deficient in certain critical areas – seals and thermal perturbation modeling. And we have shown that ANDRA's own estimates of doses in case of failure of seals would result in doses that would greatly exceed both French and U.S. disposal standards. The NRC itself has deemed salt unsuitable for spent fuel. Yet it did not explore the implications of that conclusion for the Waste Confidence Decision Update or for its reactor licensing program (see Section C below). The NRC mentions that the German salt dome repository program at Gorleben was suspended "[a]fter decades of intense discussions and protests,"[41] but mentioned none of the adverse technical factors that made the choice of Gorleben controversial or the fatal accident that occurred in 1987.[42]

---

[40] NRC 2008, p. 59559.
[41] NRC 2008, p. 59559.
[42] For a discussion of some of the technical factors and the accident see Franke and Makhijani 1987.

3. Conclusions regarding Finding 1

In sum, in reiterating Finding 1, the NRC has not taken into account a mountain of data and analysis that are relevant to it that show that it is far from assured that safe disposal of spent fuel in a geologic respistory is technically feasible. The NRC has not met either of the criteria we set forth at the beginning of this section for assessing whether there was reasonable assurance that safe disposal is technically feasible. In the absence of data from a repository that has been sealed after spent fuel has actually been disposed of – and such data does not exist because no such repository exists – the NRC must provide data on and analysis of the major elements of a site that could be developed in the United States and show that the three elements required in any repository system would work together satisfactorily (i.e., meet radiation protection standards) and that such a repository could be safely built. The NRC has not done this. It has not evaluated the severe problems that the U.S. repository program has encountered and the many twists and turns that rules and regulations have taken as a result, notably with respect to Yucca Mountain. Indeed, the NRC has provided no scientific evidence in its Draft Decision that there is reasonable assurance in the scientific and statistical sense of the term that there is reasonable assurance safe disposal of spent fuel in a geologic repository is technically feasible.

In view of the above, we conclude that the NRC's Finding 1 should be modified. This is necessary on its own, but it is especially necessary in view of the fact that Finding 2 depends on Finding 1. We recommend that Finding 1 be modified to read:

1. While some of the elements of deep geologic disposal have been studied to a sufficient degree that they may be viable elements of a disposal system, an entire thermally and mechanically perturbed system has never been tested. The data on the individual elements of the perturbed and sealed system and for their combined functioning are not yet sufficient to determine the performance of a repository for safe spent fuel disposal with reasonable assurance.
2. The DOE has been pursuing study and characterization of repositories for decades and essential technical questions in relation to performance continue to be in doubt. Under some circumstances, the impact of disposing of spent fuel in a geologic repository could be significant.
3. Considerable further work remains to be done before there can be reasonable assurance that safe disposal of spent fuel and high-level waste in a deep geologic repository in the United States is technically feasible.

We have also concluded that a new generic environmental impact statement is needed to address the fundamental deficiencies of Table S-3. Licenses for new reactors and extension of licenses of existing reactors cannot be properly granted on the basis of the existing Table S-3.

B. Comments on Proposed Finding 2

The proposed Finding 2 states:

> The Commission finds reasonable assurance that sufficient mined geologic repository capacity can reasonably be expected to be available within 50–60 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of any reactor to dispose of the commercial HLW and spent fuel originating in such reactor and generated up to that time.[43]

The NRC has made an unwarranted leap from its "Finding 1"[44] that a geologic repository for disposal of high-level waste and spent fuel is technically feasible to the conclusion that there is "reasonable assurance" of the actual availability of a repository within 50 or 60 years beyond the operating license of any commercial reactor in the United States.

In order to proceed from a finding that a geologic repository is technically feasible to the conclusion that one will be available within a specified time frame (in this case ~100 to 150 years), at least three additional demonstration elements are necessary. First, it must be shown that the requisite work of finding, characterizing, licensing and developing an actual site suitable for disposal of the actual amounts of waste to be generated is possible within the stipulated time. Second, a demonstration of financial feasibility and reasonableness is needed. And thirdly, a demonstration of political and social acceptability is also necessary. We will consider this last question first.

1. Social and Political Acceptability

The NRC has provided a survey of various country programs in order to review the issue of social and political acceptability.[45] This survey itself shows that there can be no confidence that the necessary social and political conditions exist in the United States to provide any assurance that a repository can be developed in any foreseeable time frame. Second, the NRC's survey is partly inaccurate. Third, the NRC's survey is essentially incomplete in that it omits the country that is often held up as being exemplary for nuclear power – France.

We discuss the NRC's survey before proceeding to the specific discussion of the situation in the United States.

1. *United Kingdom:*

The NRC appears to believe that the United Kingdom had a repository program for high level waste and spent nuclear fuel in the 1990s. Specifically the draft rule states the following

[43] NRC 2008, p. 59561.
[44] NRC 2008, p. 59553. See below for comments on Finding 1.
[45] NRC 2008, pp. 59559-59561.

> In the United Kingdom, in 1997, an application for the construction of a rock characterization facility at Sellafield was rejected, leaving the country without a path forward for long-term management or disposal of HLW or SNF. In 1998, an inquiry by the UK House of Lords subsequently endorsed geologic disposal, but specified that public acceptance was required.[46]

The NRC appears to have its facts about the UK repository program wrong. According to a timeline and status report by Alan Hooper of Nirex, Britain's waste management company, the geological investigations for a high-level waste repository were short-lived; they did not involve an application for a rock characterization facility:

- 1976—The Royal Commission on Environmental Pollution (Flower's Report) recommended the creation of a National Waste Disposal Corporation.
- 1979—Start of program of geological investigations for HLW disposal.
- 1981—**Termination of the geological investigations and suspension of a decision on high-level waste disposal for 50 years.**
- 1982—Nuclear Industry Radioactive Waste Executive (NIREX) created to implement Government policy on intermediate-level waste (ILW) and low-level waste (LLW).
- …
- 1987—Abandonment of the near-surface program and adoption of new policy that all ILW and LLW should go deep…; new deep site selection process started.
- …
- 1991—Nirex decides to focus investigations on Sellafield in Cumbria.
- 1992—Nirex announces plans for a Rock Characterisation Facility (RCF) at Sellafield; the plans were eventually considered at a public inquiry which ended in 1996.
- 1997—Decision by Government not to allow Nirex to proceed with the RCF, thus terminating the UK's siting program.[47]

As can be seen, the UK terminated its HLW geologic disposal investigations in 1981. The rock characterization facility to which the NRC refers was for Intermediate Level Waste (similar to Greater Than Class C waste in the United States), which is also mandated for deep geologic disposal. However, the geologic requirements for disposal of ILW are much less stringent than for high-level waste or spent fuel, because the characteristics of these wastes are very different. For instance, the specific activity of high-level waste and spent fuel is generally much higher, as is the heat generation.

The UK formed a Committee on Radioactive Waste Management as a vehicle for public consultation and exploration of the issue of long-term waste management. As the NRC

---

[46] NRC 2008, p. 29559.
[47] Hooper 2006, pp. 249- 250. Emphasis added.

noted, the most recent evidence is that this is also failing. According to the draft waste confidence rule:

> This [program] led to the initiation of a national public consultation, and major structural reorganization within the UK program. In 2007, the Scottish Government officially rejected any further consultation with the UK Government on deep geologic disposal of HLW and SNF. Discussions may continue on issues of interim storage only. This action by the Scottish Government effectively ends more than 7 years of consultations with stakeholders from communities near Scottish nuclear installations and represents another major setback for the UK program.[48]

Actually, the Scottish government press release does not mention high-level waste or spent nuclear fuel explicitly, but "higher activity" waste,[49] which includes intermediate level waste in the UK. In point of fact, the UK has no active repository program that is looking at a specific site for high-level waste or spent nuclear fuel and has not had any since 1981.

In other words, even though British nuclear waste authorities may believe that a repository is technically feasible, the program is at a dead end and only interim storage is on the table. So far the public consultation program has failed to elicit any progress towards a high-level waste repository. In the meantime, the decommissioning and clean-up of its main reprocessing site (Sellafield) is estimated to take more than 100 years and costs have skyrocketed to 73 billion pounds (roughly $100 billion).[50] While Sellafield was born as a nuclear weapons materials production site, most of the work there and most of the waste there has been generated in the past few decades from reprocessing of British and (more recently) foreign spent fuel. These costs do not include waste disposal or repository development costs.

2. *Germany*

The German repository program began investigating a salt dome at Gorleben in 1977. Major construction and characterization activities were carried out. The NRC described its status as follows:

> After decades of intense discussions and protests, an agreement was reached in 2000 between the utilities and the government to suspend exploration of Gorleben for at least three, and at most, ten years. In 2003, the Federal Ministry for the Environment set up an interdisciplinary expert group to identify, with public participation, criteria for selecting new candidate sites.[51]

There is as yet no specific site being characterized. After more than three decades, the program is moribund.

---

[48] NRC 2008, p. 59559.
[49] Scottish Government 2007
[50] Irish Times 2008
[51] NRC 2008, p. 59559-59560.

3. Switzerland

The Swiss have done a quarter century of geologic repository research. In 1998, the Swiss was authorities found that a repository was technically feasible and that it has been successfully demonstrated, the repository was rejected in a referendum in the canton.[52] The Swiss authorities have no firm date for the opening of a repository, but, according to the NRC, they "do not expect [that] a deep geologic repository will be available in their country before 2040."

4. Canada

An independent commission, empanelled by the Canadian government found in 1998 that a geologic repository was technically feasible and that the concept had been sufficiently demonstrated. Yet, public acceptance is not assured. Canadian law requires public consultation. In 2007, Canada adopted an approach of public consultation with communities, which will supposedly be "community-driven" and "collaborative." No site has been selected as yet for characterization. The authorities recognize that the process will take time. According to the NRC, the Canadian waste authority "*assumes* the availability of a deep geological repository in 2035"[53] An assumption is clearly not the same as a reasonable assurance. It simply allows financial calculations to be made. Given that the authorities are still on square-one in regard to public acceptance after 37 years of implementing a program and considerably more than that of nuclear reactor experience, the date of 2035 can only be considered notional. It is not based on an actual program of characterization on the ground or the acceptance of a particular community located at a specific site.

5. Finland

Finland is the only country with an active nuclear power program and an active repository program where the host community government has approved of the repository site and agreed to host it. The opening of the deep repository is expected in 2020.[54]

6. Sweden

Two municipalities in Sweden have agreed to be potential hosts of a geologic repository and an application for repository development is estimated to be filed in 2009.[55] However, it should be noted that Sweden has had a national moratorium on the construction of new nuclear power plants.[56] Therefore, its entire public consultation process has been carried out in the context that the waste stream would be limited to that

---

[52] NRC 2008, p. 59560.
[53] Both quotes are from NRC 2008, p. 59560, italics added.
[54] NRC 2008, p. 59560.
[55] NRC 2008, p. 59560.
[56] Lundqvist 2006 p. 227

from its existing reactor fleet. It is an open question whether public acceptability would be forthcoming should Sweden reconsider its moratorium and rescind it.

7. *France*

The NRC has described the above six cases as part of its discussion of Finding 2 and the proposed update of this finding. It is interesting that the NRC did not discuss the French program (other than a passing mention in a footnote). In fact, the French program has faced serious public opposition and its history is somewhat similar to the one in the United States. The original intent was to characterize more than one site. Only one site, in north-eastern France is being characterized. It has faced considerable local opposition. The selection of a second site (in western France) for characterization was abandoned after serious public opposition.[57] The French appear to be as averse to having high-level nuclear waste in their backyards as people in other countries. Further, as noted above, there are serious technical questions about how ANDRA, the French nuclear waste agency, is proceeding to characterize the site and whether the results will be adequate to provide a satisfactory scientific basis for performance assessment. In other words, the public's skepticism about official technical work may not be misplaced, contrary to the NRC's implication that public and political non-acceptance of a geologic repository is somehow not based in science.[58]

2. Political and Social Acceptance Issues in the United States

Political and social acceptance is as essential in a democracy as technical feasibility. We have already discussed that the NRC has not provided the basis for its finding that there is reasonable assurance that a repository is technically feasible. We discuss here the social and political aspects of feasibility, which are also important for estimating a schedule. The NRC now acknowledges that in developing a repository schedule:

> The Commission's proposed revision of Finding 2 is based on its assessment not only of our understanding of the technical issues involved, but also **predictions of the time needed** to bring about the necessary societal and political acceptance for a repository site.[59]

The U.S. program has been beset with difficulties that are well known. Some of them are described in the discussion of the proposed update to the NRC's waste confidence findings. Some others have been discussed above. The failure of the second repository program provides another example. It was, in large measure, due to public opposition; but at least some of that opposition was technically well-founded since there were many technical problems with the approach that the DOE used to select the sites in its Draft

[57] CNE 2001, pp. 53-55.

[58] The proposed waste confidence rule states "International developments have made clear that technical experience and confidence in geologic disposal, on their own, have not sufficed to bring about the broader societal and political acceptance needed to realize the authorization of a single national repository." NRC 2008, p. 59559.

[59] NRC 2008, p. 59561, emphasis added.

Area Recommendation Report. (An unscientific element in the DOE's approach to site ranking, an essential technical element of site section, is briefly discussed above as an example of the problems in the report). The narrowing of site characterization to one site in Nevada was also political. As discussed above and below, the Yucca Mountain site has characteristics that make it unsuitable for a repository. But in the present context of a discussion of the proposed revision to Finding 2, it is sufficient to note that the State of Nevada and its representatives have been vigorously opposed to it on a bipartisan basis. Further, the political position of those representatives is considerably stronger today than it was when the 1987 amendments to the 1982 Nuclear Waste Policy Act (NWPA) were passed. Senator Harry Reid of Nevada is now Majority Leader of the U.S. Senate.

The Yucca Mountain Project also faces serious budgetary constraints. DOE's announced timetable of an opening by 2020 is contingent on Congressional appropriations. There is no basis in present political reality to assume that the DOE would get what it wants for site development. The United States program is also mired in litigation. Though a final EPA standard has been issued, it is not a given that it will hold up in the courts or that the Yucca Mountain site can meet the limits that the EPA has set.

The vigorous opposition of the people of Nevada and also of many along the transportation routes to Nevada is a fact that does not bode well for the eventual operation of the Yucca Mountain repository. Only one repository program is proceeding with a specific site where a repository may be assumed to open with reasonable assurance. That is the Finnish program, which was undertaken with both national and local approval. There is no other repository program that is on a road that would allow a conclusion that a repository would open with "reasonable assurance." Indeed, the NRC's revision of Finding 2 is not now dependent on the opening of Yucca Mountain, but on the opening of some repository within 50 to 60 years of the termination of the license of any operating reactor.[60]

We now have a President of the United States who is on the record as having stated that the Yucca Mountain site is unsuitable. President Obama has written:

> I want every Nevadan to know that I have always opposed using Yucca Mountain as a nuclear waste repository, and I want to explain the many reasons why I've held that view.
>
> In my state of Illinois, we have faced our own issues of nuclear waste management. There are some who believe that Illinois should serve as a repository for nuclear waste from other states. My view on this subject was made clear in a 2006 letter to Sen. Pete Domenici, who at the time was chairman of the Senate Energy Committee. "States should not be unfairly burdened with waste from other states," I wrote. "Every state should be afforded the opportunity to chart a course that addresses its own interim waste storage in a manner that makes sense for that state."
>
> That is a position I hold to this day when it comes to both Illinois and Nevada.

---

[60] NRC 2008, p. 59558 and p. 59561.

> After spending billions of dollars on the Yucca Mountain Project, there are still significant questions about whether nuclear waste can be safely stored there. I believe a better short-term solution is to store nuclear waste on-site at the reactors where it is produced, or at a designated facility in the state where it is produced, until we find a safe, long-term disposal solution that is based on sound science.
>
> In the meantime, I believe all spending on Yucca Mountain should be redirected to other uses, such as improving the safety and security of spent fuel at plant sites around the country and exploring other long-term disposal options.[61]

But if Yucca Mountain fails, it is not at all evident that a second program could be successfully put into place, as the NRC assumes. Besides the repeated delays, cost overruns, and technical problems that have plagued the Yucca Mountain program, there are other historical facts that need to be taken into account here. For instance, the DOE's Nuclear Waste Negotiator program, which aimed to find a community by consent, was eventually a failure. President George H.W. Bush appointed David H. Leroy as the Nuclear Waste Negotiator in 1990.[62]

Some attempts to locate a "temporary storage" facility at Native American reservations failed outright. The Private Fuel Storage proposed for Goshute reservation in Utah has also essentially failed, despite approval by the NRC, because of state opposition and opposition of people within the Goshute tribe to a tribal council decision to host it. A legal challenge remains.[63] It is highly unlikely that PFS will get to use the license that the NRC has granted it.

There is nothing in the history of the U.S. high-level waste program, from the first characterization program near the Lyons, Kansas, site in the 1960s to the Yucca Mountain site in 2009, that encourages the view that a repository would gain state approval. In its discussion of Finding 2, the NRC itself has acknowledged that "technical experience and confidence" are not enough to create a successful repository program:

> It is important to note, however, that broader institutional issues have emerged since 1990 that bear on the time it takes to implement geologic disposal. International developments have made clear that technical experience and confidence in geologic disposal, on their own, have not sufficed to bring about the broader societal and political acceptance needed to realize the authorization of a single national repository.[64]

---

[61] Obama 2007
[62] Wald 1991
[63] Two agencies of the Department of the Interior have issued decisions effectively ending the proposed Private Fuel Storage facility. See BIA 2006 and BLM 2006. Discussion of the opposition to the PFS in Nevada can be found at http://deseretnews.com/article/content/mobile/1,5620,645199671,00.html?printView=true and at http://healutah.org/nuclearutah/waste/pfs, among other sources. Not all challenges have ended. In July 2007, Private Fuel Storage made a claim against the Department of the Interior, hoping to reverse the decision. See NRC 2008, p. 59566 (footnote 24) – the claim has not been settled.
[64] NRC 2008, p. 59559.

The entire history of the program, from Lyons Kansas, to the second round repository sites, to PFS, to the continuing legal, technical, and political challenges to Yucca Mountain, including now from the President of the United States, lends support to the view that both state and local consent are necessary (and consent of the people and governments of the tribes in the case of Native Americans) in the United States to the opening of a spent fuel repository.[65] With this history and with the strong U.S. tradition of state political prerogatives and rights, a statement that there is "reasonable assurance" that a repository would open in the foreseeable future without both state and local consent is unwarranted and unjustified. This conclusion would stand even if Yucca Mountain were a technically suitable site. And, as discussed above, there are many indications that Yucca Mountain is not a technically suitable site.

Yucca Mountain could not even accommodate spent fuel from existing reactors without new legislation, much less spent fuel from any new reactors that might be built. A second repository would also require new legislation and, as the proposed update acknowledges, it may require new NRC regulations.[66] There needs to be reasonable assurance that workable legislation would be passed before the NRC can conclude that there is "reasonable assurance" that a repository will be available in some general time frame. To fail to provide a basis for assuming that there would be such legislation is to fail to provide a satisfactory basis for the central claim in the proposed Finding 2.

The NRC stated in its Draft Waste Confidence rule that its revision of Finding 2 is based in part on "**predictions of the time needed** to bring about the necessary societal and political acceptance for a repository site."[67] But the NRC has not provided any political, historical, legislative, or social fact, much less an analysis, to support its prediction that that there will be sufficient political or societal support for a repository by 50 to 60 years after the license of any reactor has expired. Under the present circumstances, with opposition from the President of the United States and from the Majority Leader of the U.S. Senate, it is reasonable to conclude that the Yucca Mountain project will sputter along with inadequate funds or be ended entirely.

In the absence of action to lift the 70,000 metric ton cap, legislation to authorize a second repository is needed. Moreover, such legislation should be workable. The history of nuclear waste programs around the world indicates that state, local, and (when applicable) tribal consent is one essential ingredient of a successful program (though by no means the only one). Further, the federal government must be of one mind in pursuing the project over a long period of time. The history of the NWPA shows that not one of these societal and political conditions has been met. There is no indication in political reality that they will be met. The history of the second repository, which was abandoned in 1986, and the Nuclear Waste Negotiator program also points in the same direction.

---

[65] This does not mean state and local support would be sufficient; it is just one necessary condition. Technical, legal, environmental and health criteria also needed to be satisfied.
[66] See footnote 3, NRC 2008, p. 59555.
[67] NRC 2008, p. 59561, emphasis added.

Even though it recognizes the important of social and political factors, the NRC proposes to find that there is reasonable assurance that there will be a repository any underlying legislative or political feasibility analysis. In effect, the NRC is assuming that the Executive Branch of government can confront the Legislative Branch with a *fait accompli* of granting license extensions to existing reactor licensees and licenses to new applicants. The implicit assumption is that Congress must then act to create a repository program that will accommodate all the waste and that new legislation will actually result in a repository.

The NRC apparently recognizes the weakness of its position regarding Finding 2 in that it explicitly solicits comment as to whether it should find instead that storage on site is safe "until a disposal facility can reasonably be expected to be available."[68] There is even less reasonableness in punting to the indefinite future, when the uncertainties and risks become greater. A large part of the very notion of spent fuel disposal is that it is far too risky to leave spent fuel lying around at dozens of sites for the indefinite future. This matter cannot be settled within the framework of dates or simply indefinite deferral of decisions. After repeatedly incorrect Waste Confidence Decisions regarding reasonable assurance of repository availability, the reasonable thing now is to do an Environmental Impact Statement that properly considers all the alternatives. This is necessary in any case, since a large part of the environmental impact evaluation done in the reactor licensing process is either obsolete or wrong or both (see below).

3. Financial considerations

There is also no fiscal or economic basis for concluding that there is a reasonable assurance that a repository will be available. The Nuclear Waste Policy Act requires nuclear utilities to collect 0.1 cents per kilowatt-hour from ratepayers and provide them to the federal government for spent fuel disposal in a repository. Annual nuclear electricity generation was about 787 billion kWh in 2006,[69] making that year's contribution to the Nuclear Waste Fund of about 787 million dollars. About 56,000 metric tons of spent fuel have already been generated as of April 2008. The figure is expected to rise to 119,000 metric tons by 2035.[70] However, reactor relicensing is continuing so this quantity is likely to increase, for instance, if nearly all operating reactors are relicensed.

In addition, the geologic repository must also accommodate Department of Energy reprocessing high-level waste disposal. As discussed above, it is highly unlikely that the 70,000 metric ton cap for the Yucca Mountain site will be lifted by Congress. The financial consequences of these facts must be taken into account in any waste confidence ruling dealing with both existing and new reactors.

The DOE's cost estimate for Yucca Mountain has escalated from about 57.5 billion dollars in 2001 to 96 billion dollars in 2008 for a variety of reasons, including more waste

---

[68] NRC 2008, p. 59561.
[69] Data from the U.S. Energy Information Administration (DOE EIA 2009)
[70] DOE OCRWM 2008.

and inflation.[71] This estimate is based on a smooth functioning of the program from here on out. This is highly unlikely given that program funds are highly likely to be cut, if it is not terminated altogether. It would be prudent and reasonable to assume that the costs of Yucca Mountain likely to be well over $100 billion, if it opens. At 0.1 cent per kWh, and 90 percent capacity factor for 60 years, the present U.S. reactor fleet will generate about $50 billion in revenue.[72] Moreover, this revenue is in current dollars, since the fee is not adjusted for inflation. But the costs are subject to inflation, one reason that they keep going up with every delay. Note that the cost estimate of $96 billion is in constant 2007 dollars. While there is some additional revenue from DOE defense high-level waste and some revenue from interest, this is unlikely to keep pace with rising costs.

It is not reasonable to assume that the present 0.1 cent per kWh fee will suffice to pay for the U.S. repository program. Further, given the political and legislative situation and the history of Nevada's opposition to Yucca Mountain, it is not reasonable to assume that the 70,000 metric ton cap will be lifted. Hence a second repository may well be necessary to accommodate spent fuel from existing reactors, and the problem will be worse if most or all of the reactors are relicensed. This would be true even if no new reactors are built.

There is at present no way to estimate the costs of a second repository, since the cost escalations for the first have been large and the program may fail altogether for one or more of a variety of reasons. In the interim, governmental liabilities for failing to meet its statutory deadline for beginning the process of taking ownership and disposing of the spent fuel are mounting. With no reasonable date for Yucca Mountain or a second repository in sight, the government's liabilities may become huge and must be taken into account in the overall cost of spent fuel storage and disposal. The penalty costs cannot at present be charged to ratepayers, since the government is in contractual default. The costs are nonetheless real to the people of the United States as a whole and much of the money is coming from ratepayers via federal taxes, and the rest from other taxpayers who are not now consuming nuclear electricity.

The NRC needs to address the financial uncertainties, legislative difficulties, and other political and social problems in making its estimate of the time in which a repository might become available. While political situations are subject to change, there is nothing in the past that encourages the view that it is becoming easier to find political acceptance for a repository in any part of the country.

In view of the above, the Institute for Energy and Environmental Research makes the following recommendations regarding the update of Finding 2. This finding should be change to explicitly state that:

1. It is far from assured that a second repository site can be successfully opened in the United States without the acceptance of the host state and local community.

[71] DOE 2008b

[72] Some of this has already been generated, of course, since ratepayers have been paying into the fund for the past quarter of a century.

Such acceptance may or may not be forthcoming. The history of the U.S. repository program is not encouraging in this regard.

2. It is far from assured that the cap of 70,000 metric tons of heavy metal that is imposed by the Nuclear Waste Policy Act will be lifted.
3. In view of 1 and 2 above, commercial nuclear reactor licensees should make financial, security, and technical provisions for indefinite, secure, and hardened storage of spent fuel at reactor sites. These provisions should include infrastructure for transferring spent fuel bundles from one dry cask to another.
4. In view of 1, 2, and 3 above a generic EIS on spent fuel management and disposal including the alternatives mentioned above needs to be prepared, along with cost estimates and estimates of comparative security risks.

C. Requirements for a Generic Environmental Impact Statement on Spent Fuel Waste Confidence

The Waste Confidence Decision Update is being proposed in the context of NRC relicensing reactors in the existing fleet and of the applications for licenses for new reactors that it is considering. This update has major implications for safety and environmental impact. It will commit generations far into the future to potential harm if the NRC does not properly consider all relevant aspects of "safe disposal" and of environmental and health impacts of the wastes and radioactivity releases associated with reactor operations.

1. Need for a Generic EIS on Waste and Reactor-Related Emissions

As set forth in Section A above, the NRC has not presented a scientific analysis to support its claim that there is "reasonable assurance" that "safe disposal" of spent fuel in a geologic repository is "technically feasible" (Finding 1) or that it can be opened within the time frame set forth in the proposed revision of Finding 2. On the contrary, it far from assured that such safe disposal is technically feasible. It is important to note in this context that the prior Commission bases, on which its earlier findings were based, have been invalidated by experience, time, and new scientific understandings, many of which have been discussed above. Consider Yucca Mountain, which should provide the strongest case for a technical feasibility determination. Deadlines have repeatedly slipped. New data on corrosion have emerged. Some experts have deemed this site as inadequate and even "fatally flawed.' Most of the DOE dose estimates made since 1990 show exposures in excess of the current EPA standard of 100 millirem beyond 10,000 years. As a result, there is considerable scientific basis to doubt that Yucca Mountain is a suitable repository or that it should be licensed. We have discussed a critical problem with DOE's license application in that it sidestepped a key recommendation of the NWTRB by declaring it insignificant. There is also no real basis to estimate a future time, either as a date or in relation to expiry of reactor licenses, when there can be reasonable assurance that a repository can be opened.

The escalation of costs without an actual result in the form of a repository as well as the escalation of penalties for the government's failure to begin disposing of existing wastes is causing waste management costs to escalate well beyond what was projected when the program was put into place. There is no clear current cost estimate of what it will cost to dispose of all the spent fuel currently scheduled to be produced from existing licenses and license extensions that have already been granted. This means that it is impossible to make a reasonable comparison with alternatives methods of electricity production that do no involve the creation of long-lived radioactive waste such as spent fuel and Greater Than Class C waste and depleted uranium.

In view of these facts, it is essential for the NRC to prepare a thorough generic environmental impact statement on spent fuel that would be generated by new reactors as well as from relicensing of existing reactors.

The NRC also needs a current and coherent analysis of the health impacts of the nuclear waste that will be created incident to the licensing of new nuclear plants and re-licensing of existing nuclear plants. The need for such a statement is further demonstrated by the fact that much of the basis for the assessment of the environmental impacts of reactor operation, which is part of the reactor licensing process, is obsolete and/or wrong. Specifically, Table S-3 at 10 CFR 51.51, is obsolete or incorrect in many respects, especially in regard to assumptions about the impacts of disposal of spent fuel, Greater than Class C Waste, Depleted Uranium as well as about other impacts (see below). Since the NRC is now engaged in a sweeping process, via relicensing existing reactors and considering new reactor licensees, to allow the creation of vast amounts of new waste, a generic EIS is needed.

Finally, the prior EIS on geologic disposal, prepared by the DOE is, like Table S-3, hopelessly out of date and also incorrect in essential parts about its estimates of environmental and health impacts.

No pre-existing EIS, already prepared by the NRC or the U.S. Department of Energy ("DOE"), is sufficient to support the Waste Confidence Decision. For instance, the EIS prepared by the DOE in 1980 is insufficient in scope and grossly out of date. As one example, the DOE EIS does not anticipate any releases from a properly constructed repository in the absence of extraordinary and rare events. In fact, it stated that:there was "every expectation that long-term radiological impacts will be nonexistent."[73] As discussed at length above, this is contrary to present understanding of any medium but salt, which the NRC itself now says is unsuitable for spent fuel disposal.

As another example, the DOE did not even examine a repository in tuff, which is the rock at Yucca Mountain and has been the only repository being characterized since 1987. It was written before there was an adequate understanding of the complexities of the three elements of the disposal system, discussed above in Section A, and the difficulties of estimating their joint performance. For instance, at the time, containers were expected to perform the role of a barrier for the early period of disposal, while the geologic system would take care of the long-term:

---

[73] DOE 1980, p. 5.72. The DOE only considered long-term radiological releases in case of improbable events such as meteorite impacts

> 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 millenia [sic] 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 1,000 years…[74]

It is clear that when DOE prepared this EIS in 1980, engineered barriers, including containers, were not expected to fulfill the main long-term function of containment for 10,000 years or more. But the NRC now only requires only an overall performance assessment which combines the performance of all elements together and does not put any sublimits on the performance of any particular element. As we have noted in Section A, in the case of Yucca Mountain, the essential performance burden in the sense of compliance with regulations rests with the containers. Indeed, the NRC's rules in this regard have also changed since the DOE's EIS was issued. The NRC's first rules corresponded more to the DOE's EIS concept that engineered barriers were to contain the waste in an initial period with the geology taking up the function after that. Those rules, which apply to geologic repositories to be licensed by the NRC, are at 10 CFR 60, but they Yucca Mountain was exempted from them, just as it was exempted from 40 CFR 191, Subpart B, which applies to all other repositories. 10 CFR 63, which requires only a combined performance assessment, was promulgated specially for Yucca Mountain.

Finally, a central part of licensing of new reactors and of the relicensing of existing reactors is as it concerns light water reactors (that is, all licensed power reactors in the United States) is the requirement that the license applicant prepare an Environmental Report that addresses:

> Table S-3, Table of Uranium Fuel Cycle Environmental Data, as the basis for evaluating the contribution of the environmental effects of uranium mining and milling, the production of uranium hexafluoride, isotopic enrichment, fuel fabrication, reprocessing of irradiated fuel, transportation of radioactive materials, and management of low level wastes and high level wastes related to uranium fuel cycle activities to the environmental costs of licensing the nuclear power reactor.[75]

In the sections below we show that Table S-3 is obsolete and incorrect in a number of critical areas and needs revision, correction, and updating.[76] Since this is the main vehicle for assessing the environmental impacts of nuclear energy, a revision of this table and of the corresponding parts of 10 CFR 51, needs to be a part of the generic EIS on waste and the environmental impacts of nuclear energy.

---

[74] DOE 1980, p. 5.1

[75] 10 CFR 51.51(e) 2008. [N.B.: formerly 51.20(e) 1984]

[76] The comments below on Table S-3 apply as well to Table S-3A, which is in WASH-1248 and provides more detail for Table S-3, when applicable.

2. Solid high-level waste and spent fuel disposal impacts

This requirement applies to "any applicant's environmental report submitted on September 4, 1979, or thereafter."[77] In regard to high-level waste or spent fuel, Table S-3 purports to provide environmental impacts that "are maximized to either of the two fuel cycles (uranium only and no recycle)."[78] While this purports to be the maximum impact from spent fuel disposal (either with or without reprocessing), the claim is either wrong, obsolete, or both.

First, the Nuclear Waste Policy Act envisions disposal of spent fuel. The reprocessing impact calculations are therefore irrelevant for present licensing and environmental impact considerations. Second, the Statements of Consideration associated with the promulgation of the final rule effective on September 4, 1979, explain the regulation note the following in regard to storage and disposal as follows:

> In determining the impacts associated with waste management and disposal, the [Nuclear Regulatory Commission] staff assumed that high-level waste (or reactor spent fuel treated as waste) would be stored in interim facilities (water basins and retrievable surface storage facilities) for about twenty years and then disposed of by burial in a bedded salt repository.[79]

In a footnote to this passage, the NRC noted that the original rulemaking had not extensively covered deep geologic disposal but subsequent work, published in NUREG-0116 has remedied that problem:

> …NUREG-0116, Section 4.4, provides a 30-page quantitative discussion of disposal of long-lived wastes in a bedded salt repository, with citations to many relevant technical documents prepared since 1973. [80]

Thus, in 1979, the NRC had considered bedded salt as suitable for disposal either of reprocessed high-level waste or unreprocessed spent fuel. Yet, the draft waste confidence rule of 2008 states that salt formations are not being considered for spent fuel disposal for technical reasons (see quote above). Hence, Table S-3 is completely outdated and inappropriate according to current law, which requires spent fuel disposal, and the NRC's own understanding of salt repositories.

To wit, disposal in salt, which is the basis for estimating the environmental impact of high-level waste or spent fuel disposal, is only considered suitable for high-level waste resulting from reprocessing, but reprocessing is not the current policy. Rather, direct disposal of spent fuel, for which the NRC would not consider salt formation, is now the current policy.

---

[77] 10 CFR 51.51(e) 2008.
[78] 10 CFR 51.51 2008, Table S-3, Footnote 1. Uranium only means a reprocessing cycle in which only the recovered uranium is reused as a fuel.
[79] NRC 1979
[80] NRC 1979, footnote 19

Moreover, Table S-3 assumes that there will be no releases whatsoever from solid high-level waste disposal.[81] According to WASH-1248, which is the underlying document developed for promulgating the rule:

> The most significant solid radiological waste consists of the fission products separated from the spent fuel of an annual fuel requirement in the reprocessing operation. These high level wastes will be stored onsite for a maximum of 10 yrs., and will ultimately be shipped, probably by rail, to a Retrievable Surface Storage Facility (RSSF). The RSSF will be established to store and manage high level solid wastes under constant surveillance for up to 100 years, or until such time as a more permanent Federal repository can be established. The facility will be designed to prevent the release of significant amounts of radioactive material to the environment under all credible environmental conditions and human actions. *Therefore, such waste will not be released as effluents to the environment.*[82]

The same assumption of essentially zero release and zero impact has evidently been applied to spent fuel as well. The NRC's 1981 background information on Table S-3 affirms this as well:

> It has been assumed that a geologic repository will be designed and operated so as to retain solid radioactive waste indefinitely.[83]

And again:

> The high-level radioactive waste from the once-through fuel cycle is the spent fuel assemblies, which will be packaged and disposed of in a geologic repository. The radioactive waste from the uranium-only recycle option consists of the fuel assembly hulls, the high-level and intermediate-level wastes from reprocessing, and the plutonium waste. These wastes will be disposed of in a geologic repository in the form of solids which will have chemical and physical properties that mitigate the release of radionuclides to the environs. It is assumed that *the geologic repository will be designed and operated so that the solid radioactive wastes are confined indefinitely.*[84]

Table S-3 does not show any releases from a deep geologic repository though ten million curies per reactor-year would be disposed of. Nor are any adverse health impacts estimated. Of course, these are implicitly zero as well, corresponding to the assumed zero release of radionuclides from the repository.

---

[81] Table S-3 was revised in 1979 when 10 CFR 51 was promulgated. It has not been changed since. The references to Table S-3 are from 10 CFR 51 as it currently stands and to Table S-3A in so far as it is compatible with the present Table S-3.
[82] WASH-1248, p. S-23, italics added.
[83] NRC 1981
[84] NRC 1981, p. 13, italics added.

In 1983, the Supreme Court affirmed the reasonableness of the zero releases assumed in Table S-3 (BG&E v. NRDC, 462 U.S. 87). This decision was rendered in the context of the assumption of disposal of reprocessing high-level waste or spent fuel in a bedded salt repository. As noted above, the assumption of disposal of reprocessing waste from commercial spent fuel is obsolete; current law requires disposal of spent fuel. There is no commercial reprocessing facility in the United States. The assumption of disposal of spent fuel in salt has been is no longer scientifically supportable due to the thermo-mechanical properties of salt. The NRC itself has concluded that only reprocessing high-level waste is suitable for disposal in salt. Further, the assumption of zero release of radioactivity due to disposal of spent fuel is contrary to the established scientific understanding of the expected performance of all other geologic settings. For instance, all of the DOE documents cited above as well as the graphs shown in Attachment A to these comments show positive doses due to disposal of spent fuel in Yucca Mountain. Of course, positive doses can only be the result of positive releases of radionuclides into the human environment. As far back as 1983, the report on geologic isolation prepared for the DOE by the National Research Council concluded that radiation doses would be positive doses for spent fuel and high level reprocessing waste disposal in all settings other than salt that were evaluated – tuff, granite, and basalt.[85]

The Supreme Court's 1983 finding that an assumption of zero release from high-level waste or spent fuel disposal has therefore been rendered obsolete by the combination of following three considerations:

1. The Nuclear Waste Policy Act requires the disposal of waste from commercial nuclear power plants in the form of spent fuel rather than reprocessing waste.
2. Spent fuel cannot be safely disposed of in a salt repository, as acknowledged by the NRC (see above)
3. All other repository settings are now acknowledged to have some releases of radioactivity.

10 CFR 51 therefore is no longer valid and as the basis for determining the environmental performance of nuclear power plants so far as releases from spent fuel are concerned. As a result it does not provide a satisfactory basis for licensing new nuclear power plants or relicensing existing ones. It also does not provide the basis for confidence that a suitable repository will be available that will keep the environmental impacts within the limits assumed by Table S-3.

Instead of addressing the substantive issues that it faces in regard to waste confidence in the licensing of new reactors or the relicensing of existing reactors under the technical and legal conditions that exist today, the NRC has wrongly assumed the problem away in its draft waste confidence findings by implicitly assuming that Table S-3 is still valid. A new and valid estimate of the set of environmental impacts from high-level waste and

[85] NAS-NRC 1983, Chapter 9. Estimates of doses from spent fuel disposal are only presented for basalt along with the statement that the conclusions for basalt "will apply as well to the other repository media." p. 282.

spent fuel disposal is evidently needed as part of any waste confidence rule. A generic environmental impact statement is needed in order to establish the basis on which new reactors can be licensed or existing reactors can be relicensed.

We note here that there are other parts of Table S-3 that is obsolete or wrong or both that do not concern high-level waste or spent fuel, but relate to the impacts from other parts of the fuel cycle. These also needed to be covered in the new, generic environmental impact statement. Some additional requirements for revision of Table S-3 are discussed in below.

As noted above, Table S-3 is either incorrect or obsolete or both in regard to high-level waste and spent fuel disposal in a geologic repository. There are other ways in which these tables do not properly or adequately assess the impact of wastes and effluents associated with nuclear reactor operation. A thorough revision of these tables and the associated analysis is necessary to correct them and to assess the environmental impact from relicensing existing commercial reactors or licensing new reactors, both of which will result in the generation of large amounts of new waste and radioactivity. We will first cover the ways in which Table S-3 is deficient in matters other than high-level waste and spent nuclear fuel disposal. Then we will provide recommendations for the scope of the generic environmental impact statement that is needed to address those aspects of environmental and health impacts of reactor licensing and re-licensing.

3. Releases of volatile radionuclides from spent fuel

Volatile radionuclides are mainly released to the atmosphere from spent fuel when it is reprocessed if not captured.[86] For instance, iodine-129 would be released to the atmosphere in this way, if not captured. There are also liquid effluents as a result of reprocessing.

In constructing Table S-3, the NRC assumed that I-129 would be released to the atmosphere prior to spent fuel disposal in a repository even though, physically this would not occur. The NRC claimed that this was a "conservative" assumption:

> For spent fuel disposal the staff made the conservative assumption that fission-product gases in the spent fuel, including all tritium, krypton-85, carbon-14, and iodine-129, would be released during handling and emplacement of the waste prior to sealing of the repository. This assumption reflects the possibility that the spent fuel storage canisters and the fuel rod cladding will be corroded by the salt during the period the repository is open (roughly 6 to 20 years, and volatile materials in the fuel will escape to the environment. The staff assumed, however, that after the repository is sealed there would be no further release of radioactive materials to the environment.[87]

[86] The release of carbon-14 as carbon-14 dioxide gas is covered separately below.
[87] NRC 1979.

The NRC made this assumption in the context of disposal in a bedded salt repository, which, as noted, is obsolete for spent fuel. It is also not conservative for any other geologic setting, since iodine-129 releases into groundwater could cause much higher doses either via groundwater or where the groundwater is discharged into surface water.

For instance, the largest dose calculated by the French nuclear waste agency ANDRA, was due to I-129 in spent fuel. As noted in Section A, the whole body effective dose equivalent from I-129 in the event of seal failure was estimated to be 1,500 millirem, greatly in excess of both the French and current U.S. EPA performance requirements. Since the main organ that is irradiated is the thyroid, the implied dose to the thyroid is about 30,000 millirem.[88]

It is clear that under present circumstances, with present technical information, and under current law, Table S-3 is not conservative. On the contrary, by assuming that I-129 is dispersed into the atmosphere, the doses are implicitly assumed to be quite low. For instance, WASH-1248, the document underlying 10 CFR 51, estimates the thyroid dose due to the release of volatile radionuclides (mainly I-129) as only 6.3 millirem from one-reactor year of operation.

This dose appears to be well with compliance limits and hence the NRC can proceed to liecense reactors on this basis. However, if it is assumed that spent fuel will be disposed of in a geologic repository where groundwater could become contaminated, then the performance measure to be used is not longer that applying to one reactor for one eyar, but whther the geologic repository system is suitable for disposal of all the spent fuel that is created in the program as a whole. In the French case, the spent fuel disposed of is much less than will be required in the U.S., since the French have fewer reactors and they have reprocessing. It is plausible that the U.S. impacts from iodine disposal could therefore be far in excess of the limits set in 40 CFR 197 for geologic disposal.[89] Therefore the cumulative impact of licensing new reactors and re-licesing existing reactors would be far in excess of that estimated in Table S-3, which assumes zero releases into the environment from disposal of solid spent fuel.

Other parts of Table S-3 relating to volatile or gaseous radionuclides are also obsolete. For instance, Table S-3 assumes a release of 400,000 curies of krypton-85 into the atmosphere per reactor-year. While this may be conservative, it is greatly in excess of the EPA's maximum allowable release of krypton-85 from one-gigawatt-year[90] of operation as specified in 10 CFR 190.10(b):

---

[88] Calculated using thyroid and committed dose equivalent dose conversion factors for ingestion of iodine-129 in EPA 1999 and 2002 suppl. The weighting factor used for the thyroid is 0.03, according to 40 CFR 191.

[89] The DOE's license application for Yucca Mountain estimates low doses only because it assumes near-total container integrity for very long periods of time and treats deliquescence-induced corrosion as insignificant.

[90] This is equal to one 1,000 megawatt reactor operating for one year at 100 percent capacity factor. Table S-3 assumes a "Reference Reactor Year" which is the same reactor operating at 80 percent capacity factor,

(b) The total quantity of radioactive materials entering the general environment from the entire uranium fuel cycle, per gigawatt-year of electrical energy produced by the fuel cycle, contains less than 50,000 curies of krypton-85, 5 millicuries of iodine-129, and 0.5 millicuries combined of plutonium-239 and other alpha-emitting transuranic radionuclides with half-lives greater than one year.[91]

Hence, the assumed release of Kr-85 in Table S-3 is far in excess of that allowed under current EPA rules, demonstrating yet another aspect of the obsolescence of Table S-3. We understand that these releases would occur mainly in the case of the reprocessing option being chosen and that reprocessing is not the current law for spent fuel management and disposal. But Table S-3 is designed to cover both the reprocessing and non-reprocessing cases. The releases it estimates, as an upper bound, are not in compliance with current regulations.

Table S-3's estimate of 1,300 millicuries (1.3 curies) of iodine -129, and 203 millicuries (0.203 curies) of fission products and transuranic radionuclides not otherwise specified are also not aligned with 40 CFR 190.10(b).

It is clear that some of the NRC assesses releases from reactor operations to be insignificant that are far in excess of those allowed by the EPA. The fact that these releases would be primarily from reprocessing operations and that reprocessing is no longer envisaged as the basis for disposal only highlights the obsolescence of Table S-3.

Further, it is possible that reprocessing may become the basis for spent fuel management for some or all of spent fuel. While we have concluded that such a course would create far more serious problems than it solves, it is nonetheless within the realm of possibility. For instance, it is part of a set of options being considered under the Global Nuclear Energy Partnership.[92]

As of April 2008, U.S. nuclear power plants had created 56,000 metric tons of spent fuel. The DOE anticipates that 119,000 metric tons of spent fuel will be created by existing reactors by 2035. There is some uncertainty about waste generation per reactor for new reactors, since it will depend on enrichment, burn-up etc. But 30 new reactors would likely generate in excess of 600 metric tons per year of spent fuel, or 24,000 metric tons over 40 years.

In sum, just considering spent fuel alone, there are a many ways in which Table S-3 is obsolete and/or incorrect. Hence revision of operational norms and release estimates in both the reprocessing and non-reprocessing cases is essential as is a reevaluation of the impacts and costs in a new generic EIS.

---

see NUREG-0116, Table 3.2, p. 3-14. When translated into the same basis as the EPA regulation, the krypton-85 emissions would be 500,000 curies per gigawatt-year.

[91] 40 CFR 190.10(b) 2008

[92] GNEP PEIS draft 2008, see Section S.2.4 for a summary of options the DOE is considering. A Final EIS has not yet been prepared.

4. Greater than Class C (GTCC) waste and low-level waste

Table S-3 is severely outdated with respect to GTCC waste. It is also outdated with respect to Class A, B, and C low-level waste.

a. GTCC waste

There was no GTCC waste category when the 10 CFR § 51.51 and Table S-3 was revised in the late 1970's.[93] NRC regulations regarding GTCC waste were part of low-level waste regulations, which were not issued until 1982 and revised periodically after that.[94] The Part 61 low-level waste regulations generally require disposal of GTCC in a deep geologic repository and prohibit shallow land burial unless a specific exemption is obtained.[95] At present Table S-3 assumes all solid radioactive waste, except high-level waste, including what is now called GTCC waste, will be buried in a shallow land burial facility.[96] This is clearly incorrect. GTCC waste cannot be disposed of in shallow low-level waste facilities unless a specific exemption to do so is provided by the NRC. None has been provided; nor is there any application for such an exemption.

GTCC waste has a relatively high radioactivity per unit volume and many components of GTCC waste have long half-lives. The impacts in the absence of repository disposal could therefore be considerable – though the amounts would be site specific. Therefore, Table S-3, which was prepared prior to the understanding that led to the creation of a GTCC category, cannot be relied upon for estimating the environmental impact of GTCC disposal. We note here that Table S-3 has been republished in the same way since the late 1970s without change, including after the low-level waste regulations requiring deep geologic disposal of GTCC waste (unless specifically exempted). The current version of 10 CFR 51 also contains this same provision for disposal "on site."[97] The following is copied from the present Table S-3 at 10 CFR 51.51[98]:

Solids (buried on site):		
Other than high level (shallow)	11,300	9,100 Ci comes from low level reactor wastes and 1,500 Ci] comes from reactor decontamination and decommissioning--buried at land burial facilities. 600 Ci comes from mills--included in tailing returned to ground. Approximately 60 Ci comes from conversion and spent fuel storage. No significant effluent to the environment.

Table S-3 is therefore legally wrong in its *a priori* assumption of shallow land burial (on site or at any site) of GTCC waste.

---

93 NRC 1979. Table S-3 was first published in WASH-1248 and revised in the late 1970s, in which form it has been republished since that time.
94 10 CFR Part 61 2008
95 See 10CFR 61.55(a)(2)(iv) 2008 and 10 CFR 61.55(a)(4)(iv) 2008.
96 10 CFR 51.51 2008. Table S-3 mentions onsite burial (i.e., "buried on site"). This would clearly not be allowed for any of the wastes discussed here.
97 Disposal on site at reactors would not be permitted since none have a license do to so and no applications have been made. There are other issues as well in relation to low-level waste compacts see below.
98 10 CFR 51.51 2008.

The Department of Energy (DOE) is preparing an Environmental Impact Statement (EIS) regarding GTCC disposal.[99] This EIS is being prepared because the DOE considers the development of capability to dispose of GTCC waste as a "major Federal action."[100] A full evaluation of the impacts of options of GTCC disposal has never been done. The impacts of GTCC disposal as evaluated in this EIS need to be incorporated into a revised Table S-3. .

Table S-3 is also incorrect in another respect. As can be seen, above, it assumes that there will be "[n]o significant effluent to the environment" and no health impact is estimated. In other words, the assumption here is the same as that for high-level waste and spent fuel disposal – zero environmental impact.

The more stringent requirement for GTCC waste disposal is because the specific activity of the waste is higher than for the Class A, B, and C low-level waste categories as defined in 10 CFR 61.55. No difference in the types of radionuclides or their chemical composition is assumed to exist. The technical inference clearly is that shallow land burial would produce greater impacts than Class A, B, and C waste disposal. The radiation doses estimated by the NRC for these latter waste categories in its low-level waste EIS are greater than zero for all disposal cases, even those in conformity with the 10 CFR 61 regulations, over a period of 500 years.[101] *A forteriori*, the impacts associated with GTCC disposal in shallow land burial at the same reactor site or at some other site would likely be greater.

While the impacts of Disposal of GTCC waste disposal have not been evaluated in the United States, they are required to be disposed of in a deep repository in France. The French evaluation of Class B waste (corresponding approximately to GTCC waste) provides some interesting evidence. According to ANDRA's assessment, the dose from Class B waste disposal at the French Bure site could exceed allowable limits due to exposure to chlorine-36 in the scenario that assumes a failure of the repository seals.[102]

There is no explicit discussion of transuranic waste in Table S-3. Yet NUREG-0116, which supplements WASH-1248, and which is referred to in the notes to Table S-3 explicitly mentions that transuranic waste, mainly generated during reprocessing, should be disposed of in a deep geologic repository. Table S-3 does not even consider chlorine 36.

There will be a considerable amount of GTCC waste even if there is no reprocessing. The DOE estimated that a Boiling Water Reactor would generate 47 cubic meters and a

---

[99] See DOE 2007 and DOE 2007b.

[100] According to the GTCC EIS website set up by Argonne National Laboratory for the GTCC EIS process, "The Secretary of Energy has determined that development of disposal capability for GTCC LLW is a major Federal action that may have a significant impact upon the environment within the meaning of the National Environmental Policy Act of 1969 (NEPA)." On the Web at http://www.gtcceis.anl.gov/eis/why/index.cfm.

[101] NRC 1982, v. 1, Table 4.6 (pp. 4-30 to 4-32).

[102] ANDRA 2001, p. 139.

Pressurized Water Reactor would generate 133 cubic meters upon decommissioning.[103] On this basis the existing reactor fleet would generate in excess of 10,000 cubic meters of GTCC waste upon decommissioning.

Again, it clear that Table S-3 is obsolete or incorrect in a number of respects in regard to GTCC waste. The impact of this needs to be assessed either by the NRC as part of the impacts associated with nuclear energy production.

b. Class A, B, and C low-level waste

10 CFR 61 allows disposal of Class A, B, and C low-level waste in shallow land disposal facilities. However, such facilities must be licensed and must meet the dose limits specified at 10 CFR 61 Subpart C. Table S-3 mentions "on site" disposal. WASH-1248, the underlying document supporting Table S-3 also mentions on site diposal. No current reactor sites have such licenses. No application for a new reactor contains provision for obtaining a license for on-site disposal of low-level waste. The table needs to revised and clarified in this regard.

Table S-3 also assumes that shallow land disposal of waste will have not environmental and health impact. This is incorrect. The low-level waste EIS recognizes that some impacts may occur. The standard computational model used for assessing the radiation dose impact of land contamination (and disposal of radioactive waste in shallow land burial facilities is a form of land contamination) generally produces non-zero radiation doses under any reasonable assumption of technical site parameters. This is especially so as 10 CFR 61 Subpart C contains no time limit for performance. That is, the dose limits specified there must be met for the durations that are multiples of the longest lived radionuclides disposed of at the facility. Hence Table S-3 is obsolete and wrong in its assumption of essentially zero release from shallow land burial of low-level waste as well. .

5. Depleted Uranium

Table S-3 makes no mention of the large amounts of depleted uranium that will be generated in the course of enrichment of uranium to produce fuel for the proposed nuclear reactors. Large amounts of DU from uranium enrichment plants were not regarded as a waste when Table S-3 was created. But the Nuclear Regulatory Commission has declared depleted uranium as a low-level waste. However, the classification of large amounts of DU from enrichment plants within the low-level waste scheme (Class A, B, C or GTCC) has yet to be decided. The NRC as asked its staff to conduct a generic proceeding to determine such a classification.[104]

[103] DOE data as cited in Makhijani and Saleska 1992, Table 6.
[104] "…the Commission directs the NRC staff, outside of this adjudication, to consider whether the quantities of depleted uranium at issue in the waste stream from uranium enrichment facilities warrant amending section 61.55(a)(6) or the section 61.55(a) waste classification tables." (NRC 2005).

The NRC staff has recently begun that assessment. It has determined that 10 CFR 61 does not automatically apply to DU in large amounts such as those created by enrichment plants. In fact, it has decided that DU from enrichment plants differs essentially from other low-level wastes in some respects in that it has a much higher level of specific activity, the radionuclides are exceptionally long-lived, and there is in-growth of thorium-230 and radium-226 (which emits radon-222) over hundreds of thousands of years.[105]

DU has radiological characteristics similar to Greater than Class C low-level waste, containing long-lived, alpha-emitting transuranic radionuclides at concentrations greater than 100 nanocuries per gram. Shallow land disposal of over 10,000 metric tons of DU would cause substantial health and environmental impacts in the long run. An assessment done by the Institute for Energy and Environmental Research in the context of evaluating the disposal of 133,000 metric tons of DU from an enrichment plant proposed for New Mexico, concluded that peak doses from the disposal would be in the hundreds of rem per year to the maximally exposed individual under a variety of shallow land disposal conditions, including disposal in dry or wet areas.[106] In contrast, the maximum allowable dose from low-level radioactive waste disposal is only 0.025 rem per year.[107] This means that DU from enrichment plants, over the life of the plant, if disposed of in shallow land burial, would produce doses thousands of times greater than the allowable limit at the time of peak dose.

The NRC staff paper has itself estimated that the disposal of DU in shallow land burial will cause non-zero radiation doses.[108]

Table S-3 does not take any of these realities into account. Indeed, at the time it was published in its present form, in the late 1970s, DU was not even considered a waste. However, the NRC now requires it to be considered as waste in the context of the licensing of uranium enrichment plants.[109] Hence Table S-3 is obsolete in not explicitly considering the impacts of DU.

---

105 Borchardt 2008 Enclosure 1.

106 Makhijani and Smith 2004, Table 5 (p. 24). "Version for Public Release Redacted March 20, 2007."

107 10 CFR 61.41 2008

108 Borchardt 2008, See Enclosure 1. Note that we do not agree with the results of the NRC staff's calculations. For instance, the NRC staff has assumed that "there will not be significant releases of waste to the environment from fluvial or aeolian erosion." This is completely unrealistic and in general scientifically incorrect for the time periods evaluated – well over 1,000 years and up to one million years. As a result, the quantitative impacts assessed by the NRC for arid sites are serious underestimates (since erosion is the main pathway for long-term dose, which is external dose, in arid areas). See Makhijani and Smith 2004. The NRC's conclusion that that some shallow land burial sites may be suitable for DU disposal is based on the incorrect assumption of zero erosion rates, is therefore also incorrect. There has been no scientifically credible demonstration that there would be essentially zero impact from erosion at shallow burial sites, even if these are more than three meters deep, given the time scales involved.

109 NRC 2005

The 56,000 metric tons of spent fuel that have been created so far correspond to more than 300,000 metric tons of DU.[110] There will be hundreds of thousands of metric tons of additional DU due to future fuel production for the existing reactor fleet. Relicensing the rest of existing reactors and licensing new reactors will commit to production of further large amounts.[111]

DU cannot be buried at the reactor site or the enrichment plant site without an appropriate license. Under the current path, DU from an enrichment plant or even more than one enrichment plant may be disposed of at a single facility.

The impacts of DU management and disposal and whether such safe disposal of DU – that is disposal of DU in conformity with low-level waste disposal standards at 10 CFR 61 Subpart C – is possible needs evaluated in the generic EIS on waste that would include a revision of Table S-3. The costs of disposal that would conform to 10 CRF 61 Subpart C also need to be estimated.[112]

6. Radon

The matter of doses from radon-222 due to emissions from mill tailings had not been included in Table S-3. On March 20, 2008, the NRC denied a petition by the New England Coalition on Nuclear Pollution, which had requested that a value for the impact of radon-222 be included in Table S-3. In denying the petition, the NRC concluded that "the radiological impacts of the uranium fuel cycle, including those from radon-222 emissions, on individuals off-site will remain at or below the Commission's regulatory limits, and as such, are of small significance."[113] The NRC referred to Chapter 6 of NUREG-1437 for technical details about the denial.

Limiting radon-222 emissions from uranium mill sites requires the maintenance of the mill tailings site. This includes maintenance of a cover to prevent radon emissions:

> The design and implementation of the radon cover and erosion protection features are the primary reliance for maintaining radon emissions within the [10 CFR] Part 40 limits; significant failure of the covers is considered highly unlikely. However, the indefinite licensed long-term custody and care provide additional assurances.[114]

---

[110] This is an approximate figure. It is much greater than the amount used in the illustrative calculation in the paragraph before. The exact figure attributable to commercial nuclear power plants is difficult to estimate, since the U.S. has had dual use enrichment plants for its civilian and military enrichment requirements and because in recent years the U.S. has also imported enrichment services from Russia in the form of Russian highly enriched uranium that was downblended into low enriched reactor fuel.
[111] The exact amounts are difficult to estimate since some depleted uranium tails may be used as enrichment feedstocks and the assay of U-235 in the tails may vary as uranium prices change.
[112] See for instance Makhijani and Smith 2004.
[113] NRC 2008c. The quote is on p. 14947
[114] NRC 1996, Vol. 1, pp. 6-9 and 6-10.

This assumption that there will be custody and maintenance for the indefinite future in NUREG-1437 is patently absurd. While the decay of radium-226, which has a half-life of 1,600 years, is the proximate source of radon-222 emissions from mill tailings, radium-226 itself is the decay product of thorium-230.

So long as there is thorium-230 in the tailings, the amount of radium-226 will be about the same (excepting that part accounted for by differential environmental mobilization). Thorium-230 has a half-life of over 75,000 years. Hence, there will be significant amounts of radium-226 in the tailings ponds for about ten half-lives or about three quarter of a million years. No human institution has lasted even one percent of this time. The United States, which has had a long political continuity, is not even 300 years old, and it has had a Civil War less than a hundred years after its creation. While the Atomic Energy Act may require institutional control and maintenance of mill tailings, an environmental impact assessment is a technical matter. That assessment cannot rely on a legal requirement that is patently out of touch with any reasonable expectation or technical judgment. For instance, the National Research Council has advised that long-term institutional control should not be assumed in waste disposal or matters relating to the use of contaminated sites:

> *The committee believes that the working assumption of DOE planners must be that many contamination isolation barriers and stewardship measures at sites where wastes are left in place will eventually fail, and that much of our current knowledge of the long-term behavior of wastes in environmental media may eventually be proven wrong. Planning and implementation at these sites must proceed in ways that are cognizant of this potential fallibility and uncertainty.*[115]

The NRC has done exactly the opposite of the recommendation of the National Research Council. Instead of being "cognizant of this potential fallibility and uncertainty" arising from the failure of stewardship and the possibility of incorrect assumptions, it has simply reckoned that all of its essential assumptions and all the necessary institutions and finances will be in place for three quarters of a million years. While this time frame is not specified in NUREG-1437, it is implicit in it because radon-222 emissions ultimately originate in the thorium-230 present in the mill tailings. Indeed, over the long periods considered, the potential for high population doses due to erosion and airborne radioactive particles from the mill tailings should be explicitly considered.

Further, radon releases will also occur from DU disposal, which was not considered in Table S-3. DU disposal is now acknowledged by the NRC to create risks for a million years or more.[116] Since U-238 decay will create radium-226 buildup over time, radon-222 risks from DU disposal will persist for the indefinite future.

---

[115] NAS-NRC 2000, p. 5. Italics in the original.

[116] Borchardt 2008. See for instance Figure 7. While this Figure stops at one million years, it is evident from the charts that non-zero doses continue after that time.

Finally, it should also be noted that EPA's Federal Guidance Report 13, which provides dose conversion and risk factors for persons by age does not provide any data for radon-222. In updating Table S-3 the NRC will need to consider whether children or women get a higher dose than men under specified environmental conditions.

7. Carbon-14

While Table S-3 makes an estimate of 24 curies of carbon-14 releases as gaseous effluents from one reactor year of operation, WASH-1248 does not provide an analysis of the dosimetric consequences. Carbon-14 is oxidized either during reprocessing or in an unsaturated oxidizing environment like Yucca Mountain. While the individual doses from C-14 releases can be expected to be very small, the population doses integrated over time would be very large. This is because carbon-14 has a very long half-life (5,730 years); it will continually be recycled through the biosphere along with non-radioactive carbon. Over ten thousand years, the population doses could be very high in an oxidizing environment. The SAB report cites a population dose of 14 million person rem over 10,000 years assuming that half the carbon-14 is released. This corresponds to 4,000 cancer fatalities over 10,000 years.[117] The total amount of spent fuel considered in this calculation was 70,000 metric tons of heavy metal, the present legal limit for repository disposal. The corresponding estimate per reactor-year, assuming 20 metric tons per reactor-year, would be 1.14 cancer fatalities over 10,000 years. This amounts to 45 fatal cancers due to carbon-14 releases from spent fuel generated over a 40-year operating life and twice that if the license is extended by another 40 years.

Such consequences would be estimated only for unsaturated oxidizing repositories, which is the description that fits the Yucca Mountain site as presently designed and characterized. They would also be estimated in reprocessing scenarios. Hence, the estimates of C-14 fatalities and corresponding estimates of cancer incidence need to be included in a revised Table S-3. We note here that the dose conversion factors have been updated since the EPA carbon-14 report, cited above, was published. Doses and cancer risks need to be calculated on an age-specific, gender-specific basis in the generic waste EIS.

8. Conclusions regarding aspects of Table S-3 other than Spent Fuel and High-Level Waste

Table S-3 is obsolete and/or wrong in its legal, technical, environmental and health assumptions and estimates in regard to spent fuel, gaseous releases from spent fuel, GTCC waste, Class A, B, and C low-level waste, DU, radon-222, and carbon-14. In light or more rigorous requirements for waste management and the fact that repository costs have escalated without a repository having been commissioned as previously envisaged, a thorough revision of the cost basis of nuclear power in regard to its waste aspects is also

[117] Loehr, Nygaard, and Watson 1993, p. 21

needed. This is essential because without such estimates, the costs of nuclear energy with alternative options cannot be fairly made.

A generic environmental impact statement must compare the environmental impacts and costs of the present course with the following alternatives in regard to spent fuel:

1. At reactor storage for the indefinite future, including periodic replacement of storage containers and inter-container transfer.
2. Consolidated monitored storage in one or more locations for the indefinite future, including replacement and transfer as in Item 1 above.
3. Yucca Mountain at 70,000 metric tons with no second repository.
4. Yucca Mountain at a higher capacity than 70,000 metric tons.
5. Yucca Mountain with a second repository.
6. Yucca Mountain fails as a program and one or more other sites in a new program to accommodate all spent fuel.
7. Reprocessing of spent fuel with fast reactor reuse of plutonium and uranium, plus a waste repository for high-level waste and Greater Than Class C waste.
8. Reprocessing with light water reactor re-use of plutonium (including costs of reactor modification), with a repository as in Item 7 above.
9. Reprocessing of spent fuel without fast reactor reuse of plutonium and uranium, with a repository as in Item 7 above.
10. Uranium only fuel recycle, with a repository as in Item 7 above.
11. Partial reprocessing, with repository disposal of uranium and mixed uranium-plutonium oxide spent fuel, uranium spent fuel, high-level waste and Greater Than Class C waste.

The risk of terrorist attacks and proliferation risks must be included in the generic EIS. These risks are different for the various options and those differentials need to be factored into the process of choosing a preferred alternative in the EIS process.

It must also consider the various options for GTCC disposal and DU disposal that would conform with existing low level waste dose limits specified at 10 CFR 61 Subpart C.

A waste confidence rule as well as a generic EIS on spent fuel must consider the above alternatives and provide cost estimates for them. These costs must be added to reactor costs for new reactors in the licensing process and in the re-licensing process of existing reactors. The costs must be added to nuclear power costs when evaluating alternatives when preparing environmental impact statements for new reactors. Without a realistic estimate of costs and a generic waste confidence EIS, the EIS process for new reactor licenses and the adjudicatory process for re-licensing reactors will remain fundamentally deficient. If the costs of repository alternatives cannot be realistically estimated based on present U.S. data and history (including technical, legal, regulatory, political, social, and fiscal aspects), then the waste confidence finding must be that there is no reasonable assurance that a repository for spent fuel can be opened in the United States at any time in the foreseeable future. Specifically, if a well-founded upper bound cannot be attributed to waste management and disposal costs, then there is no basis on which to compare the total costs of nuclear with various combinations of renewable energy, storage, combined heat and power, and efficiency alternatives as a part of the EIS process of licensing new reactors.

D. Conclusions

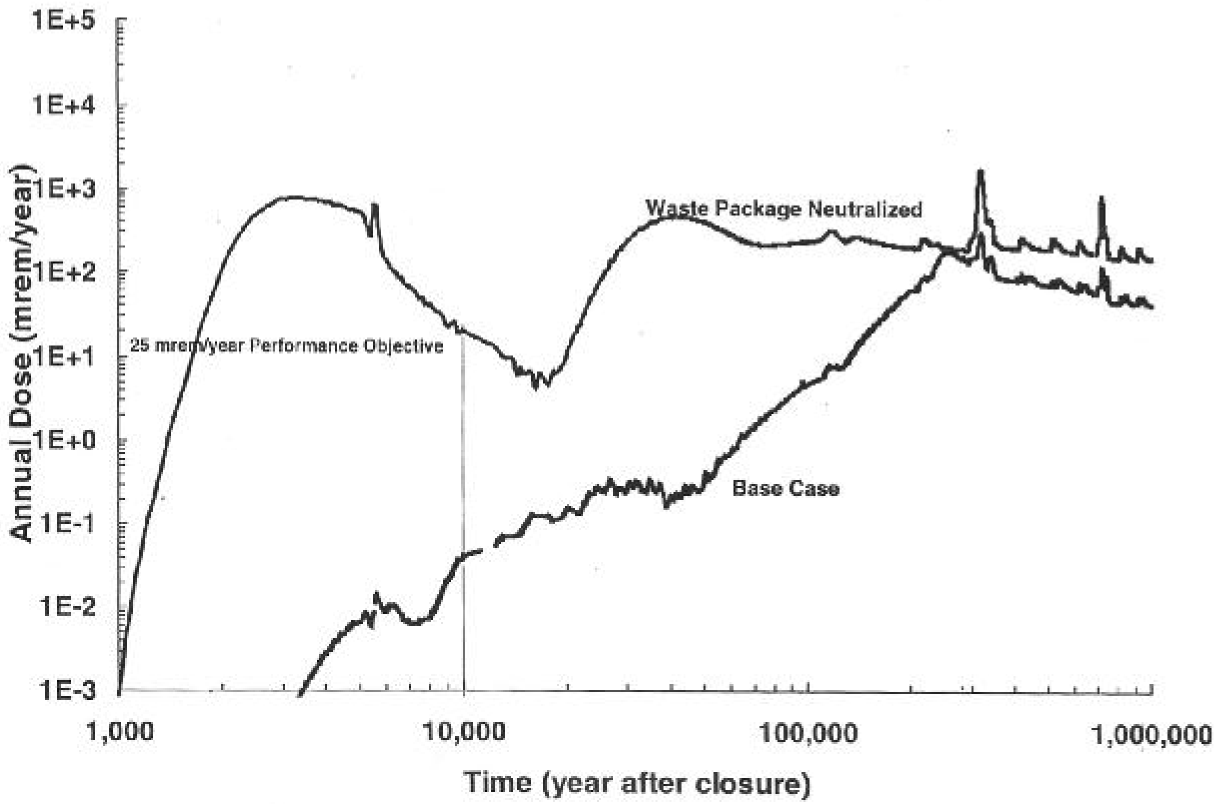
The NRC has not provided a sound scientific, technical, legal, political, social financial, or fiscal basis for its conclusions that (i) a geologic repository for disposal of spent fuel is technically feasible, (ii) it can state with reasonable assurance that a geologic repository to accommodate the required waste volumes can be opened within 50 to 60 years after the license expiry of any U.S. nuclear power plant, including new plants.

Further, Tables S-3 is either obsolete or wrong needs to be fundamentally revised to take into account new scientific and legal realities. We have concluded that at present there is no reasonable assurance that a repository in the United States can be opened within the time frame specified in the revised Finding 2 or indeed at any time. A generic EIS on nuclear spent fuel management, including a revision of Tables S-3, is required before new reactors can be licensed or existing reactors can be relicensed.

This generic EIS should include consideration of the impacts of the various options described above. It should include consideration of costs of the various options. Compliance with regulations limiting public exposure should be the fundamental basis for assessing whether the impact is small or not. Note that compliance with annual dose limits needs to be estimated for the most exposed individual, who may be a male or female, infant, or a male or female of any other age, using dose conversion factors that are specific to that age and gender. Population doses should also be estimated as this is important for understanding the full extent of the health risks over time. Other aspects of waste management and disposal to be considered as part of the process of licensing new reactors or relicensing existing reactors are discussed below.

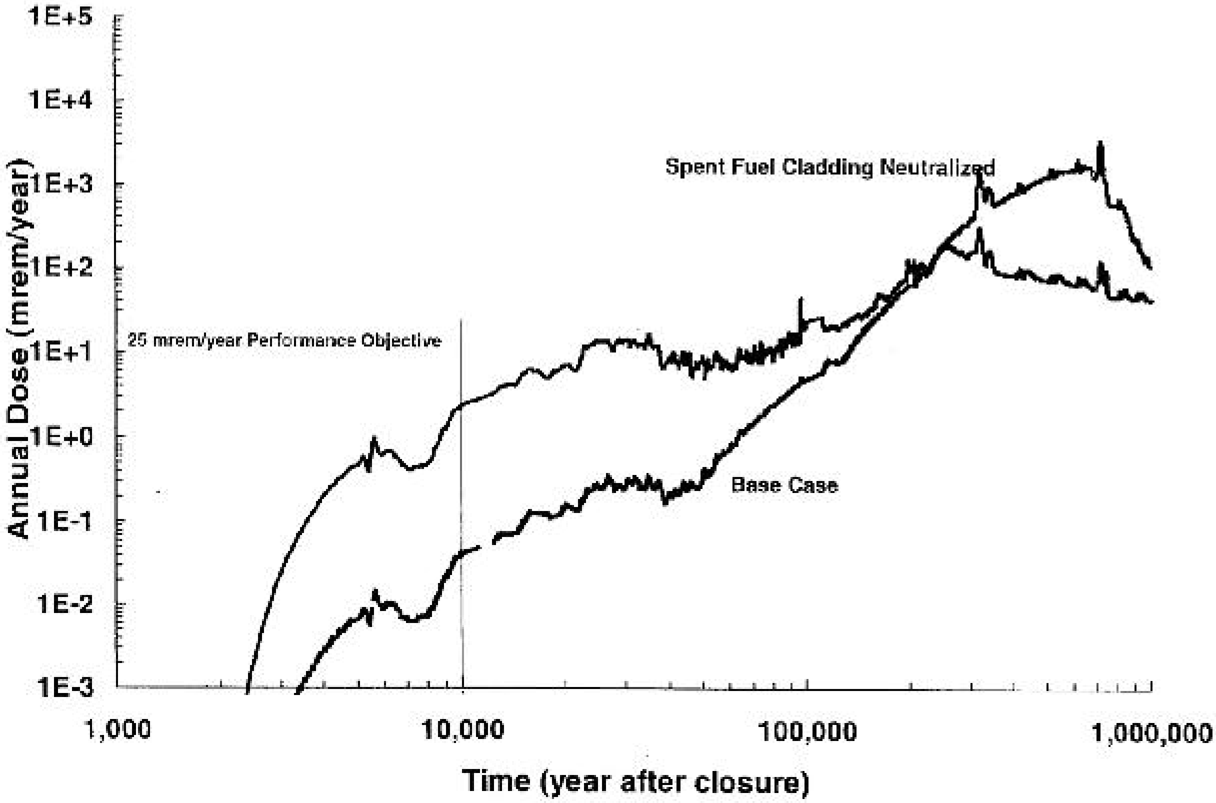
Attachment A[118]

Graph A: Neutralize Waste Package

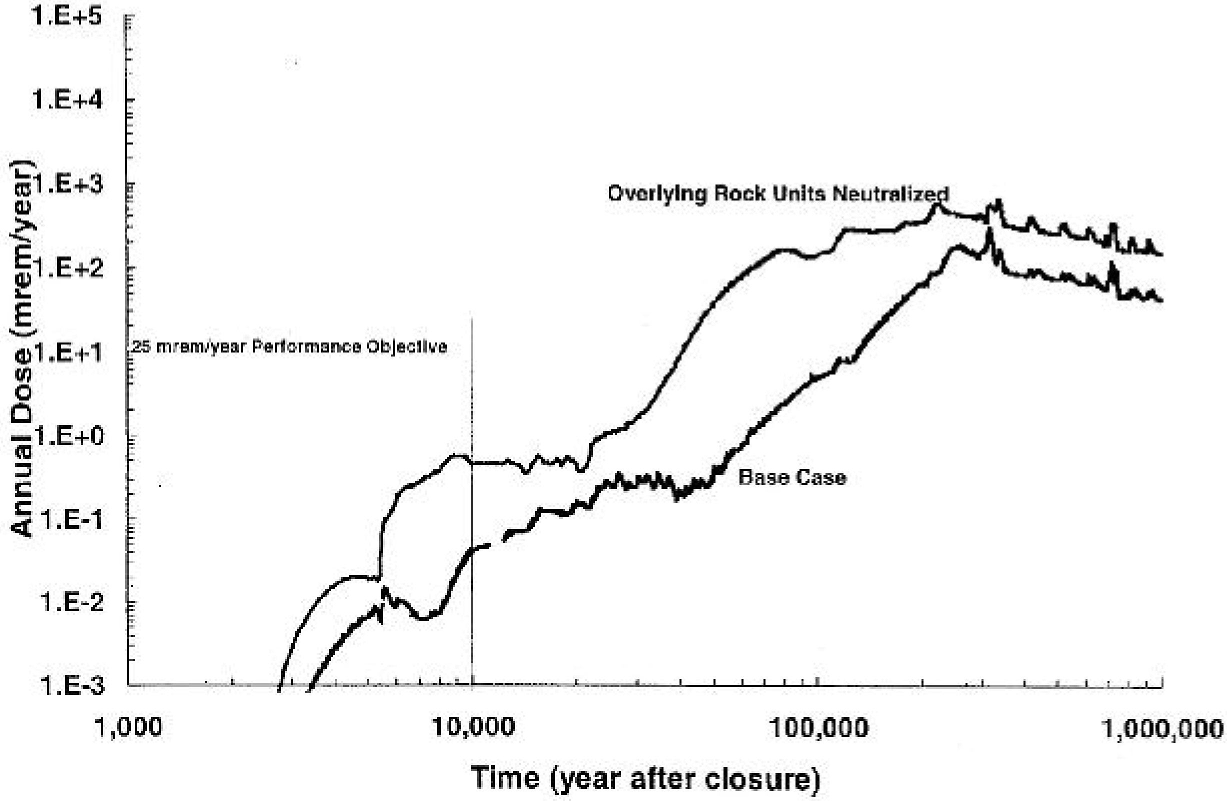


118 Source for all graphs: DOE OCRWM 1999.

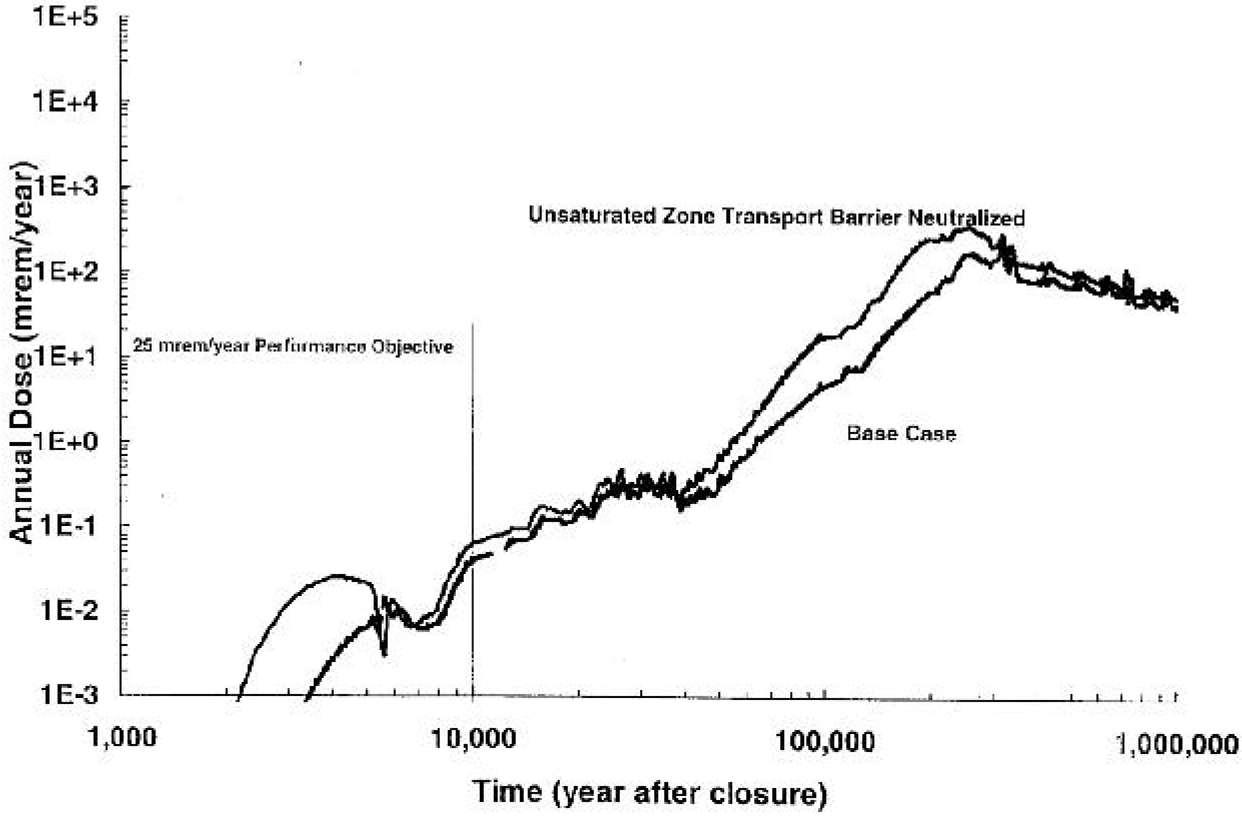
Graph B: Neutralize Spent Fuel Cladding



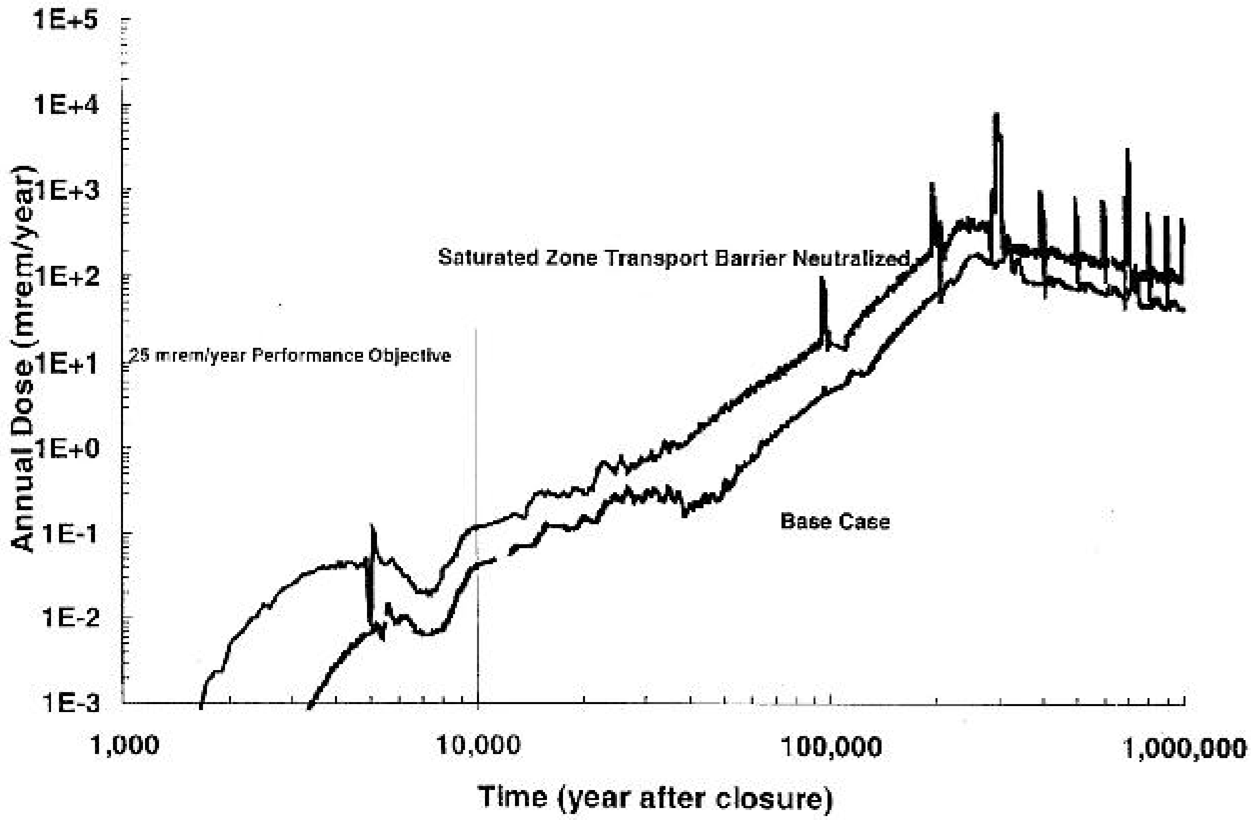
Graph C: Neutralize Overlying Flow Barriers



Graph D: Neutralize Unsaturated Zone Transport Barrier



Graph E: Neutralize Saturated Zone Transport Barrier



Source for all graphs: U.S. DOE Office of Civilian Radioactive Waste Management, "NWTRB Repository Panel meeting: Postclosure Defense in Depth in the Design Selection Process," presentation for the Nuclear Waste Technical Review Board Panel for the Repository, January 25, 1999. Presented by Dennis C. Richardson. Online at http://www.nwtrb.gov/meetings/1999/jan/richardson.pdf.

Attachment B

INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH

6935 Laurel Avenue, Suite 201
Takoma Park, MD 20912

Phone: (301) 270-5500
FAX: (301) 270-3029
e-mail: ieer@ieer.org
http://www.ieer.org

Curriculum Vitae

des membres de l'équipe IEER et un relecteur

présent à l'IEER 29-30 novembre 2004

Examen critique du programme de recherche de l'ANDRA pour déterminer l'aptitude du site de Bure au confinement géologique des déchets à haute activité et à vie longue

RAPPORT FINAL

préparé par
l'Institut pour la recherche sur l'énergie et l'environnement (IEER)

pour
Le Comité Local d'Information et de Suivi

Directeur du Projet
Arjun Makhijani, Ph.D.

Coordinatrice du projet
Annie Makhijani

27 décembre 2004
avec corrections 11 janvier 2005

Arjun Makhijani, Ph.D.
Annie Makhijani
Prof. Jaak Daemen, Ph.D.
Prof. George Danko, Ph.D.
Prof. Rod Ewing, Ph.D.
Detlef Appel, Ph.D.
Yuri Dublyansky, Ph.D.
Prof. Gerhard Jentzch, Ph.D.
Mike Thorne, Ph.D., relecteur

Les différents membres de l'équipe ont eu la responsabilité des disciplines scientifiques suivantes et ont rédigé les chapitres correspondants :

Chapitre 1: Principes de confinement géologique - Arjun Makhijani. Yuri Dublyansky a contribué à la section sur la paléoclimatologie
Chapitre 2: Mécanique des roches - Jaak Daemen
Chapitre 3: Aspects thermiques de la conception et de la construction du site de stockage - George Danko
Chapitre 4: Programme de recherches sur le terme source et le champ proche - Rod Ewing
Chapitre 5: Hydrogéologie - Detlef Appel
Chapitre 6:Aspect minéralogiques et géochimiques dans la formation hôte - Yuri Dublyansky
Chapitre 7: Sismologie et déformation - Gerhard Jentzsch et Horst Letz

Traduction: Annie Makhijani
Relecture de traduction: Annike et Jean-Luc Thierry
Appui scientifique: Annie Makhijani
Documentaliste: Lois Chalmers

Curriculum Vita of
Arjun Makhijani

Education:

Ph.D. University of California, Berkeley, 1972, from the Department of Electrical Engineering. Area of specialization: plasma physics as applied to controlled nuclear fusion. Dissertation topic: multiple mirror confinement of plasmas.
M.S. (Electrical Engineering) Washington State University, Pullman, Washington, 1967. Thesis topic: electromagnetic wave propagation in the ionosphere.
Bachelor of Engineering (Electrical), University of Bombay, Bombay, India, 1965.

Current Employment:

1987-present: President and Senior Engineer, Institute for Energy and Environmental Research, Takoma Park, Maryland. (part-time in 1987).
February 3, 2004-present, Associate, SC&A, Inc., one of the principal investigators in the audit of the reconstruction of worker radiation doses under the Energy Employees Occupational Illness Compensation Program Act under contract to the Centers for Disease Control and Prevention, U.S. Department of Health and Human Services.

Professional Societies:

Institute of Electrical and Electronics Engineers and its Power Engineering Society
American Physical Society
Health Physics Society
American Association for the Advancement of Science

Official positions

Subcommittee on carbon-14 emissions from Yucca Mountain of the Radiation Advisory Committee, U.S. Environmental Protection Agency, 1992-1993
Radiation Advisory Committee, U.S. Environmental Protection Agency, 1992-1994
Technical Advisory Panel, Hanford high level waste tanks, early 1990s (ex-officio)
Consultant to the Office of Technology Assessment of the U.S. Congress

Consulting Experience, 1975-1987

Consultant on a wide variety of issues to various organizations including:

Tennessee Valley Authority
Lower Colorado River Authority
Federation of Rocky Mountain States
Environmental Policy Institute
Lawrence Berkeley Laboratory
Food and Agriculture Organization of the United Nations
International Labour Office of the United Nations
United Nations Environment Programme

United Nations Center on Transnational Corporations
The Ford Foundation
Economic and Social Commission for Asia and the Pacific
United Nations Development Programme

Some publications relevant to nuclear waste and radioprotection

Makhijani, A., K.M. Tucker, with Appendix by D. White, *Heat, High Water, and Rock Instability at Hanford*, Health and Energy Institute, Washington, D.C., 1985.

Makhijani, A., R. Alvarez, and B. Blackwelder, *Deadly Crop in the Tank Farm: An Assessment of Management of High-Level Radioactive Wastes in the Savannah River Plant Tank Farm,* Environmental Policy Institute, Washington, D.C., 1986.

Makhijani, A., *Release Estimates of Radioactive and Non-Radioactive Materials to the Environment by the Feed Materials Production Center, 1951-85*, Institute for Energy and Environmental Research, Takoma Park, 1988.

Makhijani, A., and B. Franke, *Addendum to Release Estimates of Radioactive and Non-Radioactive Materials to the Environment by the Feed Materials Production Center, 1951-85*, Institute for Energy and Environmental Research, Takoma Park, 1989.

Makhijani, A. and S. Saleska, *High Level Dollars Low-Level Sense: A Critique of Present Policy for the Management of Long-Lived Radioactive Waste and Discussion of an Alternative Approach*, Apex Press, New York, 1992.

Makhijani, A. and Annie Makhijani, *Fissile Materials in a Glass, Darkly: Technical and Policy Aspects of the Disposition of Plutonium and Highly Enriched Uranium,* IEER Press, Takoma Park, 1995.

Makhijani, A., H. Hu, K. Yih, eds., *Nuclear Wastelands: A Global Guide to Nuclear Weapons Production and the Health and Environmental Effects*, MIT Press, Cambridge, MA, 1995.

Fioravanti, M. and A. Makhijani, *Containing the Cold War Mess: Restructuring the Environmental Management of the U.S. Nuclear Weapons Complex,* Institute for Energy and Environmental Research, Takoma Park, October 1997.

Makhijani, A., Bernd Franke, and Hisham Zerriffi, *Preliminary Partial Dose Estimates from the Processing of Nuclear Materials at Three Plants during the 1940s and 1950s*, Institute for Energy and Environmental Research, Takoma Park, September 2000. (Prepared under contract to the newspaper *USA Today*.)

Makhijani, A. and Bernd Franke, *Final Report of the Institute for Energy and Environmental Research on the Second Clean Air Act Audit of Los Alamos National Laboratory by the Independent Technical Audit Team*, Institute for Energy and Environmental Research, Takoma Park, December 13, 2000.

Makhijani, Arjun, Hisham Zerriffi, and Annie Makhijani, "Magical Thinking: Another Go at Transmutation," *Bulletin of the Atomic Scientists,* March/April 2001.

Makhijani, A. and Michele Boyd, *Poison in the Vadose Zone: An examination of the threats to the Snake River Plain aquifer from the Idaho National Engineering and*

Environmental Laboratory Institute for Energy and Environmental Research, Takoma Park, October 2001.

Makhijani, A. and Sriram Gopal, *Setting Cleanup Standards to Protect Future Generations: The Scientific Basis of Subsistence Farmer Scenario and Its Application to the Estimation of Radionuclide Soil Action Levels (RSALs) for Rocky Flats*, Institute for Energy and Environmental Research, Takoma Park, December 2001.

Makhijani, A. and Michele Boyd, *Nuclear Dumps by the Riverside: Threats to the Savannah River from Radioactive Contamination at the Savannah River Site*, Institute for Energy and Environmental Research, Takoma Park, Maryland, forthcoming, March 2004.

Annie Makhijani

Education:

M.S. (Chemistry, with emphasis on Physical Chemistry) University of Maryland, College Park, Maryland, 1994. Research topic: the physical properties of nanostructures.
Bachelor of Science (Chemistry) University of Maryland, College Park, 1985.
Studied Hindi at the Institut des Langues Orientales in Paris (1980).
Bachelor of Arts (Psychology) Université de Tours, France (1972)

Employment:

- 1994-present: Project Scientist, Institute for Energy and Environmental Research, Takoma Park, Maryland.
- Staff Scientist, Institute for Energy and Environmental Research, Takoma Park, Maryland.
- Consultant for the White House Council on Environmental Quality (1979).
- French teacher, Alliance Française, Bombay, India (1977-1979)

Publications:

- Makhijani, Arjun and Annie Makhijani, *Fissile Materials in a Glass Darkly:* Technical *and Policy Aspects of the Disposition of Plutonium and Highly Enriched Uranium,* IEER Press, Takoma Park, 1995.
- Hisham Zerriffi and Annie Makhijani, *An Assessment of Transmutation as a Nuclear Waste Management Strategy,* Institute for Energy and Environmental Research, Takoma Park, 2000.

Some accomplishments

- Did research on the management of depleted uranium for the proposed Claiborne uranium enrichment plant in Louisiana (1996).
- Did research on the decommissioning or the Sequoyah uranium conversion plant in Oklahoma.
- Was responsible for some of the background research for the Institute for Energy and Environmental Research technical report: *Radiation Exposures in the Vicinity of the Uranium Facility in Apollo, Pennsylvania* (1998).

RESUME
JAAK J.K. DAEMEN

Education: Ph.D. Geo_Engineering, University of Minnesota, June 1975
Mining Engineer (Honors), University of Leuven, Belgium, July 1967

Registration: State of Arizona: Registered P.E. Civil Engineering (AZ 12158) and Mining Engineering (AZ 12980)

Professional:
American Institute of Mining Engineers, American Society of Civil Engineers, International Society for Soil Mechanics and Foundation Engineering, American Society for Engineering Education, International Society for Rock Mechanics, Royal Flemish Engineering Association, Royal Belgian Society of Engineers and Industrialists, American Geophysical Union, American Rock Mechanics Association.

Past Member, National Tunneling Committee, U.S. National Rock Mechanics Committee and Committee on Geological and Geotechnical Engineering of the National Research Council of the National Academy of Sciences; Reviewer for National Science Foundation, Geotechnical Engineering Program; U.S. Geological Survey; Mining Engineering, Society of Mining Engineers of AIME; International Journal of Rock Mechanics and Mining Sciences; Water Resources Research; Canadian Geotechnical Journal

Employment Record:

October 2001 - Present Professor, Mining Engineering, Mackay School of Mines, University of Nevada, Reno.

July 1990 - Sept.2001 Professor and Chair, Mining Engineering, Mackay School of Mines, University of Nevada, Reno.

September 1976 _ June 1990 Assistant and Associate Professor, University of Arizona, Department of Mining and Geological Engineering.

Summer 1980, 1981 Visiting Associate Research Engineer, Research Associate, University of California, Berkeley.

Summer 1977 Occidental Research Corporation. Investigations of roof control problems, Island Creek Coal Company.

April 1975 - September 1976 Research Engineer, E. I du Pont de Nemours & Co., Potomac

River Development Laboratory, Martinsburg, West Virginia 2504.

Sept. 1967 - March 1975 Research Assistant, Teaching Assistant, Teaching Associate, Research Fellow and Post_Doctoral Research Associate, Univ. of Minn, Minneapolis, Department of Civil & Mineral Engineering.

Sponsored Research:
Mechanics of Fully Grouted Bolts in Bedded Mine Rook (United Engineering Foundation); Rock Mass Sealing (U.S. Nuclear Regulatory Commission); Numerical Analysis of the influence of Bench Stiffness on Rock Fragmentation in Surface Blasting (AZ MMRRI); Ground and Air Vibrations Induced by Large Surface Blasts (Office of Surface Mining; U.S. Bureau of Mines); Mechanical Characterization of Welded Tuff (Center of Nuclear Waste Regulatory Analyses); Permeability-Strain Measurements in Rock Salt (Sandia National Laboratories); Sealing Studies for WIPP (SNL); Sealing Studies for Yucca Mountain, (SNL), Rock
Movement Induced by Blasting (Placer Dome); Long Term Drift Sability (DOE).

Courses Taught:
University of Arizona: Rock Excavation Practice; Tunneling and Underground Construction; Surface Mining; Coal Mining; Geomechanics; Applied Geomechanics: Underground Construction; Advanced Geomechanics; Design of Underground Structures; Rock Fracture and Flow; Subsidence Engineering; Rock Dynamics: Drilling, Blasting; Key Block Theory; Boundary Element Analysis.
University of Nevada, Reno: MINE 210 Mining Methods; MINE 301 Coal Mining; MINE 380 Quarry Engineering; MINE 445 Rock Excavation; MINE 448 Rock Mechanics; MINE 658 Rock Mechanics for Underground Mining and Construction.

Consulting: Morrison_Knudsen, Inc.; Sandia National Laboratories; Anaconda Minerals Company; Golder Associates; E.I. du Pont de Nemours & Co.; Fluor Mining & Metals; Cia Minera Las Cuevas, San Luis Potosi; Engineers International, Inc.; Itasca Consulting Group, Inc.; Nuclear Waste Management Consultants, Inc.; GRC Consultants, Inc; Hargis and Associates, Inc.; Southwest Research Institute; Asarco Mining Co., Inc.; Getchell Gold , Inc.; Petroplug, Inc.; U.S. DOE, J.S. Redpath.

CURRICULUM VITAE OF DR. GEORGE DANKO

EDUCATION:

Ph.D.	(Candidacy Degree in Technical Sciences), 1985, Hungarian Academy of Sciences. Thesis: Measurement and Model-building for the Convective Heat Transfer Examinations.
Dr. Tech.	(Doctor's Degree in Fluid Dynamics), 1976, Department of Fluid Dynamics, University of Technology, Budapest. Thesis: Matrix Analysis of Hydraulic Transients in Pipeline Flow.
M.S.	Applied Math, 1975, Eotvos University of Sciences, Budapest
M.S.	Mechanical Engineering, 1968, University of Technology, Budapest

EMPLOYMENT HISTORY:

7/95-present	Professor, Mining Engineering Department, Mackay School of Mines, University of Nevada, Reno.
8/90-6/95	Associate Professor, Mining Engineering Department, Mackay School of Mines, University of Nevada, Reno.
09/87-8/90	Lecturer in Mechanical Engineering, College of Engineering, University of Nevada, Reno.
11/86-8/90	Research Associate, Mining Engineering Department, Mackay School of Mines, University of Nevada, Reno.
1/79-11/86	Associate Professor, Institute of Thermal Energy and Systems Engineering, University of Technology, Budapest.
8/78-1/79	Visiting Postdoctoral Associate, Department of Mechanical Engineering, University of Minnesota.
9/75-8/78	Fellow of Hungarian Academy of Sciences.
8/68-9/75	Assistant Professor, Department of Mechanical Engineering, University of Technology, Budapest.

Selected recent publications relevant to nuclear waste disposal:

Danko, G., (1999), "In Situ REKA Probe Measurements at Yucca Mountain," Proceedings, International Bureau of Mining Thermophysiscs, St. Petersburg, pp 1-12.

Danko, G., (2000), "Coupled Convection-Diffusion Modeling with MULTIFLUX," Proceedings of the International Symposium on Hydrogeology and the Environment, Wuhan, China, pp 26-31.

G. Danko, D. Bahrami, (2001), "Ventilation Analysis of a Cold Conceptual Repository using MULTIFLUX with NUFT," Proceedings, 9th International high-Level Radioactive Waste Management Conference , April 29th-May 3rd.

G. Danko, D. Bahrami, and A. Adu-Acheampong, (2001), "In Situ Thermophysical Properties Measurements Under Hydrothermal Disturbances at DST," Proceedings, 9th International high-Level Radioactive Waste Management Conference , April 29th-May 3rd.

G. Danko and D. Bahrami, (2002), “The Application of CFD to Ventilation Calculations at Yucca Mountain”, Proceedings, WM 02’ Conference, February 24-28, 2002, Tucson, AZ, Session 39B, Paper 12, Abs. 243, pp. 1-11.

Danko, G., Shah, N., and Bahrami, D., (2002). "Evaluation of Lithophysal Conductivity, Diffusivity, and Porosity Measurements using the REKA Method," Proceedings, WM’ 02 Conference, February 24-28, Tucson, AZ. pp. 1-13.

Danko, G., Jain, A., (2002). "Parameter Identification of a Numerical Transport Code," Proceedings, WM’ 02 Conference, February 24-28, Tucson, AZ. pp.1-7.

Danko, G., and Bahrami, D., (2003). " Sensitivity Analysis of Ventilation Parameters and Site Input Properties," Proceedings, 10th Int. High-Level Radioactive Waste Management Conference, pp.1-8.

Danko, G., and Bahrami, D., (2003). "Natural Ventilation of a Deep Geologic Nuclear Waste Storage Facility," Proceedings, 10th Int. High-Level Radioactive Waste Management Conference, pp.1-8.

Danko, G., Shah, N., and Bahrami, D., (2003). "Monte Carlo Analysis of In Situ Lithophysal Properties Identification," Proceedings, 10th Int. High-Level Radioactive Waste Management Conference, pp.1-10.

Danko, G., Shah, N., and Bahrami, D., (2003). "In Situ Thermophysical Properties Variation at DST, Yucca Mountain," Proceedings, 10th Int. High-Level Radioactive Waste Management Conference, pp.1-8.

Danko, G., Bahrami, D., Leister, P., and Croise, J., (2003). "Temperature and Humidity Control for Underground Spent Fuel Storage," Proceedings, 10th Int. High-Level Radioactive Waste Management Conference, pp.1-8.

RODNEY C. EWING

Rod Ewing is a professor in the Department of Nuclear Engineering and Radiological Sciences at the University of Michigan, responsible for the program in radiation effects and nuclear waste management. He also holds appointments in Geological Sciences and Materials Science & Engineering and is an Emeritus Regents' Professor at the University of New Mexico in the Department of Earth and Planetary Sciences, where he was a member of the faculty from 1974 to 1997 and chair of the department from 1979 to 1984. He is also an *Adjungeret Professor* at the University of Aarhus in Denmark.

Ewing received a B.S. degree in geology from Texas Christian University (1968, summa cum laude) and M.S. (l972) and Ph.D. (l974, with distinction) degrees in mineralogy from Stanford University where he held an NSF Fellowship. His graduate studies focused on an esoteric group of minerals, metamict Nb-Ta-Ti oxides that are unusual because they have become amorphous due to radiation damage caused by the presence of radioactive elements (U and Th) and radionuclides in their decay series. This radiation-induced phase transformation from a crystalline to amorphous (periodic-to-aperiodic) structure can have significant effects on the properties of materials, such as the decreased durability of radioactive waste forms. Over the past twenty years, the early study of these unusual minerals has blossomed into a broadly based research program on radiation effects in complex ceramic materials. Such studies have lead to the development of techniques to predict and confirm the very long-term behavior of materials, such as those used in radioactive waste disposal. The key to such studies has been the use of natural phases of great age in designing highly durable nuclear waste forms. Present research includes: radiation effects caused by heavy-particle interactions with crystalline materials (e.g., ion-beam modification of ceramics and minerals); the structure and crystal chemistry of complex Nb-Ta-Ti oxides; the crystal chemistry of actinide and fission product elements, the application of "natural analogues" to the evaluation of the long-term durability of radioactive waste forms and the release and transport of radionuclides; the low-temperature corrosion of silicate glasses; the neutronics and geochemistry of the natural nuclear reactors in Gabon, Africa. The research has utilized a wide variety of solid-state characterization techniques, such as x-ray diffraction, x-ray absorption spectroscopy and high-resolution electron microscopy. The work of the research group has been supported not only by U.S. funding agencies but also from sources abroad (Sweden, Germany, Australia and Japan, as well as by the European Union and NATO). Ewing is the author or co-author of approximately 400 research publications and the editor or co-editor of seven monographs, proceedings volumes or special issues of journals. He was recently granted a patent for the development of a highly durable material for the immobilization of excess weapons plutonium. He received a Guggenheim Fellowship in 2002.

Ewing is a fellow of the Geological Society of America and the Mineralogical Society of America and has served the Materials Research Society as a Councilor (1983-1985; 1987-1989) and Secretary (l985-l986). He was president of the Mineralogical Society of America (2002) International Union of Materials Research Societies (1997-1998) and the New Mexico Geological Society (1981). He was a member of the Board of Directors of the Caswell Silver Foundation (l980-l984) and Energy, Exploration, Education, Inc. (l979-l984). He has served as a guest scientist or faculty member at Battelle Pacific Northwest Laboratories, Oak Ridge National Laboratory, the Hahn-Meitner-Institut in Berlin, the Department of Nuclear Engineering in the Technion University at Haifa, the Centre D'Etudes Nucléaires de Fontenay-Aux-Roses, Commissariat A L'Énergie Atomique in France, Charles University in Prague, the Japan Atomic Energy Research Institute, the Institut für Nukleare Entsorgungstechnik of the Kernforschungszentrum Karlsruhe, Aarhus University in Denmark, Mineralogical Institute of Tokyo University and the Khlopin Radium Institute in St. Petersburg, Russia.

The involvement in issues related to nuclear waste disposal has proceeded in parallel with the basic research program most notably in association with the activities of the Materials Research Society where he has been a member of the program committee and the editor or associate editor for the proceedings volumes for the symposia on the "Scientific Basis for Nuclear Waste Management" held in Berlin-82, Boston-84, Stockholm-85, Berlin-88, Strasbourg-91, Kyoto-1994, Boston-1998 and Sydney-2000. He is co-editor of and a contributing author of *Radioactive Waste Forms for the Future* (published by North-Holland Physics, Amsterdam, 1988). Professor Ewing has served on National Research Council committees for the National Academy of Sciences that have reviewed the Waste Isolation Pilot Plant in New Mexico (1984 to 1996), the Remediation of Buried and Tank Wastes at Hanford, Washington and INEEL, Idaho (1992 to 1995), and the INEEL High-Level Waste Alternative Treatments (1998-1999), as well as a subcommittee on WIPP for the Environmental Protection Agency's National Advisory Council on Environmental Policy and Technology (1992 to 1998). He has served as an invited expert to the Advisory Committee on Nuclear Waste of the Nuclear Regulatory Commission and a consultant to the Nuclear Waste Technology Review Board. He is presently a member of the Board of Radioactive Waste Management of the National Research Council.

Dr. Detlef Appel

Professional background
Born 1943

1965-1971
study of geology at the University of Hannover, Lower Saxony, Germany, and the University of Vienna, Austria - diploma thesis on tectonical aspects of the Asse salt-structure in Lower Saxony (test site for radioactive waste disposal in West-Germany).
1971-1983
scientific employee: Institute of Geology and Paleontology of the University of Hannover - doctoral thesis on sedimentological questions of Upper Triassic sandstone formation in Lower Saxony.

Since 1983

freelancing consultant

Numerous expert opinions / publications in applied (hydro)geology and methodology (mostly in cooperation with other authors):

- selection, assessment and licensing of sites for final disposal of "conventional" and radioactive waste,
- risk assessment of (abandoned industrial) contaminated sites,
- site-specific and conceptual groundwater and soil protection in environmental impact assessment, water and soil management and planning,

Main clients: state authorities, regional/local water and environmental authorities, environmental NGOs (Greenpeace) and local environmental organizations.
Advisory activity

for German federal and state governments, environmental NGOs and local citizen action groups:

- Advisory Board on "Questions of Nuclear Power Phase-Out" of the Lower Saxony Ministry of the Environment (1992-1998),
- Committee on Site Selection Procedure of the Federal Ministry of the Environment, Nature Protection and Reactor-Safety (1999-2002),
- Working Group Fuel and Waste Management of the German Commission on Reactor-Safety,
- Radiation Protection Commission of BUND - Friends of the Earth,
- Scientific Advisory Board of the Konrad Mine Working Group.

International activities and cooperation

- Swiss Expert Group on Disposal Concepts for Radioactive Waste,

- Cantonal Working Group Wellenberg (Advisory Board of the Canton Nidwalden on safety aspects of the formerly planned LWA/MAW repository, Switzerland; until September 2002),
- Forum on Stakeholder Confidence (OECD/NEA),
- EC-Project COWAM (Community Waste Management),

Membership of scientific / professional associations

- German Geological Society,
- Society of Environmental Geosciences,
- Engineering-Technical Association on Contaminated Sites,
- Professional Society of German Geoscientists.

YURI V. DUBLYANSKY

EDUCATION	University of Perm, Russia: PhD (Candidate of Sciences) in Geosciences, 1987 University of Odessa, Ukraine: M.S. in Geological Engineering and Hydrogeology, 1982
WORK PLACE	Fluid Inclusion Lab. Institute of Mineralogy and Petrography, Russian Academy of Sciences, Siberian Branch, since 1985 to present
POSITION	Senior Scientist
WORK ADDRESS	Russia, 630090, Novosibirsk, 3, Koptyuga Ave. IM&P SB RAS Phone: +8-913-920-5263 (cel); FAX: +7-3832-332792 e-mail: kyoto_yuri@hotmail.com
SPECIALIZATION AND FIELD OF INTEREST	Geological disposal of nuclear waste; low temperature hydrothermal processes; fluid inclusions, isotope geochemistry. Analysis of the scientific and regulatory issues related to the geological disposal of the high-level nuclear waste.
LANGUAGES	English (fluent) and French (somewhat rusty)

PROFESSIONAL EXPERIENCE

2002	By request of the State of Nevada Attorney General Office, with the group of co-authors from USA, UK and Russia, writing a scientific monograph, providing independent evaluation of the suitability of the U.S. proposed site for geological disposal of the high-level nuclear waste at Yucca Mountain, Nevada. Monograph will be used by the State of Nevada as part of legal deposition in the forthcoming litigations, court hearings and licensing proceedings related to the Yucca Mountain high-level nuclear waste disposal site.
1999-2001	Official representative of the State of Nevada in the three-lateral (U.S. Department of Energy, State of Nevada and University of Nevada) research project on the paleo-hydrology of the proposed geological disposal site for the high-level nuclear waste at Yucca Mountain, Nevada. In this capacity testified before the presidential Nuclear Waste Technical Review Board and before the Advisory Committee on Nuclear Waste of the U.S. Nuclear Regulatory Commission. Scientific leader and manager of the research project commissioned by the Government of the State of Nevada studying critical issues of the geological suitability of the proposed high-level nuclear waste site in Nevada.
1997 - 1998	Served as an expert to TACIS (a EC program), assessing geological issues of the nuclear waste disposal in the Northwest Russia. Performed critical evaluation of the concept of the nuclear waste disposal in permafrost on the Novaya Zemlia archipelago.
1994 - 1998	Consulting the State of Nevada's Nuclear Waste Project Office and the Attorney General Office on the issues of the geological suitability of the high-level nuclear waste repository at Yucca Mountain. Submitted 19 technical reports.
1993 - 1994	International Scientific Fellowship Award from NSERC, Canada, taken up at McMaster University, Hamilton, Ontario, Canada. Fluid inclusion and stable isotope geochemistry research.

1992 - 1993 Consulting the Hungarian National Authority for Nature Conservation on fossil hydrothermal systems and caves in Budapest and the Transdanubian Range.

RECENT PROFESSIONAL PUBLICATIONS PERTINENT TO THE NUCLEAR WASTE DISPOSAL

1. Dublyansky Y.V., Smirnov, S.Z., and Pashenko S.E. 2003 Identification of the deep-seated component in paleo fluids circulated through a potential nuclear waste disposal site: Yucca Mountain, Nevada, USA. *Journal of Geochemical Exploration*, **4013**, pp. 1-5. (*In press*)
2. Dublyansky, Y., Ford, D., and Reutski, V. 2001 Traces of epigenetic hydrothermal activity at Yucca Mountain, Nevada: preliminary data on the fluid inclusion and stable isotope evidence. *Chemical Geology*. **173**, pp. 125-149.
3. Dublyansky, Y. 2001 Paleohydrogeology of Yucca Mountain by Fluid Inclusions and Stable Isotopes. Proc. Int. Con., Amer. Nucl. Soc. "High-Level Radioactive Waste Management". La Grande Park, Illinois. CD ROM
4. Dublyansky, Y., Szymanski, J., Chepizhko, A., Lapin, B., and Reutski, V. 1999 Paleohydrogeology of Yucca Mountain (Nevada, USA): Key to the Site Suitability Assessment for Planed Nuclear Waste Repository. *Geoecology*. **1**, pp. 77-87. (In Russian)
5. Dublyansky, Y., Szymanski, J., Chepizhko, A., Lapin, B. and Reutski, V. 1998 Geological History of Yucca Mountain (Nevada) and the Problem of a High-Level Nuclear Waste Repository. *Defence Nuclear Waste Disposal in Russia*. NATO Series. Kluwer Academic Publishers, The Netherlands. pp. 279-292.
6. **Hill, C., Dublyansky, Y., Harmon, R., and Schluter, C. 1995 Overview of calcite/opal deposits at or near the proposed high-level nuclear waste site, Yucca Mountain, Nevada: pedogenic, hypogene, or both? *Environmental Geology*, 26(1), pp. 69-88.**

Prof. Dr. Gerhard Jentzsch Institute for Geosciences, University of Jena

Born in 1946 in Taucha near Leipzig, Germany

Education:

Habilitation for Geophysics, Free University of Berlin, 1985, Institute for Geophysical Sciences, Free University of Berlin.

Doctoral examination, Technical University of Clausthal, Germany, 1976, from Faculty for Geosciences, Institute for Geophysics.

Exam (Diploma) in Geophysics, 1972, same institute.

Current Employment:

1996-present: Full Professor for Applied Geophysics at the Institute for Geosciences of the University of Jena

Professional Societies:

German Geophysical Society (currently President of this society), Geologische Vereinigung, European Geophysical Union, American Geophysical Union

Employment history:

1990 - 1996: Professor for General Geophysics at the Institute for Geophysics, Technical University of Clausthal.

1987 – 1990: Professor for Applied Geophysics (Angewandte Geophysik) at the Geological Institute of the University of Bonn.

1977 – 1987: Assistant at the Institute for Geophysical Sciences, Free University of Berlin, Assistence Professor (Hochschulassistent)

1972 – 1977: scientific co-worker of Prof. Dr. O. Rosenbach, Institute for Geophysics

Consulting Experience, 1990 – present:

Seismic hazard assessment for the sites of different nuclear power plants and nuclear industry in Germany, in the form of:

- check of reports
- own calculations
- member of advisory board

1999 – 2002 Member of the German siting committee to develop a procedure for the search for a site of the German nuclear repository (appointed by the German Federal Ministry of the Environment)

1993 – 1998 Member Advisory Board for the Termination of Nuclear Energy Use (Provincial Ministry for the Environment of Lower Saxony)

Additional information:

Research Interests: deformation and seismology (Earth tides, global dynamics, seismological network in East-Thuringia, Geodynamic Observatory Moxa), seismic hazard assessment, physical volcanology

Publications: more than 40 papers during the past 5 years; 15 of them in reviewed journals

National and international activities:

Chairman of working groups (IAG), convenor of special sessions (EGS Meetings, Earthtide Symposium, national meetings), reviewer for the German Research Soc. and different scientific journals

Currently: President of the German Geophysical Society

Publications relating to seismicity / deformation and nuclear waste repository:

1. Nuclear waste repositories:

AKEnd: Arbeitskreis Auswahlverfahren Endlagerstandorte des BMU, 2000. 1. Zwischenbericht, Stand: Juni 2000. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Referat RS III 4 (A), 54 S. First intermediate report.

Bräuer, V. und G. Jentzsch, 2001. Abgrenzung von Gebieten mit offensichtlich ungünstigen geologischen Verhältnissen. Bericht an den AkEnd. Separation of areas with obvious unfavourable geological conditions.

Jentzsch, G., 2001. Vulkanische Gefährdung in Deutschland. Bericht an den AkEnd. Volcanic hazard in Germany.

AKEnd: Arbeitskreis Auswahlverfahren Endlagerstandorte des BMU, 2001. 2. Zwischenbericht – Stand der Diskussion. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Referat RS III 4 (A), 179 S. Second intermediate report.

Appel, D., V. Bräuer, G. Jentzsch und K.-H. Lux, 2002. Geowissenschaftliche Kriterien zur Endlagerstandortsuche für radioaktive Abfälle – Ergebnisse des Arbeitskreises Auswahlverfahren Endlagerstandorte. Z. Angew. Geol, 2/2002, 40 – 47. Geoscientific criteria for the seek of a repository for radioactive waste – results of the AkEnd.

AKEnd: Arbeitskreis Auswahlverfahren Endlagerstandorte des BMU, 2002. Auswahlverfahren für Endlagerstandorte – Empfehlungen des AkEnd. Abschlussbericht, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Referat RS III 4 (A), 260 S. Final report.

Jentzsch, G., 2002. Temperaturverträglichkeit der Gesteine - Neigung zur Ausbildung von Wasserwegsamkeiten. Bericht an den AkEnd. Temperature acceptance of rocks – tendency to open transport paths for fluids.

2. Seismology and deformation

Kracke, D., R. Heinrich, G. Jentzsch, and D. Kaiser, 2000. Seismic Hazard assessment of the East Thuringian Region / Germany – case study. Studia Geophysica et Geodaetica, 44/4, 537 – 548.

Kracke, D., R. Heinrich, A. Hemmann, G. Jentzsch, and A. Ziegert, 2000. The East Thuringia Seismic Network. Studia Geophysica et Geodaetica, 44/4, 594 – 601.

Hemmann, A., T. Meier, G. Jentzsch and A. Ziegert, 2000. A similarity of wave-forms at stations Moxa and Plauen for the 1985/86 swarm. Studia Geophysica et Geodaetica, 44/4, 602 – 607.

Kroner, C., T. Jahr, G. Jentzsch, W. Zürn, R. Widmer-Schniedrig, and B. Heck, 2000. BFO and Moxa: Two observatories for seismological broadband observations. Orfeus Newsletter, Dez. 2000, Vol. 2, No. 3.

Jahr, T., Jentzsch, G., Kroner, C., 2001. The Geodynamic observatory Moxa / Germany: Instrumentation and purposes. Proc. 14th International Symposium on Earth Tides, Special Issue J. Geodetic Soc. of Japan, 47/1, 34 – 39.
Ishii, H., Jentzsch, G., Graupner, S., Nakao, S., Ramatschi, M. and Weise, A., 2001. Observatory Nokogiriyama / Japan: Comparison of different tiltmeters. Proc. 14th International Symposium on Earth Tides, Special Issue J. Geodetic Soc. of Japan, 47/1, 155 – 160.
Jentzsch, G., Malischewsky, P., Zaddro, M., Braitenberg, C., Latynina, A., Bojarsky, E., Verbytzkyy, T., Tikhomirov, A. and Kurskeev, A., 2001. Relations between different geodynamic parameters and seismicity in areas of high and low seismic hazards. Proc. 14th International Symposium on Earth Tides, Special Issue J. Geodetic Soc. of Japan, 47/1, 82 – 87.
Gutdeutsch, R., D. Kaiser, and G. Jentzsch, 2002. Estimation of earthquake magnitudes from epicentral intensities and other focal parameters in Central and Southern Europe. Geophys. J. Int., 151(3), 824 - 834.
Jentzsch, G. S. Graupner, A. Weise, H. Ishii, and S. Nakao, 2002. Environmental effects in tilt data of Nokogiriyama Observatory (extended abstract). Bulletin d'Information Marees Terrestres, 137, 10931 - 10936.
Jentzsch, G., M. Korn, and A. Špičák (eds.), 2003. The swarm earthquakes in the area Vogtland / NW-Bohemia: Interaction of tectonic stress and fluid migration in a magmatic environment. Special Issue J. Geodyn., 35, 1 / 2, 258 p.
Jentzsch, G., M. Korn, and A. Špičák, 2003. Editorial. In: Jentzsch, G., M. Korn, and A. Špičák (eds.): The swarm earthquakes in the area Vogtland / NW-Bohemia: Interaction of tectonic stress and fluid migration in a magmatic environment. Special Issue J. Geodyn., 35, 1 / 2, 1 -3.
Kurz, J., T. Jahr und G. Jentzsch, 2003. Geodynamic modelling of the recent stress and strain field in the Vogtland swarm earthquake area using the finite-element method. In: Jentzsch, G., M. Korn, and A. Špičák (eds.): The swarm earthquakes in the area Vogtland / NW-Bohemia: Interaction of tectonic stress and fluid migration in a magmatic environment. Special Issue J. Geodyn., 35, 1 / 2, 247 – 258.
Hemmann, A., T. Meier, G. Jentzsch, and A. Ziegert, 2003. Similarity of waveforms and relative relocation of the earthquake swarm 1997/98 near Werdau. In: Jentzsch, G., M. Korn, and A. Špičák (eds.): The swarm earthquakes in the area Vogtland / NW-Bohemia: Interaction of tectonic stress and fluid migration in a magmatic environment. Special Issue J. Geodyn., 35, 1 / 2, 191 – 208.

Curriculum Vita of Mike Thorne

Qualifications PhD FSRP

KEY SKILLS

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

CAREER HISTORY

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

Review Studies for the Proposed Australian National Radioactive Waste Repository

Client – RWE NUKEM

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

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

Client - BNFL

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

Co-ordination of biosphere research and participation in BIOCLIM

Client – UK Nirex Ltd

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

Effects of Radiation on Organisms Other Than Man

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

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

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

Support Studies on the Drigg Post-closure Performance Assessment
Client - BNFL
Biosphere Research Co-ordination and Assessment Studies
Client - United Kingdom Nirex Ltd

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

Site Investigation and Risk Assessment - Hilsea Lines
Client - Portsmouth City Council
Radiological assessment of a radium-contaminated site.

PROFESSIONAL ACTIVITIES AND MEMBERSHIP

- Fellow of the Society for Radiological Protection and Immediate Past President
- Member of the Eco-ethics International Union
- Visiting Fellow at the Climatic Research Unit, University of East Anglia

SELECTION OF PUBLICATIONS

The biosphere in post-closure radiological safety assessments of solid radioactive waste disposal, M C Thorne, Interdisciplinary Science Reviews, Vol. 23, 258-268, 1998.

Modelling radionuclide distribution and transport in the environment, K M Thiessen, M C Thorne, P R Maul, G Prohl and H S Wheater, Environmental Pollution, 100, 151-177, 1999.

Validation of a physically based catchment model for application in post-closure radiological safety assessments of deep geological repositories for solid radioactive wastes, M C Thorne, P Degnan, J Ewen and G Parkin, Journal of Radiological Protection, 20(4), 403-421, 2000.

Development of a solution method for the differential equations arising in the biosphere module of the BNFL suite of codes MONDRIAN, M M R Williams, M C Thorne, J G Thomson and A Paulley, Annals of Nuclear Energy, 29, 1019-1039, 2002.

Modelling sequential BIOsphere Systems under CLIMate change for radioactive waste disposal. Project BIOCLIM, D Texier, P Degnan, M F Loutre, D Paillard and M Thorne, Proceedings of the 10th International High-level Radioactive Waste Management Conference (IHLRWM), March 30th – April 2nd, Las Vegas, Nevada.

References

10 CFR 20 2008 — U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 – Energy. Part 20 – Standards for Protection Against Radiation.* 1-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr20_08.html.

10 CFR 51 2008 — U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 Energy. Part 51 – Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions.* 1-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr51_08.html. § 51.51 Uranium fuel cycle environmental data--Table S-3, is on the Web at http://www.nrc.gov/reading-rm/doc-collections/cfr/part051/part051-0051.html. Viewed on 1 February 2009.

10 CFR 60 2008 — U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 Energy: Chapter I Nuclear Regulatory Commission; Part 60 – Disposal Of High-Level Radioactive Wastes In Geologic Repositories*. 1-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr60_08.html.

10 CFR 61 2008 — U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 Energy: Chapter I Nuclear Regulatory Commission; Part 61 – Licensing Requirements For Land Disposal Of Radioactive Waste*. 1-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr61_08.html.

10 CFR 63 2008 — U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 Energy: Chapter I Nuclear Regulatory Commission; Part 63 – Disposal Of High-level Radioactive Wastes In A Geologic Repository At Yucca Mountain, Nevada*. 1-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr63_08.html.

40 CFR 190 2008 — U.S. Environmental Protection Agency. *Code of Federal Regulations. Title 40 – Protection of Environment. Chapter I Environmental Protection Agency. Part 190 – Environmental Radiation Protection Standards For Nuclear Power Operations*. 7-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/40cfr190_08.html.

40 CFR 191 2008 — U.S. Environmental Protection Agency. *Code of Federal Regulations. Title 40 – Protection of Environment. Chapter I – Environmental Protection Agency. Part 191 – Environmental Radiation Protection Standards For Management And Disposal Of Spent Nuclear Fuel, High-Level And Transuranic Radioactive Wastes*. 7-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; United States Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/40cfr191_08.html.

40 CFR 197 2008	U.S. Environmental Protection Agency. *Code of Federal Regulations. Title 40 – Protection of the Environment. Chapter I Environmental Protection Agency. Part 197 – Public Health and Environmental Radiation Protection for Yucca Mountain, Nevada*. 7-1-08 Edition. Washington, D.C.: Office of the Federal Register, National Archives and Record Service; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/40cfr197_08.html.
ANDRA 2001	Agence nationale pour la gestion des déchets radioactifs. *Dossier 2001 Argile, sur l'avancement des études & recherches relatives à la faisabilité d'un stockage de déchets à haute activite et à vie langue en formation géologique profonde. Rapport de synthèse.* Châtenay-Malabry: ANDRA, Décembre 2001.
BIA 2006	U.S. Bureau of Indian Affairs. "Notice of Availability of the Record of Decision (Rod) for a Proposed Lease of Tribal Trust Lands Between Private Fuel Storage, L.L.C. (PFS) and Skull Valley Band of Goshute Indian (Band) in Tooele County, UT," *Federal Register* v. 71, no. 192, October 4, 2006, pp. 58629 to 58630. On the Web at http://edocket.access.gpo.gov/2006/pdf/06-8484.pdf
BLM 2006	U.S. Bureau of Land Management, "Notice of Availability of the Record of Decision for the Right-of-Way Applications Filed by Private Fuel Storage, L.L.C., for an Independent Spent Fuel Storage Installation on the Reservation of the Skull Valley Band of Goshute Indians and the Related Transportation Facility in Tooele County, UT," *Federal Register* v. 71, no. 188, September 28, 2006, pp. 57005 to 57006. On the Web at http://edocket.access.gpo.gov/2006/pdf/E6-15734.pdf
Borchardt 2008	R.W. Borchardt. Subject: *Response to Commission Order CLI-05-20 Regarding Depleted Uranium*, Rule Making Issue. SECY-08-0147. Washington, DC: NRC, October 7, 2008. On the Web at http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2008/secy2008-0147/2008-0147scy.pdf.
CNE 2001	Commission Nationale d'Evaluation relative aux recherches sur la gestion des déchets radioactifs. *Rapport d'évaluation No 7*. Paris: CNE, juin 200. On the Web at http://lesrapports.ladocumentationfrancaise.fr/BRP/014000485/0000.pdf.
Deseret News 2006	Suzanne Struglinski. "Interior Department decisions stop nuclear-waste storage plans, Hatch says," *Deseret News*, September 7, 2006. On the Web at http://deseretnews.com/article/content/mobile/1,5620,645199671,00.html?printView=true
DOE 1980	U.S. Department of Energy. Final Environmental Impact Statement: Management of Commercially Generated Radioactive Waste. DOE/EIS-0046F. Washington, DC: DOE, Assistant Secretary for Nuclear Energy, Office of Nuclear Waste Management, Octor 1990. Vol. 1 on the Web at http://www.ocrwm.doe.gov/documents/1980_FEIS/33515/33515.pdf.
DOE 2007	U.S. Department of Energy. "Notice of Intent to Prepare an Environmental Impact Statement for the Disposal of Greater-Than-Class-C Low-Level Radioactive Waste," *Federal Register*, v. 72, no. 140, July 23, 2007, pp. 40135-40139. On the Web at http://edocket.access.gpo.gov/2007/pdf/E7-14139.pdf.
DOE 2007b	U.S. Department of Energy. "Notice of Intent to Prepare an Environmental Impact Statement for the Disposal of Greater-Than-Class-C Low-Level Radioactive Waste: Correction," *Federal Register*, v. 72, no. 146, July 31, 2007, p. 41819. On the Web at http://edocket.access.gpo.gov/2007/pdf/Z7-14139.pdf.

DOE 2008 U.S. Department of Energy, Office of Civilian Radioactive Waste Management, *Safety Analysis Report: Yucca Mountain Repository License Application*, DOE/RW-0573, Rev. 0, Las Vegas, NV: OCRWM, June 2008. Links on the Web at http://www.nrc.gov/reading-rm/adams/web-based.html, searching for ML081560400.

DOE 2008b U.S. Department of Energy. Office of Public Affairs. *U.S. Department of Energy Releases Revised Total System Life Cycle Cost Estimate and Fee Adequacy Report for Yucca Mountain Project*. [Press Release]. Washington, DC: DOE, August 5, 2008. On the Web at http://www.ocrwm.doe.gov/info_library/newsroom/documents/8_5_08_FINAL_TSLCC_PR.pdf.

DOE EIA 2009 U.S. Department of Energy. Energy Information Administration. "Table 1.1. Net Generation by Energy Source: Total (All Sectors), 1994 through October 2008 (Thousand Megawatthours)." *Electric Power Monthly* with data for October 2008, Report Released: January 15, 2009. On the Web at http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html.

DOE OCRWM 1999 U.S. Department of Energy. Office of Civilian Radioactive Waste Management. "NWTRB Repository Panel meeting: Postclosure Defense in Depth in the Design Selection Process," presentation for the Nuclear Waste Technical Review Board Panel for the Repository, January 25, 1999. Presented by Dennis C. Richardson. Online at http://www.nwtrb.gov/meetings/1999/jan/richardson.pdf.

DOE OCRWM 2008 U.S. Department of Energy. Office of Civilian Radioactive Waste Management. How Much Nuclear Waste Is In The United States? Washington, DC: DOE, last reviewed: 04/08. On the Web at http://www.ocrwm.doe.gov/ym_repository/about_project/waste_explained/howmuch.shtml.

EPA 2001 U.S. Environmental Protection Agency. "40 CFR Part 197: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV: Proposed Rule." *Federal Register*, v. 66, no. 114, June 13, 2001. pp. 32074-32135. On the Web at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2001_register&docid=01-14626-filed.pdf.

EPA 2005 U.S. Environmental Protection Agency. "40 CFR Part 197: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV: Proposed Rule." *Federal Register*, v. 70, no. 161, August 22, 2005. pp. 49014-49065. On the Web at http://edocket.access.gpo.gov/2005/pdf/05-16193.pdf.

EPA 2008 U.S. Environmental Protection Agency. "40 CFR Part 197: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada, Final Rule." *Federal Register*, v. 73, no. 200, October 15, 2008. pp. 61256-61289. On the Web at http://edocket.access.gpo.gov/2008/pdf/E8-23754.pdf.

FGR 13 1999 and 2002 Suppl. Keith F. Eckerman, Richard W. Leggett, Christopher B. Nelson, Jerome S. Puskin, and Allan C.B. Richardson. *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*. EPA 402-R-99-001. Federal Guidance Report No. 13, CD Supplement. Rev. 1. Oak Ridge, TN: Oak Ridge National Laboratory; Washington, DC: Office of Radiation and Indoor Air, U.S. Environmental Protection Agency, April 2002. Includes original 1999 FGR no. 13, which is also on the Web at http://www.epa.gov/radiation/docs/federal/402-r-99-001.pdf/.

Franke and Makhijani 1987	Bernd Franke and Arjun Makhijani. *Avoidable Death: A Review of the Selection and Characterization of a Radioactive Waste Repository in West Germany*. Washington, DC: Health & Energy Institute; Takoma Park, MD: Institute for Energy and Environmental Research, November 1987.
GNEP PEIS draft 2008	U.S. Department of Energy and Global Nuclear Energy Partnership. *Draft Global Nuclear Energy Partnership Programmatic Environmental Impact Statement*. DOE/EIS-0396. Washington, DC: DOE, October 2008. Links on the Web at http://www.gnep.energy.gov/peis.html. Summary on the Web at http://www.gnep.energy.gov/peis/Draft_PEIS/Summary.pdf.
GTCC EIS website	U.S. Department of Energy. Office of Environmental Management. *Why the GTCC LLW EIS is Needed*. DOE's Argonne National Laboratory, viewed February 2, 2009. On the Web at http://www.gtcceis.anl.gov/eis/why/index.cfm.
HEAL Utah 2006	Healthy Environment Alliance of Utah. *Private Fuel Storage: Incredible News: PFS Proposal Dead!* [Salt Lake City]: HEAL Utah, [2006?]. On the Web at http://healutah.org/nuclearutah/waste/pfs.
Hooper 2006	Alan J. Hooper. "The Long-Term Management of the United Kingdom's Radioactive Waste: Status in 2005," in *Geological Challenges in Radioactive Waste Isolation: Fourth Worldwide Review*, P.A. Witherspoon and G.S. Bodvarsson, eds., LBNL-59808 (Lawrence Berkeley National Laboratory, Berkeley, CA, 2006); pp. 249-255. On the Web at http://www-esd.lbl.gov/NW/pdfs/lbnl-59808-wwr4.pdf.
IEER 2005	Institute for Energy and Environmental Research. *Examen critique du programme de recherche de l'ANDRA pour déterminer l'aptitude du site de Bure au confinement géologique des déchets à haute activité et à vie longue*, Rapport Final, préparé par l'Institut pour la recherche sur l'énergie et l'environnement IEER) pour Le Comité Local d'Information et de Suivi, 27 décembre 2004, avec corrections 11 janvier 2005. The authors of the report were: Detlef Appel, Prof. Jaak Daemen, George Danko, Yuri Dublyansky, Rod Ewing, Gerhard Jentzsch, Horst Letz, Arjun Makhijani. On the Web at http://www.ieer.org/reports/bure/1204index.html.
Irish Times 2008	"Sellafield Decommissioning to Take Over 100 Years," *Irish Times*, July 10, 2008. On the Web at http://www.irishtimes.com/newspaper/breaking/2008/0710/breaking5.htm.
LLRWPAA 1985	Public Law 99-240, "Low-Level Radioactive Waste Policy Amendments Act of 1985," (99 Stat.1842), January 15, 1986. On the Web at http://www.gtcceis.anl.gov/documents/docs/LLRWPAA.pdf. Includes text of Public Law 96-573. This copy is missing one page. Request sent to ANL to add page.
Loehr, Nygaard, and Watson 1993	Raymond C. Loehr, Oddvar F. Nygaard, and James E. Watson. Cover letter to Carol M. Browner, forwarding the review of the report entitled *Issues Associated with Gaseous Releases of Radionuclides for a Repository in the Unsaturated Zone*, April 29, 1993. The letter and the review report (EPA-SAB-RAC-93-010) are on the Web at http://yosemite.epa.gov/sab/sabproduct.nsf/95eac6037dbee075852573a00075f732/147c6c914dfa47dc8525731b006f2e81!OpenDocument.

Lundqvist 2006	Berit Lundqvist. "The Swedish Program for Spent-Fuel Management," in *Geological Challenges in Radioactive Waste Isolation: Fourth Worldwide Review,* P.A. Witherspoon and G.S. Bodvarsson, eds., LBNL-59808 (Lawrence Berkeley National Laboratory, Berkeley, CA, 2006), pp. 227-237. On the Web at http://www-esd.lbl.gov/NW/pdfs/lbnl-59808-wwr4.pdf.
Makhijani 1986	Arjun Makhijani. *Comments on the Department of Energy's Draft Area Recommendation Report, DOE/CH-15 (1), January 1986*. Washington, DC: National Committee for Radiation Victims, April 5, 1986.
Makhijani 2008	Arjun Makhijani. *The Use of Reference Man in Radiation Protection Standards and Guidance with Recommendations for Change*. Takoma Park, MD: Institute for Energy and Environmental Research, December 2008. On the Web at http://www.ieer.org/reports/referenceman.pdf.
Makhijani and Makhijani 2006	Arjun Makhijani and Annie Makhijani. "Disposal of Long-Lived Highly Radioactive Wastes in France: An IEER Evaluation," *Science for Democratic Action*, v.13, no.4, January 2006. On the Web at http://www.ieer.org/sdafiles/13-4.pdf. .
Makhijani and Saleska 1992	Arjun Makhijani and Scott Saleska. High-Level Dollars, *Low*-Level *Sense*. New York: Apex Press, 1992. Selected chapters on the Web at http://www.ieer.org/pubs/highlvl1.html.
Makhijani and Smith 2004	Arjun Makhijani and Brice Smith. *Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico by LES.* Takoma Park, MD: Institute for Energy and Environmental Research, November 24, 2004. On the Web at http://www.ieer.org/reports/du/lesrpt.pdf. "Version for Public Release Redacted March 20, 2007."
Makhijani and Smith 2005	Arjun Makhijani and Brice Smith. *Comments on the U.S. Environmental Protection Agency's Proposed Rule for the Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada.* Takoma Park, Institute for Energy and Environmental Research, November 21, 2005. On the Web at http://www.ieer.org/comments/waste/yuccaepa.htmlhttp://www.ieer.org/comments/waste/yuccaepa.html.
Makhijani and Tucker 1985	Arjun Makhijani and Kathleen M. Tucker. *Heat, High Water, and Rock Instability at Hanford: A Preliminary Assessment of the Suitability of the Hanford, Washington Site for a High-Level Nuclear Waste Repository*. Washington. DC: Health and Energy Institute, February 1985.
NAS-NRC 1983	National Research Council. Commission on Physical Sciences, Mathematics, and Resources. Board on Radioactive Waste Management. Waste Isolation Systems Panel. *A Study of the Isolation System for Geologic Disposal of Radioactive Wastes.* Washington, DC: National Academy Press, 1983.
NAS-NRC 1995	National Research Council. Board on Radioactive Waste Management. Committee on Technical Bases for Yucca Mountain Standards. *Technical Bases for Yucca Mountain Standards*. National Academy Press, Washington, D.C., 1995. On the Web at http://books.nap.edu/catalog.php?record_id=4943.

NAS-NRC 2000	National Research Council. Board on Radioactive Waste Management. Commission on Geosciences, Environment, and Resources. *Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites*. Washington, DC: National Academy Press, 2000. On the Web at http://www.nap.edu/catalog.php?record_id=9949.
Nevada timeline 1999	Nevada. Nuclear Waste Project Office. *Nuclear Waste Policy Dilemma - The First Fifty Years*. Carson City, NV: NWPO, [1999?]. On the Web at http://www.state.nv.us/nucwaste/yucca/nwchron1.htm.
Nevada v. EPA 2008	State of Nevada v. Environmental Protection Agency (D.C. Cir., No. 08-1327, consolidated with No. 08-1345)
NRC 1979	U.S. Nuclear Regulatory Commission. "10 CFR Part 51: Licensing and Regulatory Policy and Procedures for Environmental Protection; Uranium Fuel Cycle Impacts from Spent Fuel Reprocessing and Radioactive Waste Management, Promulgation of a final fuel cycle rule," *Federal Register*, v. 44, published 8/12/79; effective 9/4/79, as reprinted in "Part 51: Statements of Consideration," pp. 51-SC-7 to 51-SC-18.
NRC 1981	U.S. Nuclear Regulatory Commission. "10 CFR Part 51, Appendix A, Narrative Explanation of Table S-3, Uranium Fuel Cycle Environmental Data," *46 FR 15154,* March 4, 1981. (*Federal Register*, v. 46, pp. 15154+)
NRC 1982	U.S. Nuclear Regulatory Commission. *Final Environmental Impact Assessment on 10 CFR 61 'Licensing Requirements for Land Disposal of Radioactive Waste.* NUREG-0945. Washington, DC: NRC, Office of Nuclear Material Safety and Safeguards, November 1982.
NRC 1996	U.S. Nuclear Regulatory Commission. *Generic Environmental Impact Statement for License Renewable of Nuclear Plants*. NUREG-1437. Washington, DC: NRC, Office of Nuclear Regulatory Research, May 1996. Links on the Web at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1437.
NRC 2005	U.S. Nuclear Regulatory Commission, *Memorandum and Order, CLI-05-20*, In the Matter of Louisiana Energy Services, L.P. (National Enrichment Facility) Docket No. 70-3103-ML, October 19, 2005. On the Web at http://www.nrc.gov/reading-rm/doc-collections/commission/orders/2005/2005-20cli.html.
NRC 2008	U.S. Nuclear Regulatory Commission. "Waste Confidence Decision Update," *Federal Register* v. 73, no. 197, October 9, 2008, pp. 59551 to 59570. On the Web at http://edocket.access.gpo.gov/2008/pdf/E8-23381.pdf.
NRC 2008b	U.S. Nuclear Regulatory Commission. "Consideration of Environmental Impacts of Temporary Storage of Spent Fuel after Cessation of Reactor Operation," *Federal Register* v. 73, no. 197, October 9, 2008, pp. 59547 to 59551. On the Web at http://edocket.access.gpo.gov/2008/pdf/E8-23384.pdf.
NRC 2008c	U.S. Nuclear Regulatory Commission. "New England Coalition on Nuclear Pollution; Denial of Petition for Rulemaking," *Federal Register*, v. 73, no. 55, March 20, 2008, pp. 14946-149549. On the Web at http://edocket.access.gpo.gov/2008/pdf/E8-5647.pdf.

NUREG-0116 — William P. Bishop and Frank J. Miraglia, Jr, editors. *Environmental Survey of the Reprocessing and Waste Management Portion of the LWR Fuel Cycle*. *NUREG-0116* (Supp.1 to WASH-1248). Washington, DC: Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, October 1976.

NWPA 1982 — Nuclear Waste Policy Act of 1982. On the Web at http://epw.senate.gov/envlaws/nwpa82.pdf.

NWTRB 2008 — U.S. Nuclear Waste Technical Review Board. *Report to The U.S. Congress and The Secretary of Energy: March 1, 2006-December 31, 2007*. Arlington, VA: NWTRB, [2008]. On the Web at http://www.nwtrb.gov/reports/nwtrb_2007_web_508.pdf.

Obama 2007 — Barack Obama, "Barack Obama Explains Yucca Mountain Stance," Letter to the Editor, *Las Vegas Review-Journal* (May 20, 2007). On the Web at http://www.lvrj.com/opinion/7598337.html.

Pigford 1995 — Thomas H. Pigford. "Invalidity of the Probabilistic Exposure Scenario Proposed by the National Research Council's TYMS Committee." UCB-NE-9523. Berkeley, CA: Nuclear Engineering Department, University of California, November 1995, as cited in "Calculating Doses from Disposal of High-Level Radioactive Waste: Review of a National Academy of Sciences Report," by Arjun Makhijani, (*Science for Democratic Action* v.4, no.4, Fall 1995). On the Web at http://www.ieer.org/sdafiles/vol_4/4-4/4_4art1.html.

Scottish Government 2007 — Scottish Government. "Ministers Decline to Endorse Deep Storage," News Release, June 25, 2007. On the Web at http://www.scotland.gov.uk/News/Releases/2007/06/25101822.

Shettel 2004 — Don L. Shettel (Chairman, Geoscience Management Institute, Inc.). Comments before the United States Nuclear Waste Technical Review Board, transcript of the May 18, 2004 meeting, pp. 239-240. On the Web at http://www.nwtrb.gov/meetings/2004/may/04may18.pdf.

Staehle 2004 — Roger W. Staehle. *Bases for Predicting Occurrences of Rapid Corrosion on the Surfaces of Containers of C-22 at Yucca Mountain*, presented at the Spring Meeting of the NWTRB…May 18, 19, 2004 On the web at http://www.nwtrb.gov/meetings/2004/may/staehle.pdf.

Staehle 2004b — Roger Staehle (Materials Science and Engineering Consultant). Comments before the Nuclear Waste Technical Review Board, transcript of the May 18, 2004 meeting, p. 241. On the Web at http://www.nwtrb.gov/meetings/2004/may/04may18.pdf.

Wald 1991 — Matthew L. Wald, "Hired to be Negotiator, but Treated Like Pariah," *New York Times,* February 13, 1991. On the Web at http://query.nytimes.com/gst/fullpage.html?res=9D0CE5DC163BF930A25751C0A967958260&sec=&spon=&pagewanted=all.

WASH-1248 — U.S. Atomic Energy Commission. *Environmental Survey of the Uranium Fuel Cycle*. WASH-1248. Washington, DC: AEC, Fuels and Materials – Directorate of Licensing, April 1974.

White 1983 Donald E. White. "Background Paper for Assessment of Basalt Lava Flows (BWIP), Washington." June 1983 & the "Foreword to the Appendix [i.e., to "Background Paper for Assessment of Basalt Lava Flows, Hanford, Washington"], supplement to *Heat, High Water, and Rock Instability at Hanford: A Preliminary Assessment of the Suitability of the Hanford, Washington Site for a High-Level Nuclear Waste Repository*, by Arjun Makhijani and Kathleen M. Tucker (Washington. DC: Health and Energy Institute, February 1985).