# 1
# INTRODUCTION

On June 3, 2008, the U.S. Department of Energy (DOE) submitted a license application to the U.S. Nuclear Regulatory Commission (NRC) for authorization to construct a deep geologic repository for disposal of High Level Nuclear Waste (HLW) and commercial Spent Nuclear Fuel (CSNF). The Yucca Mountain license application represents a milestone itself as the culmination of close to two decades of study and evaluation. As a candidate licensee for the construction and eventual operation of a deep geologic HLW repository, DOE has made numerous assumptions and estimates that are conservative in nature. For example, in the January 2008 Total System Performance Assessment – License Application Analysis and Model Report (referred to within this report as the TSPA-LA AMR or TSPA-LA) (DOE, 2008a, pg. ES-9], DOE states: "Typically, when two or more models exist for the same phenomena and data, the more conservative one from a total-system perspective has been chosen for implementation."

For nearly 20 years, the Electric Power Research Institute (EPRI) has been reviewing the U.S. Department of Energy's development of the proposed geologic repository for disposal of high-level radioactive waste and spent nuclear fuel at Yucca Mountain, Nevada. Independent analyses and data collection conducted by EPRI suggest that there are many issues with respect to the current DOE design and analyses, as presented in the License Application, that may result in unnecessary occupational health hazards to workers in the nuclear industry and other related industries.

In its Yucca Mountain Review Plan (NRC, 2003), NRC states:

> Consideration of radiological risk in the design and construction of the repository and the limitation of such risk is also consistent with a commitment to the 'As Low as Reasonably Achievable' (ALARA) principles of Regulatory Guide 8.8, as is called for in 10 CFR Part 20 and Section 2.1.1.8 of NUREG 1804, the Yucca Mountain Review Plan (YMRP).

Thus, NRC is stating it will review DOE's Yucca Mountain license application with consideration of ALARA principles. In this report, EPRI has interpreted NRC (2003) to mean ALARA principles should be considered for the *entire* spent fuel waste management process – from storage of commercial spent nuclear fuel (CSNF) at the reactor sites, loading and transfer of CSNF at the reactor sites, transportation of the CSNF to receipt, handling, and disposal of the CSNF at Yucca Mountain. EPRI has considered both radiological and non-radiological occupational health and safety risks during reactor-site storage, CSNF transfer and loading, CSNF transportation, CSNF management at Yucca Mountain, and construction of appropriate CSNF management facilities at the reactor sites and at Yucca Mountain.

The purpose of this report is to identify those issues and provide semi-quantitative estimates of the "unnecessary" occupational health risks that may result from the DOE Yucca Mountain analyses and repository design such that the proposed analyses and designs are not consistent with ALARA principles. While EPRI recognizes there could be additional, "unnecessary" health hazards to the public due to DOE's analysis and design, public health hazards are not assessed quantitatively in this report. Except on a limited basis, neither will this report quantitatively estimate economic consequences of unnecessary or inappropriate elements of the DOE design or analyses.

For purposes of this report, the term "unnecessary" is intended to mean the additional risk that may be incurred by performing an activity in the manner proposed by DOE versus the more limited amount of risk that may be incurred by performing the activity in some alternative manner that EPRI considers to be more consistent with the principles of ALARA. The difference between the two levels of risk is considered by EPRI to be "unnecessary." EPRI recognizes that there are a certain amount of hazards and risks associated with all such activities and that it is impossible to reduce such hazards and risks to zero.

In this report, the terms "risk", "hazard", "impact", "consequence", among others are used in their most general sense and interchangeably to denote the undesirable outcome or effect that results from an action, assumption, or decision made by DOE in its approach to the design, assessment, and operation of Yucca Mountain. EPRI recognizes that these terms also have more precise technical meanings.

As in other EPRI reports, the intent of this report is not to present worst-case analyses, but rather to adhere to the intent of the EPA's proposed regulatory structure in 40 CFR 197 (EPA, 2005), which is to provide more realistic analyses:

> Overly conservative assumptions made in developing performance scenarios can bias the analyses in the direction of unrealistically extreme situations, which in reality may be highly improbable, and can deflect attention from questions critical to developing an adequate understanding of the expected features, events, and processes ("Assumptions, Conservatisms, and Uncertainties in Yucca Mountain Performance Assessments," Sections 11 and 12, July 2005, Docket No. OAR-2005-0083-0085). The reasonable expectation approach focuses attention on understanding the uncertainties in projecting disposal system performance so that regulatory decision making will be done with a full understanding of the uncertainties involved. Thus, realistic analyses are preferred over conservative and bounding assumptions, to the extent practical. (40 CFR 197: EPA, 2005)

According to 40 CFR 197.14, "reasonable expectation":

- "Requires less than absolute proof because absolute proof is impossible to attain…"
- "Accounts for the inherently greater uncertainties in making long-term projections…"
- "Does not exclude important parameters from assessments and analyses simply because they are difficult to precisely quantify…"
- "Focuses performance assessments and analyses upon the full range of defensible and reasonable parameter distributions rather than only upon extreme physical situations and parameter values"

While some conservatism in the face of uncertainty is warranted, especially given the proposed one million year compliance period for repository performance, repeated application of overly conservative assumptions and estimates in performance assessment will likely result in overly designed facilities in order to provide excess performance margins for the protection of the health of hypothetical future lives at the expense of present day workers and public. Overly conservative and unrealistic assessment of repository performance is not a risk-neutral endeavor. Each additional activity undertaken by DOE and its contractors during construction, operation, and closure of the repository carries with it finite levels of risk to the workers that must carry out those activities. Moreover, assumptions integral to the DOE proposed approach to the repository also have serious consequences for the utilities that currently manage the spent nuclear fuel onsite in wet and/or dry storage configurations.

DOE's cleanup efforts under its Environmental Management program have been repeatedly criticized for what has been termed "the unacknowledged transfer of risk" (Young and Wood, 2001; Church, 2001) in which conservative assumptions drive costly remedial actions that impose unjustified risks of fatalities and injuries to workers and the public during construction and transportation.

Workers, including those at utility sites, are likely to bear the greatest burden associated with such risk transfer each time DOE chooses overly conservative options in its repository design, analyses, and operational planning.

Workers are likely to bear the greatest burden associated with such unintended and unjustified transfers of risk each time DOE chooses overly conservative options in its repository design, analyses, and operational planning. Unjustified and unnecessary elements of the DOE license application represent an unfair and unjustified transfer of risk from hypothetical future lives to existing nuclear industry and utility workers, as well as present day members of the public.

The purpose of this report is bring attention to elements of the DOE total-system performance assessment and proposed approach to the repository design, construction, and operation, as presented in the 2008 license application and supporting documents, that could result in additional, non-trivial risk burdens for present day workers both in terms of radiological and non-radiological risks, and to provided quantitative estimates of those risks, where possible.

## 1.1 Issues and Potential Consequences for Occupational Health

The issues and potential unnecessary occupational health hazards are summarized in the following subsections. Each of these issues and their effect on occupational health risks are discussed in more detail in the following chapters.

### *1.1.1 Some Dual-purpose Canisters are Suitable for Direct Disposal*

EPRI analyses suggest that at least some of the existing dual-purpose canisters (DPCs) used by the nuclear industry could be safely transported, aged, and disposed of at Yucca Mountain. Currently licensed DPCs hold approximately 1.14 to 1.55 times as much SNF as do TADs. Thus, using TADs instead of DPCs will result in 1.14 to 1.55 times as many canisters being loaded at nuclear utility sites, transported to Yucca Mountain, potentially aged, and eventually emplaced in the repository.

*Potential impact on occupational health:*
The DOE decision to not consider direct disposal of DPCs in its License Application imposes significant unnecessary occupational health risks on workers associated with the operations needed to open the loaded DPCs, transfer the CSNF to a TAD canister, manage the empty DPCs as low-level radioactive waste (LLW), and close the newly loaded TAD. Also significant would be the additional occupation risks borne by workers due to the need for additional loading TAD canisters arising from the limited capacity of the TAD versus larger capacity DPCs.

### 1.1.2 The Size of the Proposed Transportation, Aging, and Disposal Canisters is Smaller than is Necessary

DOE has proposed the use of transportation, aging, and disposal canisters (TADs) such that the utilities would load commercial spent nuclear fuel (CSNF) into the TAD canisters at the reactors, and with appropriate transportation, aging, and disposal overpacks, the TAD canisters would not need to be reopened after closure at the reactor sites. DOE also proposed to use TAD canisters for CSNF it will receive at Yucca Mountain from the utilities that would arrive in shipping containers other than TADs. The proposed capacity of the TADs is 21 pressurized water reactor (PWR) assemblies or 44 boiling water reactor (BWR) assemblies. Assuming DOE and the utilities reach agreement on the use of TADs at reactor sites, the sizes of the TADs are smaller than is necessary to reliably meet EPA and NRC regulatory performance criteria. EPRI analyses suggest that TADs could be up to 1.55 times larger without impinging on overall repository performance or exceeding thermal design limits. Thus, using TADs instead of DPCs will result in up to 1.55 times as many canisters being loaded at nuclear utility sites, transported to Yucca Mountain, potentially aged, and then disposed.

*Potential impact on occupational health:*
Using the proposed 21P/44B TAD size compared to use of a larger TAD, with a capacity that is similar to larger capacity DPCs currently in use for on-site dry storage, will result in additional unnecessary radiological and non-radiological risks borne by workers at utility sites, at Yucca Mountain itself, and in the transportation sector. These impacts result from the need for additional activities associated with canister loading, transport, and handling at Yucca Mountain. Each additional waste package will require excavation of an additional length of emplacement drift. Additional installation of drift hardware (invert, pallet, drip shield) and subsurface infrastructure (rock bolts, tunnel (mesh) liner), along with additional person-hours of labor associated with all aspects of handling, maintenance, inspection, and emplacement. In additional, manufacturing of additional repository system components for waste packages and developed drift components, will incur additional occupational risk during their manufacture and transport.

### 1.1.3 DOE Underestimated the Amount of Commercial Spent Nuclear Fuel Arriving at Yucca Mountain not in TADs

Even assuming the use of TADs, DOE has underestimated the amount of commercial spent nuclear fuel (CSNF) that would be shipped to Yucca Mountain in non-TADs. While DOE estimates a base case of 10% and a maximum of 25% of the CSNF would be shipped in non-TADs, EPRI estimates that more than 25% of the CSNF will already have been placed in non-TAD containers. At present, the DOE and utilities have not entered into specific agreements regarding the use of TADs for Yucca Mountain disposal, yet the proposed action does not specifically provide for CSNF acceptance in any form other than in TADs or as bare fuel.

*Potential impact on occupational health:*
Since DOE has underestimated the amount of CSNF that will be stored in canisters other than TADs at the reactor sites (mostly in DPCs), it may be necessary for workers to open and unload even more DPCs than discussed in Section 1.1.1. The use of additional TADs and the potential need to repackage CSNF already in DPCs at Yucca Mountain, and potentially at the utility sites, will cause increases in potential occupational hazards with respect to the reopening and unloading of existing DPCs, CSNF transfer from the DPCs into TADs, TAD closure, and

preparation of the TAD and its transportation overpack for shipment of CSNF to Yucca Mountain. In addition, there would be additional handling of CSNF in more TADs (relative to the number of DPCs due to the TADs' lower CSNF capacities) at Yucca Mountain. By requiring that only a fraction of the CSNF that will exist in DPCs or other storage canisters can be shipped to Yucca Mountain without repackaging into TADs, there will be increased occupational risks associated with additional handling of CSNF in DPCs including radiological and non-radiological risks.

### 1.1.4 The Probability of Igneous Activity within the Repository Footprint has been Overestimated

EPRI has determined that the probability of an igneous event intersecting the Yucca Mountain repository is less than $10^{-8}$ per year. As such, potential consequences of igneous activity need not be presented in DOE's license application per the draft 40 CFR 197 Yucca Mountain regulation. Furthermore, EPRI has determined that DOE's estimates of consequences due to igneous eruption and intrusion scenarios have been overstated.

*Potential impact on occupational health:*
Including igneous consequence analysis in the Yucca Mountain licensing proceedings could cause unnecessary delays in the licensing proceedings by deflecting attention from questions critical to developing an adequate understanding of the expected features, events, and processes. This could cause nuclear utilities to have to load and store additional spent nuclear fuel at the reactor sites, leading to additional radiation dose to both workers and the public nearby to the spent fuel storage facilities. In addition, workers involved with loading and transferring spent fuel storage casks at the utility sites would be exposed to additional, non-radioactive hazards involved with potential accidents leading to worker injury.

### 1.1.5 Drip Shields are Unnecessary

There are several conservatisms in DOE's analyses of post-closure performance that have led DOE to unnecessarily include drip shields in its repository design.

- Overestimation of the amount of net infiltration thereby incorrectly indicating a larger benefit of the use of a drip shield than is actually the case;
- Overestimation of the fraction of the repository experiencing seepage into the open drifts, having the same effect as overestimation of net infiltration;
- Overestimation of seismic energy and rockfall. This leads DOE to the conclusion that drip shields would provide significant protection from rockfall;
- Overestimation of damage to the TADs due to seismic and rockfall events. This also leads to the incorrect conclusion that drip shields would provide additional protection from damage of the waste packages;
- Overestimation of the rate at which Alloy 22 will degrade. This, in turn, gives greater performance credit to the drip shields than is warranted. This could lead to additional, unnecessary regulatory scrutiny that could delay the licensing process;
- Cladding performance has been neglected. EPRI analyses indicate that including cladding performance would provide an additional barrier to the release of radionuclides from the waste form. This would also reduce the need for a drip shield;

- DOE notes that it typically uses the more conservative of two or more conceptual models. Some of these conservatisms could also result in the apparent need for drip shields.

*Potential impact on occupational health:*
The construction, transportation, and installation of drip shields would cause unnecessary, radiological and non-radiological occupational health hazards. Mining of titanium, conversion to metal, and manufacture of the drip shields would cause unnecessary industrial hazards to the relevant workers and will put pressure on available titanium resources. Installation of the drip shields would also impose unnecessary risks to Yucca Mountain workers.

### 1.1.6 The Surface Facilities have been Overdesigned to Withstand Seismic Ground Motion

DOE has assessed the risk of seismic ground motion during the pre-closure period. While it is certainly necessary to design systems, structures, and components to withstand this risk, EPRI believes DOE's surface facility is overdesigned for this risk. This has led to an unnecessarily large, robust surface facility structures and elements.

*Potential impact on occupational health:*
Additional health risks to workers and the public caused by the construction of over-designed surface and sub-surface facilities would be caused by, for example, transportation and use of additional construction materials and additional, unnecessary construction activities.

### 1.1.7 DOE Overestimated the Seismic Energy that is Possible During the Post-closure Period

EPRI contends that DOE's estimates of seismic energy risk at Yucca Mountain are overstated – especially for the long recurrence interval seismic events. Because DOE has overestimated seismic energy, it has also overestimated the amount and timing of rockfall (especially during the time period shortly after repository closure). This has led to an overestimate of dose to the public in DOE's analyses, especially for early times after repository closure.

*Potential impact on occupational health:*
This could also cause a delay in the availability of the Yucca Mountain repository if, for example, DOE needs to perform additional, unnecessary construction tasks to accommodate DOE's overestimate of seismic energy. Furthermore, EPRI feels that one of the reasons DOE has specified a very robust TAD design is to mitigate damage to the TAD overpack that could be caused by the seismic energy overestimates. Additional delays in the ability to move CSNF from reactor sites to the Yucca Mountain repository could be caused by the need to develop, license, construct, load, and dispose of unnecessarily robust TAD canisters and overpacks. Delays in the ability to move CSNF to Yucca Mountain could cause both occupational and public radiological and non-radiological health hazards.

### 1.1.8 Co-disposal versus TAD Waste Package Design and/or Analysis Caused the Peak Dose to be Driven by Co-disposal Waste Packages

It appears that DOE's TSPA indicates the first peak in post-closure dose is due primarily to the relatively early failure of the co-disposal waste packages compared to the now very robust TAD waste packages for CSNF. The first peak is roughly the same magnitude as the peak due primarily to TAD failure many hundreds of thousands of years in the future. There are also conservatisms in how DOE calculates the peak dose for the co-disposal waste packages.

*Potential impact on occupational health:*
The fact that DOE has estimated the peak dose due to co-disposal waste packages is roughly the same as from the TADs containing CSNF may cause unnecessary regulatory scrutiny, thereby leading to potential licensing delays. Occupational health impacts due to delays in opening the repository have been discussed earlier.

### 1.1.9 The Spacing between Disposal Drifts is Unnecessarily Large

DOE's drift center-to-center spacing requirement of 81 meters is based on conservative estimates of temperature in the rock pillars over time, as well as the artificially imposed requirement of keeping some of the rock pillar below boiling temperatures at all times. The result of the unnecessarily large drift spacing is that more rock will need to be excavated, and more rock supports will need to be installed than is actually necessary.

*Potential impact on occupational health:*
Excavation of additional rock and installation of additional rock supports will increase both the radiological and non-radiological hazard to workers excavating the drifts and installing the rock support, as well as occupational and public health hazards due to the transportation of extra rock support materials;

### 1.1.10 The Waste Handling Facility Throughput DOE proposes is Insufficient to Process the CSNF that will be Shipped to Yucca Mountain not in TADs

As discussed above, EPRI concludes there will be more CSNF shipped to Yucca Mountain that would need to be processed in DOE's Wet Handling Facility (WHF) than DOE is planning in its Proposed Action. Either DOE will need to construct additional WHFs or it will take longer to process the larger amount of CSNF in one WHF.

*Potential impact on occupational health:*
If all 63,000 MTHM of CSNF is to be processed in 24 years as DOE proposes, additional WHFs will have to be constructed, with the concomitant increase in occupational health risks due to material fabrication and transportation, and construction activities. Additional WHF construction will likely lead to a delay in the ability to transfer CNSF from reactor sites to Yucca Mountain. Alternatively, if just one WHF is constructed, the it will require additional processing time, which could cause nuclear utilities to have to load and store additional spent nuclear fuel at the reactor sites, leading to additional radiation dose to both workers and the public nearby to the spent fuel storage facilities. In addition, workers involved with loading and transferring spent fuel storage casks at the utility sites would be exposed to additional, non-radioactive hazards involved with potential accidents leading to worker injury.

### 1.1.11 Conservatisms in DOE Analyses Led to an Overestimate of Post-closure Dose

EPRI has determined that DOE's TSPA has incorporated many conservatisms that have led DOE to overestimate dose rates to the RMEI during the post-closure period. These many conservatisms cannot simply be considered independently, since many conservatisms compound with others, so that the net effect is greater than each taken individually.

*Potential impact on occupational health:*
Because DOE's multiple conservatisms cause DOE to overestimate dose rates to the RMEI, the repository system design may be more robust than a repository design based on a different design based on more reasonable assumptions and data inputs to DOE's dose assessment calculations. Secondarily, the loss of margin below the draft EPA and NRC dose limits has the potential to increase the licensing process. Either of these causes could lead to a delay in the availability of Yucca Mountain. Any delay in the licensing, construction, and operation of the repository places additional radiological and non-radiological risk burdens on workers at the utility sites due to the need to construct additional ISFSI capacity; to extend and/or expand inspection and maintenance programs for existing ISFSI facilities at operating plants.

## 1.2 Approach

EPRI's approach in developing the analyses in this report was to utilize, as possible and appropriate, cautious but realistic assumptions in the performance of its various analyses and investigations, as recommended by the National Academy of Sciences in its *Technical Bases for Yucca Mountain Standards* report (NAS, 2005). For example:

- Occupational risk is considered only for involved workers, although it is recognized that each additional unit of activity requires the support of professionals and other ancillary staff that are not directly exposed to the hazards of the work site but still incur risk associated with office settings and travel to and from work. These additional workers are typically referred to a "non-involved workers."
- Whenever possible and where deemed appropriate, EPRI utilized DOE data and estimates obtained from the various Yucca Mountain related documents such as the Environmental Impact Statements, the License Application itself, and supporting documents and calculation packages. This was done in order for EPRI to be able to make direct comparison between its assessment of worker risk and the risk calculations contained in the DOE documents. In the event that the DOE data and estimates were not available or are did not provide enough supporting detail to allow for derivative analysis, EPRI used publicly available data from the U.S. Nuclear Regulatory Commission (NRC), Bureau of Labor Statistics (BLS), and other citable sources.
- DOE performed a detailed assessment of impacts to workers at nuclear power plants sites and DOE sites in its analysis of the No Action Alternative for the Yucca Mountain EIS, as supplemented. EPRI relied on some of the at-reactor worker impacts utilized by DOE in its No Action Alternative analysis. When available, EPRI has also identified other citable sources of data associated with worker impacts at nuclear power plant sites.
- Collective occupation dose is the primary metric used in this report for tracking radiological risk burdens as it provides a convenient means for tracking such risks to workers without the need to make assumptions about how a company, utility, or DOE contractor divides that burden among its workforce. While the use of collective dose has important limitations, here it is used as exclusively an accounting tool and not for causally linking specific health effects to low exposures.
- Radiological hazards to workers during transport are evaluated for accident free transport only. Radiological exposure associated with transportation accidents is not considered.
- Transportation accidents are considered for evaluating non-radiological risks to workers.

- Non-radiological hazards are primarily tracked via the standard Bureau of Labor Statistics categorization of total recordable cases (TRC), and lost workday cases (LWC). and fatalities and are typically indexed to full-time equivalent.worker years (FTE).
  - Total Recordable cases include Recordable cases include work-related injuries and illnesses that result in one or more of the following: death, loss of consciousness, days away from work, restricted work activity or job transfer, medical treatment (beyond first aid), significant work-related injuries or illnesses that are diagnosed by a physician or other licensed heath care professional
  - Lost work-time cases include all cases involving days away from work, or days of restricted work activity, or both.
  - Fatalities include all cases of work related deaths.
  - Non-radiological health and safety data are presented either as a rate (number of cases per X number of FTE) or as total number of cases.
  - A full-time equivalent worker year is equivalent to 2,000 work hours, i.e., the typical number of hours for a typical worker year comprised of 8 hours per day, 50 weeks per year.

The occupational health impacts resulting from the approaches taken by DOE in its Yucca Mountain design, analyses and operations are estimated in Appendices B and C of this report, with supporting data presented in Appendices A, D, and E.. Most estimates are provided on a generic basis using the best available data and what are deemed to be reasonable assumptions. These estimates are then used to calculate overall impacts to the extent data and assumptions allow. However, in some cases, the estimated impacts may be provided for "unit" increments of:

1. Time (for example, the impact due to a delay of opening the repository by one year);
2. Individual operational steps (for example, the occupational impact of loading one additional TAD canister);
3. Length of access or disposal drifts (for example, the occupational impact of having to excavate and develop an extra one meter of drift); or
4. Facility construction units, such as the construction of one additional Wet Handling Facility or the use of additional concrete and building materials.

These unit values are used, when possible, to estimate the occupational health effects for each one of the issues in the following chapters.

# 2
# SOME DUAL-PURPOSE CANISTERS (DPCS) ARE SUITABLE FOR DIRECT DISPOSAL

## 2.1 Technical Bases

The License Application states that DOE has rejected the idea of directly disposing of *any* DPCs in favor of repackaging the CSNF into TADs prior to disposal:

> DPCs are currently used by several utilities to store and potentially ship commercial SNF. Currently licensed DPCs have not been shown to be suitable for disposal purposes. However, although not currently acceptable under the provisions of 10 CFR Part 961, the DOE may choose to receive DPCs at the repository and repackage the commercial SNF into a TAD canister for disposal after the execution of mutually agreeable amendments to the utilities disposal contract. (DOE 2008b, Section 1.5.1.1.1.2.1.2)

DOE also defines a "disposable canister" as:

> A metal vessel for commercial and DOE spent nuclear fuel assemblies ... or solidified high-level radioactive waste suitable for storage, shipping, and disposal. At the repository, DOE would remove the disposable canister from the transportation cask and place it in a waste package. There are a number of types of disposal canisters, including DOE standard canisters, multicanister overpacks, naval spent nuclear fuel canisters, and TAD canisters. (DOE 2008d, Section 2.1.1)

EPRI evaluated the possibility of the larger DPCs meeting DOE's criterion for a "disposable canister" against several criteria (EPRI, 2008a):

- Size -- to determine if the inner DPC canister plus a modified disposal overpack (modified to fit the DPC canister, but otherwise dimensionally consistent with the proposed TAD design) will fit inside the proposed disposal drift diameter, and still allow room for installation of the invert, pedestal, drip shield, and rock support;
- Rock wall temperature -- to determine if direct disposal of DPCs will cause rock wall temperatures to exceed ~200°C. This temperature limit is a reasonable upper bound that would prevent significant rock expansion leading to potentially significant rock spallation. However, previous EPRI analysis suggests this temperature limit could be increased to ~225°C (EPRI, 2006a), if necessary.
- Seismicity and rockfall – to determine if there are any special issues with respect to the ability of DPCs to withstand anticipated seismic and rockfall events;
- Pillar dry-out – to determine if the water saturation in some of the rock between the disposal drifts remains above zero, thereby allowing passage of groundwater infiltrating from above the repository to below the repository. While beneficial, EPRI contends that it is not necessary to maintain water saturation in the pillar above zero at all times (EPRI, 2006a; 2007a);

- Criticality – to determine if DPCs in appropriate disposal overpacks will remain sub-critical during the post-closure period, or if critical for some scenarios, whether the canisters are likely to become prompt critical (EPRI, 2007b; 2008a); and
- Long-term dose to the RMEI (reasonably maximally exposed individual) – to compare the peak RMEI dose in the post-closure period due to the disposal of CSNF in DPCs with disposal overpacks with that due to the disposal of TADs.

EPRI (2008a) and EPRI (2007b) find there are no known technical barriers to direct disposal of at least some of the DPCs. Peak temperatures at the rock wall and in the rock pillars will not exceed values to cause excessive rock spalling and pillar dry-out, respectively:

> Direct DPC disposal was examined to determine if there would be any significant issues relative to thermal effects, thermal-mechanical effects, corrosion, TSPA of the nominal repository evolution scenario and credible alternative repository evolution scenarios, as well as criticality. It is concluded that there are very small differences in performance of DPCs in the post-closure period compared to performance of TADs. Criticality is also extremely unlikely for both TADs and DPCs. No obstacles have been identified that would preclude the use of DPCs for disposal of commercial spent nuclear fuel (CSNF) in a geologic repository at Yucca Mountain. …
>
> Both TADs and a significant portion of the DPCs that will exist at the time of TAD availability are disposable. For the sizeable inventory of CSNF already safely sealed in DPCs, EPRI believes that … a substantial inventory of dual-purpose casks, which are designed for storage and transport, could be certified for disposal at Yucca Mountain based on performance based criteria.

Therefore, EPRI argues that at least some of the DPCs anticipated to be in existence at the time DOE is ready to accept CSNF at Yucca Mountain *can* be disposed of directly by inserting them inside an appropriate Alloy 22 outer canister.

## 2.2 Occupational Health Risk Impacts

The DOE decision to not consider direct disposal of any DPCs in its License Application imposes significant unnecessary occupational health risks on workers associated with the operations needed to open the loaded DPCs, transfer the CSNF to a TAD canister, manage the empty DPCs as low-level radioactive waste (LLW), and close the newly loaded TAD. Also, significant additional occupation risks would be borne by workers due to the need for additional loading TAD canisters arising from the limited capacity of the TAD versus larger capacity DPCs.

The occupational health impacts caused by the need to transfer CSNF from the DPC into TADs, presumably at Yucca Mountain, are described in detail in Appendices B and C. Some key impacts are summarized in Table 2-1. For DPC systems transported to Yucca Mountain and unloaded, rather than being placed in waste packages for direct disposal, a net additional worker dose of 135 person-mrem per package (260 person-rem – 125 person rem from Table B-6) is incurred (Table B-8). Accordingly, this same dose also represents the potential dose avoided per canister if DPCs or other existing, loaded canister systems were qualified by DOE for direct disposal.

**Table 2 - 1**
**Net Occupational Doses Associated with Unloading and Disposal of DPCs**

| DPC scenario | Number of DPCs for Receipt at Yucca Mountain | Worker Dose Associated with DPC Unloading (person-rem) | Worker Dose Associated with DPC Waste Management (person-rem) |
|---|---|---|---|
| DOE baseline | 307 | 80 | 14 |
| DOE high estimate | 966 | 250 | 43 |
| EPRI high estimate | 2375 | 620 | 110 |

Likewise, each emptied DPC (or other canister) will need to be managed as LLW, incurring estimated additional doses to workers of 0.045 person-rem for each DPC discarded. Thus, the dose in Table 2-1 represents both the estimated dose to workers associated with LLW management activities under the DOE proposed operational approach and the dose that could be avoided if DPCs or other existing, loaded canister systems were employed for direct disposal in Yucca Mountain.

The additional handling steps associated with unloading and disposing of DPCs also pose additional potentially unnecessary occupational risk to workers at Yucca Mountain (or reactor sites should unloading operations be required prior to shipment). EPRI was not able to develop specific estimates for these impacts, but the DOE considers the following industrial injury and fatality rates for workers at Yucca Mountain during operations:

- TRC 1.4 per 100 FTE
- LWC 0.58 per 100 FTE
- Fatalities 0.55 per 100,000 FTE

# 3 TAD CANISTER CAPACITY IS SMALLER THAN NECESSARY FOR DISPOSAL

EPRI analyses conclude that the Transportation, Aging, and Disposal (TAD) canisters and disposal overpacks are smaller than could be used for disposal at Yucca Mountain. Thus, the sizes of the TADs are smaller than necessary. As discussed in EPRI (2008a) and summarized in Section 2.1 of this report, EPRI finds that many of the existing dual-purpose canisters (DPCs) used by the nuclear industry could be safely transported, aged, and disposed of at Yucca Mountain. Currently licensed DPCs hold approximately 1.14 to 1.55 times as much spent nuclear fuel as do the proposed TADs. Thus, using the proposed TAD size instead of DPCs or larger capacity TADs will result in a larger number of canisters being loaded at nuclear utility sites, transported to Yucca Mountain, potentially aged, and then disposed of in the repository.

Section 3.1 makes the argument that TADs capacities could be at least as large as DPCs that have a capacity of 1.5 times that of the DOE-proposed TAD capacities. Section 3.2 discusses the avoidable occupational health risks by increasing the capacity of the TADs by a factor of 1.5.

## 3.1 Technical Bases

DOE proposes to use TADs for the transportation, aging, and disposal of CSNF (DOE, 2008b). The proposed TAD canisters would hold 21 PWR assemblies or 44 BWR assemblies. This TAD size is termed a "21P/44B". While EPRI agrees that TADs of this size can be safely transported, aged, and disposed of at Yucca Mountain, it is also possible to use larger waste packages (including both the inner canisters and the relevant overpacks for transportation, aging, or disposal).

U.S. nuclear utilities are currently using a variety of CSNF dry storage systems at their reactor sites. The earliest dry storage systems were designed for storage-only operations; later designs are almost exclusively "dual-purpose" canisters – designed for both dry storage and transportation. However, most DPCs are currently certified for storage only. Many of the utilities using the storage-only systems have or are in the process of submitting license applications to the NRC to certify these systems for transport. While a handful of the earliest storage-only systems are smaller than the 21P/44B TAD capacity, the majority of storage-only and DPCs are larger than 21P/44B.

Section 2.1 summarizes EPRI's conclusion that some DPCs could be considered "disposable canisters". EPRI considered a DPC capacity 1.5 times as large as the DOE-proposed 21P/44B TAD. Given that EPRI concludes some of the larger DPCs can be directly disposed of (EPRI, 2008a), EPRI argues that larger TAD capacities could have been selected by DOE based on findings from EPRI's evaluation of larger DPCs for direct disposal, which apply to large TAD designs as well.

EPRI evaluated the possibility of direct disposal of the larger DPCs against several criteria (EPRI, 2008a):

- Size -- to determine if the inner DPC canister plus a modified disposal overpack (modified to fit the DPC canister, but otherwise dimensionally consistent with the proposed TAD design) will fit inside the proposed disposal drift diameter, and still allow room for installation of the invert, pedestal, drip shield, and rock support;
- Rock wall temperature -- to determine if direct disposal of DPCs will cause rock wall temperatures to exceed ~200°C. This temperature limit is a reasonable upper bound that would prevent significant rock expansion leading to potentially significant rock spallation. However, previous EPRI analysis suggests this temperature limit could be increased to ~225°C (EPRI, 2006a), if necessary.
- Seismicity and rockfall – to determine if there are any special issues with respect to the ability of DPCs to withstand anticipated seismic and rockfall events;
- Pillar dry-out – to determine if the water saturation in some of the rock between the disposal drifts remains above zero, thereby allowing passage of groundwater infiltrating from above the repository to below the repository. While beneficial, EPRI contends that it is not necessary to maintain water saturation in the pillar above zero at all times (EPRI, 2006a; 2007a);
- Criticality – to determine if DPCs in appropriate disposal overpacks will remain sub-critical during the post-closure period, or if critical for some scenarios, whether the canisters are likely to become prompt critical (EPRI, 2007b; 2008a); and
- Long-term dose to the RMEI (reasonably maximally exposed individual) – to compare the peak RMEI dose in the post-closure period due to the disposal of CSNF in DPCs with disposal overpacks with that due to the disposal of TADs.

EPRI (2008a) and EPRI (2007b) find there are no known technical barriers to direct disposal of at least some of the DPCs. Peak temperatures at the rock wall and in the rock pillars will not exceed values to cause excessive rock spalling and pillar dry-out, respectively.

## 3.2 Potential Impacts of Using a Smaller TAD

Using the proposed 21P/44B TAD size compared to use of a larger TAD, with a capacity that is similar to larger capacity DPCs currently in use for on-site dry storage, will result in additional unnecessary radiological and non-radiological risks borne by workers at utility sites, at Yucca Mountain itself, and in the transportation sector. These impacts result from the need for additional activities associated with canister loading, transport, and handling at Yucca Mountain.. Each additional waste package will require excavation of an additional length of emplacement drift. Additional installation of drift hardware (invert, pallet, drip shield) and subsurface infrastructure (rock bolts, tunnel (mesh) liner), along with additional person-hours of labor associated with all aspects of handling, maintenance, inspection, and emplacement. Furthermore, manufacturing of additional repository system components for waste packages and developed drift components, will incur additional occupational risk during their manufacture and transport.

EPRI evaluated the potential occupational health and safety impacts associated with DOE's decision to exclusively use the proposed 21P/44B TAD rather than use of larger TAD designs. For the reactor site and transportation activities, these effects are the same as for DOE's decision to not consider direct disposal of larger DPCs. This is because it is assumed that the transfer of CSNF from DPCs to TADs would occur at Yucca Mountain, per DOE's Proposed Action.

The evaluation considered here uses two alternative scenarios, EPRI Case 1 and EPRI Case 2. Case 1 assumes that larger (32-PWR/68-BWR) TADs are deployed for loading of fuel at reactor sites, leading to concomitant reductions in loading operations, shipments, handling, and drift length. Case 2 extends Case 1 further to exclude the exclusive truck shipments from seven reactor sites that are assumed in DOE's baseline estimate. The resulting occupational impacts are summarized in Table 3-1 below.

The basis for these estimates are provided in Appendices A, B. and C for quantities of required canisters/casks, radiological impacts, and non-radiological impacts respectively.

**Table 3 - 1**
**Radiological and Non-Radiological Impacts of Using TADs that are Smaller than Necessary**

| Affected Worker Population | EPRI Scenario for Comparison | Source of Impact | Additional Cumulative Dose (person-rem) | Additional Injuries and Fatalities |
|---|---|---|---|---|
| **Reactor sites** | Case 1 | 21P/44B TAD capacity results in additional canister loading | 2,028<br>Table B-2 | 19 TRC<br>13 LWC<br>0.04 fatalities |
| | Case 2 | 21P/44B TAD capacity and assumption of 7 nuclear plants shipping by truck results in additional package loading | 2,813<br>Table B-2 | 31 TRC<br>21 LWC<br>0.07 fatalities |
| **Transportation** | Case 1 | 21P/44B TAD capacity results in additional shipments of CSNF to the repository | 1,174<br>Table B-5 | Rail accident:<br>$1.15 \times 10^{-8}$ fatality/ railcar-km<br>For shipments involving 3 CSNF casks (8 railcars total), the fatality rate was estimated to be $9.20 \times 10^{-8}$ accidents/train-km |
| | Case 2 | 21P/44B TAD capacity and assumption of 7 nuclear plants shipping by truck results in additional shipments of canisters | 1,783<br>Table B-5 | Truck accident<br>5.34E-07 accidents per truck km<br>1. 55E-08 fatalities per truck km |

Table 3-1 (continued)

| Affected Worker Population | EPRI Scenario for Comparison | Source of Impact | Additional Cumulative Dose (person-rem) | Additional Cumulative Dose (person-rem) |
|---|---|---|---|---|
| **Yucca Mountain operations** | Case 1 | 21P/44B TAD capacity results in additional canisters for receipt and handling | 701<br><br>Table B-7 | 1.4 TRC per 100 FTEs<br>0.58 LWC per 100 FTE<br>0.55 fatalities per 100,000 FTW worker years |
| | Case 2 | 21P/44B TAD capacity and assumption of 7 nuclear plants shipping via truck casks results in additional packages for receipt and handling | 1,792<br><br>Table B-7 | 1.4 TRC per 100 FTEs<br>0.58 LWC per 100 FTE<br>0.55 fatalities per 100,000 FTW worker years |
| **Yucca Mountain subsurface construction** | Case 1 | Drift excavation to accommodate additional CSNF waste packages | 155 | 18 TRC<br>7.7 LWC<br>0.0049 fatalities |
| | Case 2 | Drift excavation to accommodate additional CSNF waste packages | 166 | 19 TRC<br>8.2 LWC<br>0.0052 fatalities |

### *Other Health and Economic Impacts*

*Additional Radiological Health Impacts to Workers at Reactor Sites Associated with Unloading Storage-Only Dry Storage Systems*

While the YMSEIS did not calculate the worker dose associated with unloading CSNF in dry storage at reactor sites for repackaging prior to shipment to Yucca Mountain, it is possible that some of these packages would be unloaded at reactor sites. EPRI assumes that industry workers would incur a dose of 260 person-mrem per package unloaded, as identified in B-1. If storage only casks must be unloaded, this will result in an estimated worker dose of 83 person-rem. If dual-purpose metal casks must be unloaded at reactor sites, the estimated worker dose would be 35 person-rem. If DPCs and storage-only canisters are unloaded at reactor sites for repackaging, the estimated worker dose would be 617 person-rem. (Table B-4)

*Radiological Health Impacts to the Public During TAD Transportation from the Reactor Sites to Yucca Mountain :*

*Incident-Free Transportation Radiation Doses:*

- Rail: 800 person-rem
- Truck: 350 person-rem

The use of higher capacity TAD designs as well as the shipment of CSNF in higher capacity TAD designs from sites identified by DOE as truck sites, would result in fewer packages being shipped. This would result in a proportional decrease in the incident-free dose to the public similar to the reduction in worker dose during transport discussed in Appendix B.

*Non-radiological Impacts to the Public during TAD and Ancillary Equipment Transport to Reactor Sites*

The YMSEIS assumed that approximately 6,500 empty TAD canisters would be shipped to commercial reactor sites by truck under the 70,000 MTU repository scenario. In addition to the shipment of TADs, approximately 4,900 kits of ancillary equipment needed for loading at reactor sites would also be shipped. DOE assumed that a total of 1.2 traffic fatalities would result from these shipments and 0.23 fatalities from vehicle emissions (assuming a shipping distance of 3,000 kilometers per shipment). (DOE 2008a, Section 6.2.1). If higher capacity TAD canisters were used to load CSNF as described by EPRI Case 1 or EPRI Case 2, a fewer number of TAD canisters and ancillary equipment would need to be transported resulting in a smaller number of vehicle fatalities and vehicle emission fatalities,

*Economic Impacts*

Increase in costs associated with DOE's proposal to use 21P/44B TADs compared to EPRI Case 1:

| | |
|---|---|
| ▪ At reactor loading costs | $0.38 billion |
| ▪ Transport costs | $0.33 billion |
| ▪ Disposal costs (TAD canisters and waste packages | $3.14 billion |
| ▪ Total potential cost impacts: | $3.85 billion |

Increase in costs associated with DOE's proposal to use 21P/44B TADs compared to EPRI Case 1:

| | |
|---|---|
| ▪ At reactor loading costs | $0.44 billion |
| ▪ Transport costs | $0.41 billion |
| ▪ Disposal costs (TAD canisters and waste packages) | $3.33 billion |
| ▪ Total potential cost impact | $4.18 billion |

## 3.4 Summary of Impacts

Using the proposed 21P/44B TAD size compared to use of a larger TAD will result in increases in radiological and non-radiological risks borne by workers at utility sites, at Yucca Mountain itself, and in the transportation sector. These impacts result from the need for additional activities associated with canister loading, transport, and handling at Yucca Mountain.

As shown in Table 3-1, comparing DOE's proposed 21P/44B TAD scenario with EPRI Case 1, worker dose would increase by by 2,028 person-rem due to increased at-reactor package loading; by 1,174 person-rem due to transportation of additional casks; by 701 person-rem due to increased CSNF receipt and handling at Yucca Mountain; and by 155 person-rem to to increased drift excavation to emplace additional waste packages. Compared to EPRI Case 1, DOE's proposal to use the 21P/44B TAD canister for transport, aging and disposal could result in a 4,058 person-rem increase in worker dose.

As shown in Table 3-1, comparing DOE's proposed 21P/44B TAD scenario with EPRI Case 2, worker dose would increase by 2,813 person-rem due to increased at-reactor package loading; by 1,783 person-rem due to transportation of additional casks; by 1,791 person-rem due to increased CSNF receipt and handling at Yucca Mountain; and by 166 person-rem to to increased drift excavation to emplace additional waste packages. Compared to EPRI Case 2, DOE's proposal to use the 21P/44B TAD canister for transport, aging and disposal could result in a 6,553 person-rem increase in worker dose.

# 4
# DOE ASSUMES TOO FEW NON-TAD SHIPMENTS TO YUCCA MOUNTAIN

## 4.1 Technical Bases

The YMSEIS (DOE, 2008d) assumes that a total of 307 DPCs and storage-only canister-based systems would be shipped to the repository and unloaded at the repository under the 70,000 MTU repository case. In the case that assumes all CSNF is accepted at the repository (referred to in the YMSEIS as Module 1), a total of 966 DPCs are assumed to be shipped to the repository and unloaded at the repository. (DOE, 2008d, Section A.2, Table A-3)

A discussed in more detail in Section A.2, EPRI estimates that utilities could load as many as 2,155 DPCs at reactor sites through 2020. Utilities have also loaded 220 canister-based storage-only dry storage systems – the YMSEIS assumes that some of these canisters would be transported to the repository for repackaging at the repository. Thus, EPRI estimates that as many as 2,375 DPCs and canister-based systems could be storing CSNF by 2020.

## 4.2 Potential Impacts Associated with Unloading Dual-Purpose Metal Casks and Storage-Only Casks

As discussed in more detail in Appendix A, the YMSEIS does not assume that CSNF stored in dual-purpose metal casks or storage-only metal casks will be transported to the repository and repackaged at repository surface facilities. Therefore, EPRI estimated a worker dose of 35 person-rem associated with unloading dual-purpose metal casks and 26 person-rem associated with unloading storage-only metal casks at reactor sites for repackaging prior to transport to the repository. As noted above, the YMSEIS assumed that 307 to 966 DPCs and/or storage-only canister systems will be transported to the repository for repackaging under the 70,000 MTU repository scenario and the full MTU (DOE 2008d, Module 1) scenario, respectively.

## 4.3 Potential Impacts due to DOE Assumption of too Few Non-TADs

EPRI estimates that as many as 2,375 DPCs and storage-only canisters could be in use at reactor sites by 2020. If these systems had to be unloaded at reactor sites for repackaging prior to transport, EPRI estimates a unit worker dose of 260 person-mrem per package unloaded, which results in worker doses of 57 person-rem and 560 person-rem for with unloading storage-only canister systems and DPCs, respectively. Thus, if as many as 2,155 DPCs were unloaded at reactor sites, worker dose would increase by 796 person-rem relative to DOE's baseline scenario (307 DPCs; Table A-3) and by 309 person-rem compared to DOE's high-DPCs scenario (966 DPCs; Table A-3). Appendix B.1.4. provides more detail on this estimate.

### *Occupational Health Impacts at the Reactor Sites*

*Radiological Impacts:*

Table 4-1 summarizes the radiological impacts associated with unloading of various canister systems at the reactor sites.

**Table 4 - 1**
**Radiological Impacts Associated with Unloading of Various Canister Systems at Reactor Sites**

| Canister System | Worker Dose (person-rem) |
|---|---|
| 307 DPCs/storage-only canisters | 80 |
| 966 DPCs/storage-only canisters | 251 |
| 2,375 DPCs/storage-only canisters | 560 |
| 135 dual-purpose metal casks | 35 |
| 101 storage-only metal casks | 26 |

### *Occupational Health Impacts at Yucca Mountain*

*Radiological Impacts:*

- Increased dose associated with unloading DPCs at Yucca Mountain: 135 person-mrem per additional DPC unloaded
- 966 DPCs unloaded compared to 307 DPCs/storage-only canisters assumed in YMSEIS: 89 person-rem
- 2,375 DPCs and storage only canisters unloaded compared to 307 DPCs/storage-only canisters assumed in YMSEIS: 280 person-rem

# 5
# DOE OVERESTIMATED THE PROBABILITY OF IGNEOUS ACTIVITY

## 5.1 Technical Bases

The geological setting surrounding Yucca Mountain contains several extinct volcanic centers formed over the last 12 million years. DOE has conducted numerous surface and sub-surface investigations of exposed and buried volcanic features to develop a basis for judging the probability of a future volcanic (igneous) event intersecting the proposed Yucca Mountain repository. The results of these investigations have enabled DOE to conduct Probabilistic Volcanic Hazard Analyses (PVHA) to determine if the geological evidence supports a probability of future occurrence below or above the regulatory threshold for consideration of future scenario-initiating events, which is a future occurrence rate of 1 part in 10,000 for a 10,000 year period, or $10^{-8}$ per year (NRC, 2005). The License Application (DOE, 2008b) uses the probability value obtained in the 1996 PVHA Panel study of $1.7 \times 10^{-8}$ per year (CRWMS M&O, 1996, pp. 4-1), which means this scenario of future volcanism narrowly exceeds the threshold for exclusion in licensing review.

EPRI has recently conducted (EPRI, 2008b, in preparation) an independent assessment of the likelihood of a future volcanic event occurring at the proposed Yucca Mountain repository site. The assessment methodology adopted in the EPRI study was based on same methodology applied in the 1996 Probabilistic Volcanic Hazard Analysis (PVHA) report (CRWMS M&O, 1996, pp. 2-19) and utilized in the LA as noted above. The purpose of EPRI's study was to independently develop new insights and probability estimates for future volcanism based on the more recent, extensive geological and structural data obtained during the last 12 years in the Yucca Mountain region (YMR), especially including recent determination of relatively ancient age (8-10 million years before present) for several buried anomalies in the Yucca Mountain region, which were undated and speculated to be of much younger age in the 1996 PVHA study.

EPRI's PVHA study includes consideration of new geochemical, geophysical, seismological, geodetic and age-dating data collected since the 1996 PVHA report (e.g., Brocher et al., 1998; Day et al., 1998; Perry et al. 1998; Fridrich, 1999; Fridrich et al. 1999; Potter et al., 2002; 2004; Perry et al., 2005; Valentine et al., 2005; 2006; Parson et al., 2006; Valentine and Krough, 2006; Valentine and Perry, 2006; Gaffney et al., 2007; Perry, 2007; Valentine and Perry, 2007; Valentine et al. 2007; Keating et al, 2008), in particular information from the drilling and characterization of various anomalous features buried under alluvial deposits that have been speculated from aeromagnetic data to be additional volcanic centers. Furthermore, EPRI's independent update to the 1996 PVHA report includes consideration of structural factors that demonstrably have controlled the actual eruptive location of volcanic centers that have occurred in the Yucca Mountain region in the last 12 million years (Valentine and Perry, 2006; 2007; Gaffney et al., 2007; Keating et al, 2007). As noted by the NRC's Advisory Committee and Nuclear Waste (ACNW) report on volcanism (ACNW, 2007, pp. 63), for example, there has been no igneous intrusion into Yucca Mountain block in the last 10 million years.

The approach taken by EPRI (EPRI, 2008b, in preparation) follows that used in the 1996 PVHA (CRWMS M&O, 1996). The approach involves defining an igneous event that may intersect the footprint of the proposed repository within the next 10,000 to 1,000,000 years. The calculation requires that an igneous event be well defined and its characteristic features be quantified, and the identification of factors that govern the location and timing of a possible future igneous event in the YMR. By following a similar approach as the 1996 PVHA calculation, results from EPRI's calculation may be compared and evaluated to results in the 1996 PVHA (CRWMS M&O, 1996) and a planned PVHA-U (the updated version of the 1996 PVHA) by the USDOE. Appendix F provides a more detailed discussion of the methodology EPRI used in its PHVA.

EPRI's independent PVHA work finds the $1.7 \times 10^{-8}$ per year probability of a future igneous event intersecting the proposed Yucca Mountain repository used in DOE's TSPA License Application (OCRWM, 2008) to be an overestimate. A more reasonably expected value of $3.0 \times 10^{-9}$ per year, with a range of 0.0 to $7.3 \times 10^{-9}$ per year for the period between 10,000 and 1,000,000 following repository closure, is supported by recent independent analyses based on up-to-date, site-specific information and models (EPRI, 2008b, in preparation). The implication of this lower probability value is that consideration of future igneous/ volcanic events occurring at Yucca Mountain fall below the regulatory threshold for inclusion in licensing review.

## 5.2 Potential Impacts due to Overestimating the Probability of Igneous Activity

The draft EPA and NRC regulations for Yucca Mountain specify that if the probability of a particular event, such as igneous activity within the Yucca Mountain repository footprint, is less than one chance in 10,000 over 10,000 years, then the consequences of such an event need not be evaluated (EPA, 2005; NRC, 2005). DOE's overestimation of the probability of igneous activity at Yucca Mountain could lead to an outcome EPA specifically intended to avoid with its "reasonable expectation" approach, i.e., consideration of unlikely events at cost of "deflect[ing] attention from questions critical to developing an adequate understanding of the expected features, events, and processes."

Furthermore, the DOE estimates of igneous consequences in the licensing process may be subject to considerable regulatory scrutiny. The mean dose to the Reasonably Maximally Exposed Individual (RMEI) living downstream of Yucca Mountain due to igneous activity scenarios is the dominant contributor to overall dose to the RMEI from all scenarios[DOE LA, 2008b]. Therefore, NRC and, potentially, third parties to the licensing process may review the igneous consequence analysis work in great detail. This may extend the time to complete the licensing process.

It is difficult to link DOE's overestimation of the probability of igneous activity to specific outcomes of the licensing process that lead directly of negative impacts on worker health and safety. However, it is conceivable that by further complicating an already complex analysis and licensing task with inclusion of igneous activity its License Application, DOE has increased the likelihood that the shipment of CSNF from reactor sites and other commercial facilities will be subject to further delay. Any additional delay adds to the occupational health risk borne by workers at the storage sites.

The need to store additional amounts of CSNF for an additional amount of time will increase both radiological and non-radiological health risk primarily to workers at the reactor sites due to additional CSNF handling and monitoring in both dry and wet storage. Storage of additional

CSNF at reactor sites will also have a radiological impact on members of the public that may live near the at-reactor dry storage location(s).

For each year of delay in the start of acceptance of CSNF by DOE, nuclear utilities will have to load additional CSNF into dry storage canisters – most likely TAD canisters. Solely for the purposes of estimating occupational health risk consequences, EPRI assumes that once DOE begins repository operations, DOE would provide nuclear utilities with TAD canisters and transportation casks for shipment of CSNF offsite.

The NWPA limits Yucca Mountain capacity to 70,000 MTHM of CSNF and DOE spent nuclear fuel and HLW, 63,000 MTHM of which is available for disposal of CSNF. The nuclear utilities will soon exceed this waste inventory. Accordingly, CSNF that is discharged from reactors above and beyond the 63,000 MTHM limit does not have a final disposal pathway even with an operational Yucca Mountain unless the legislatively mandated disposal capacity is increased or until another repository becomes available.

Appendices B and C of this report provides an assessment of the potential radiological and non-radiological occupational health impacts of a one-year delay in the initiation of CSNF shipments to Yucca Mountain. Table 5-1 provides a summary of key radiological and non-radiological impacts resulting from a one-year delay in the availability of Yucca Mountain to begin receiving CSNF from reactor sites industry-wide. In addition, if existing ISFSI storage space is consumed or ISFSI storage does not exist, there would be additional occupational risk associated with the construction of a new ISFSI storage pad.

**Table 5 - 1**
**Summary of Industry-Wide Occupational Impacts Due to a One-Year Delay in the Availability of Yucca Mountain (Based on 75 Reactor Sites)**

| ISFSI Activity | Dose (person-rem) | Injuries and Fatalities (cases) |
|---|---|---|
| Surveillance and inspection | 9 | 0.052 TRC<br>0.027 LWC<br>$4.1 \times 10^{-5}$ fatalities |
| Maintenance | 112.5 | 0.052 TRC<br>0.027 LWC<br>$4.1 \times 10^{-5}$ fatalities |
| Additional storage module construction at existing ISFSI | 27 – 37 | 7.5 – 10 TRC<br>4.2 – 5.7 LWC<br>0.013 – 0.0189 fatalities |

Radiological impacts arise to routine ISFSI operations, totaling approximately 120 person-rem with incremental increases in risk due to non-radiological hazards faced by a utility worker. The construction of additional dry storage modules, as illustrated in Table 5-1 and described in more detail in Appendices B and C, also result in significant increases in worker risk associated with ISFSI expansion.

In the event that either existing ISFSI pad capacity at a particular site is full or does not exist, the construction of a new pad could become necessary. The occupational consequences associated with the construction of one ISFSI pad at a reactor site (from Section C.1.3) is estimated as:

- 22 TRC
- 12 LWC
- $3.9 \times 10^{-4}$ fatalities

*Economic Impacts*

In addition to occupational impacts, the further delays of CSNF shipments to Yucca Mountain could also potentially lead to significant costs to the utilities. EPRI expects that between 80% and 100% of CSNF discharged after 2020 will require an equivalent amount of CSNF to be loaded into dry storage. If DOE does not begin repository operations and the subsequent acceptance of CSNF by that time, EPRI assumes that nuclear utilities will have to procure TAD canisters for this additional CSNF that requires on-site storage. Thus, any additional delay in the start of repository operations will result in an economic impact for the nuclear utilities to cover the additional cost of CSNF handling and monitoring, as well as the economic impact associated with the purchase of additional TAD canisters for on-site storage. Appendix *G* provides an assessment of the potential economic impacts of a one-year delay in the initiation of CSNF shipments to Yucca Mountain. These impacts are summarized below:

- Incremental cost of additional TADs to the utilities: $0.75 million per canister, plus $300,000 per storage overpack;
- Cost of additional TAD transfer and monitoring operations at reactor sites: $150,000 to $300,000 per TAD loaded.

Table 5-2 summarizes potential occupational and economic impacts due to a one-year delay in CSNF shipments to Yucca Mountain.

**Table 5 - 2**
**Summary Occupational and Economic Impacts of a One-Year Delay in the Availability of Yucca Mountain**

| Health or Economic Risk Category | Health Risk Type | Metric of Worker Health or Economic Impact | Lower value | Upper value |
|---|---|---|---|---|
| Reactor workers | Radiological | [person-rem] | 149 | 159 |
| | Non-radiological | (cases) | | |
| | | ▪ TRC | 30 | 32 |
| | | ▪ LWC | 16 | 28 |
| | | ▪ fatalities | 0.013 | 0.019 |
| Economic [$] | Cost of additional TAD canisters and storage overpacks at reactor sites | Unit Cost per TAD and Overpackg (Millions $) | $1.05 | $1.05 |
| | Cost of loading additional TAD canisters at reactor sites | Unit cost per TAD loaded (Millions $) | $0.15 | $0.30 |

# 6
# DRIP SHIELDS ARE NOT NEEDED

## 6.1 Technical Bases

There are several conservatisms in DOE's analyses of post-closure performance that have led DOE to unnecessarily include drip shields in its repository design. These conservatisms include:

1. Overestimation of the amount of net infiltration, thereby incorrectly indicating a larger benefit of the use of a drip shield than is actually the case;
2. Overestimation of the fraction of the repository experiencing seepage into the open drifts, having the same effect as overestimation of net infiltration;
3. Overestimation of seismic energy and rockfall. This leads DOE to the conclusion that drip shields would provide significant protection from rockfall;
4. Overestimation of damage to the TADs due to seismic and rockfall events. This also leads to the incorrect conclusion that drip shields would be required to provide additional protection from damage of the waste packages;
5. Overestimation of the rate at which Alloy 22 (part of the waste package (WP)) will degrade. This, in turn, gives greater performance credit to the drip shields than is warranted.
6. Cladding performance has been neglected. EPRI analyses indicate that including credit for the performance of the CSNF cladding in the dose analysis is appropriate and that such inclusion would provide an additional barrier to the release of radionuclides from the waste form. This, in turn, would also reduce the need for a drip shield;
7. Performance of the stainless steel barriers (i.e., the inner WP cylinder and the outer shell of the TAD) in the waste package has been neglected. Including performance of these components in the overall performance analysis would also reduce the need for a drip shield.
8. DOE notes that it typically uses the more conservative of two or more conceptual models. Some of these conservatisms could also result in the apparent need for drip shields. As a consequence of this general approach, each conservatism is compounded by conservatisms in other parts of the analysis. Therefore, each of the conservatisms identified here, significant in their own right, compound each other to produce a very large degree of conservatism.

Each of these issues will be discussed in the following subsections

### *6.1.1 DOE Overestimated Net Infiltration*

Both DOE and EPRI have taken the position that there will be three climate states during the next 10,000 years. The definitions of these states are either the same or somewhat similar:

- DOE's "Present-day" and EPRI's "Interglacial" climate states are essentially the same. DOE assumes the "present-day" climate will exist from the time of repository closure to 600 years after closure; EPRI assumes its "interglacial" state will occur from 1000 to 2000 years after repository closure.
- DOE's "Monsoon" climate and EPRI's "Greenhouse" climate states are roughly the same in that both of these climate states assume warmer and wetter conditions in the Yucca Mountain region. DOE assumes the "monsoon" climate will exist from 600 to 2000 years after repository closure; EPRI assumes its "greenhouse" state will occur from the time of repository closure to 1000 years after closure.
- DOE's "Glacial transition" and EPRI's "Full Glacial Maximum" (FGM), while both representative of a cooler, wetter climate than exists today in the Yucca Mountain region, are not exactly the same. While DOE notes that the past coldest glacial states are OIS 16, 12, 6, and 2, which could provide the largest amount of net infiltration and seepage, DOE defines its "glacial-transition" climate to be the transition between OIS 11 and OIS 10. (DOE, 2008b, Section 2.1.2.1.1). As these two climate states are similar, it could be expected that EPRI's choice of the FGM would result in higher amounts of net infiltration and seepage than DOE's "glacial-transition" climate state. Both DOE and EPRI assume the "glacial-transition"/FGM state will occur from 2000 to 10,000 years after repository closure.

A comparison of net infiltration values used by DOE and EPRI is presented in Table 6-1. Since the publication of EPRI's IMARC-8 report (EPRI, 2005a), EPRI numbers in bold italic type have been adopted in its TSPA for all times as sensitivity studies indicate no sensitivity to net infiltration rates during the first 2000 years for the Base Case (no seismic, rockfall, or igneous events), and little sensitivity during the first 2000 years for the Base + Seismic/Rockfall and Base + Igneous Intrusion Cases.

EPRI's best estimate values for net infiltration (EPRI, 2005) are lower than the values used in DOE's license application for all climate states (DOE, 2008b). Hence, EPRI believes that DOE has overestimated net infiltration averaged over the Yucca Mountain repository footprint.

One of the main arguments for the use of drip shields is to reduce the amount of groundwater entering the disposal drifts. As DOE has overestimated net infiltration, this results in an overstatement of the positive effect of the drip shields with respect to long-term repository performance.

**Table 6 - 1**
**Comparison of DOE and EPRI Net Infiltration Rates (mm/y) [Sources: DOE (2008b), Tables 2.3.1-2 through 2.3.1-4 "Repository footprint" values; EPRI, 2005a)]**

| Climate State | Time Period [years after closure] | | Mean-1 s.d./Min (DOE) or Low (EPRI, P=0.05) Value | | Mean (DOE) or Moderate (P=0.9) / Probability-weighted (EPRI) Value | | Mean+1 s.d./Max (DOE) or High (EPRI, P=0.05) Value | |
|---|---|---|---|---|---|---|---|---|
| DOE and EPRI Climate State Name | DOE | EPRI | DOE (Mean - 1 s.d./Min) | EPRI (Low) | DOE Mean | EPRI (Moderate / Prob.-weighted) | DOE (Mean + 1 s.d./Max) | EPRI (High) |
| "Present Day" (DOE); "Interglacial" (EPRI) | 0-600 | 1000-2000 | 5.1/1.5 | 1.1 | 17.6 | 7.2/7.0 | 30.1/48.2 | 9.6 |
| "Monsoon" (DOE); "Greenhouse" (EPRI) | 600-2000 | 0-1000 | 9.6/1.2 | 1.1 | 32.9 | 11/11 | 56.2/95.3 | 19 |
| "Glacial-Transition" (DOE); "Full Glacial Maximum" (EPRI) | 2000-$10^6$ | 2000-$10^6$ | 17.4/4 | ***6.8*** | 38.6 | ***20***/20 | 59.8/97.3 | ***35*** |

Notes: A direct comparison of values is not possible as EPRI uses a logic tree approach whereas DOE uses a continuous distribution. EPRI assigns a probability of 0.05, 0.9, and 0.05 for the Low, Moderate, and High infiltration rate values, respectively. Hence, the closest comparison would be between DOE's Mean and EPRI's Probability-weighted values. However, the table also compares DOE's "Mean minus 1 standard deviation (s.d.)" and "Minimum" values ("Mean – 1 s.d./Min") to EPRI's "Low" value, and compares DOE's "Mean plus 1 s.d." and "Maximum" values ("Mean + 1 s.d./Max") to EPRI's "High" value.

### *6.1.2 DOE Overestimated Seepage Rates*

Table 6-2 provides a general comparison of the seepage fractions and seepage rates (averaged over all waste packages) for intact drifts (no rockfall) for the three climate states that are postulated by DOE and EPRI. Although difficult to compare directly due to the probabilistic complexity of the DOE seepage model (see the second and third notes under the table for the comparisons EPRI used), EPRI has determined that DOE has significantly overestimated the amount of seepage that would occur into the disposal drifts. Thus, EPRI concludes that DOE's seepage fraction and seepage rate estimates are conservative. Overestimates of seepage fractions and rates will also overstate the potential benefit of using drip shields as one of the purposes of the drip shields is to reduce WP seepage rates.

**Table 6 - 2**

**Comparison of DOE and EPRI Seepage Fractions and Seepage Rates (Maximum Likelihood Flow Field (DOE) Seepage Case (EPRI); Mean (DOE) or Probability-weighted (EPRI) Net Infiltration). [Sources: DOE (2008b); EPRI, 2005a)]**

| Climate State [DOE/EPRI] | Seepage Fraction (%) | | Seepage Rate (kg/yr/WP)* | |
|---|---|---|---|---|
| | DOE** | EPRI Probability-weighted Seepage Case*** | DOE Mean** | EPRI Probability-weighted Seepage Case*** |
| Present-day/Interglacial | 1.1 | 0.33 | 1.2 | 0.50 |
| Monsoon/Greenhouse | 2.2 | 0.33 | 4.6 | 0.93 |
| Glacial Transition/Full Glacial Maximum (FGM) | 4.7 | 0.44 | 14.4 | 1.9 |

Notes:
*Averaged over all waste packages.
**10th percentile infiltration scenario (maximum likelihood scenario), Section 2.1.2.1.2, (DOE, 2008b)
***Probability-weighed seepage fraction/rate: Base Seepage Case (P=0.96): High Seepage Case (P=0.04)

### *6.1.3 DOE Overestimated the Amount of Seismic Energy and Rockfall*

DOE also indicates that the presence of drip shields will protect the underlying waste packages in the event of rockfall due to thermal stresses or seismic events. The higher the estimate of rockfall, the more beneficial it would seem to install drip shields.

However, EPRI has determined that DOE overestimated the amount of rockfall that will occur for these two mechanisms during the first several hundred thousand years following repository closure (EPRI, 2005b; 2006b). EPRI determined the extent of rockfall (dynamic and static) versus time by dividing the repository into eight rock property categories. In addition to dynamic rockfall during seismic events, long-term stress corrosion cracking of the rock was also considered. Combining the effects of dynamic and static rockfall, along with waste package (WP)-to-WP collisions, over a series of ten seismic events results in only a modest increase in the number of WP failures that occur compared to the nominal scenario (no disruptive events). Thus, adding the multiple seismic event scenario to the nominal scenario increases the probability-weighted peak individual dose by less than a factor of two (EPRI, 2005b). The results from these EPRI analyses are:

- Dynamic rockfall produces inconsequential effects on the waste packages, even for large rock sizes,
- Static effects of rocks on the waste package are inconsequential for credible stresses and maximum extent of potential drift collapse, and
- WP-WP collisions produce damage to the internal lid from impacts with the waste package internals. The outer lid, however, was undamaged by the collisions."

### *6.1.4 DOE Overestimated the Amount of Damage to TADs due to*

### *Seismic/Rockfall Events*

An important clarification regarding the seismic ground motion modeling case is that the releases and annual doses for the 10,000-year time period are only for the damaged co-disposal waste packages. As described in Section 2.4.2.2.2.3 of DOE (2008b), the releases from the commercial SNF waste packages contribute only negligibly to the total dose of the seismic ground motion modeling case because of the low consequences of seismic-induced failures of commercial SNF waste packages. Seismic-induced failures of commercial SNF waste packages result in low consequences largely due to the low probability of damage to TADs bearing commercial SNF in the first 10,000 years. The expected damage frequency for TADs bearing commercial SNF is calculated to be 5.249 × 10-9 per year, which leads to the probability of failure of 5.249 × 10-5 in 10,000 years (DOE, 2008b, pg. 2.4-57). Thus, DOE determines the probability-weighted number of SNF WPs that would fail due to seismic damage during the first 10,000 years is less than one.

The occurrence of seismic events is described as a Poisson process with the highest annual exceedance frequency, max, of potentially damaging events equal to 4.287 × 10-4 per year and the lowest annual exceedance frequency of min equal to 10-8 per year (DOE, 2008a), which is the threshold in proposed 10 CFR 63.342(b) for the occurrence rate of very unlikely events that can be excluded from the performance assessment. Based on these exceedance frequencies from the seismic hazard curve, the expected number of events in any time period T is equal to ( max • min)T. Thus, during the first 10,000 years after permanent closure, approximately four potentially damaging events can be expected to occur, compared to approximately 430 potentially damaging events in the 1,000,000-year period after permanent closure (DOE, 2008a).

#### 6.1.4.1 DOE Overestimated Seismic Energy

DOE uses ground motions estimated from its Yucca Mountain Probabilistic Seismic Hazard (PSH) model (Stepp et al. 2001). The seismic hazard curve in Stepp et al. (2001) is reproduced here as Figure 6-1. At return periods of $10^6$ years, the Yucca Mountain PSH model predicts a mean PGA and PGV of 3g and 400cm/sec, respectively. These are ground motions that exceed the largest magnitudes ever recorded in the world, so there is some uncertainty as to whether they are physically realistic (Bommer et al. 2004). The PGA curve (presented in Figure 1.7-7 of DOE, 2008b) and reproduced here as Figure 6-1, is an extrapolation of the PSHA curve to $10^{-6}$/year and beyond. It is important to recognize that a statistical distribution is just a model of observed data, and extrapolation beyond the range of the data may not be valid. EPRI asserts that the extrapolation of the maximum horizontal acceleration is beyond the region that could be supported by the strength of the rock and soil at Yucca Mountain. In a review of the results of this PSHA, an expert panel convened by the USGS (Hanks, et al., 2006), concluded the following:

> As an overall and quite general finding – and also as a brief summary of the findings that follow – the Committee finds that there are many lines of evidence and argument that can be drawn from a wide range of geological, geophysical, seismological, and material-properties studies that all point to the same general conclusion: at probabilities of exceedance of $10^{-4}$/yr and smaller, the seismic hazard at Yucca Mountain as calculated from the 1998 PSHA is too high.

Similarly, a limitation found in the analyses of earthquake ground motion input for Yucca Mountain preclosure surface seismic design and post closure performance (MDL-MGR-GS-000003 Rev 01) states:

> While these ground motions can be used to assess the sensitivity of the response of waste emplacement drifts and engineered barrier system components to such high levels of motions, ultimately results should be evaluated for ground motions that are credible for Yucca Mountain.

This statement reflects the fact that even the authors of the ground motion assessment at Yucca Mountain believe that their results are too high and not credible for design. Their use is only recommended for sensitivity studies. Therefore, it is reasonable to conclude that the consensus in the community of earthquake professionals that ground motion estimates at Yucca Mountain are too high at probabilities of $10^{-6}$ /year and should be lower.

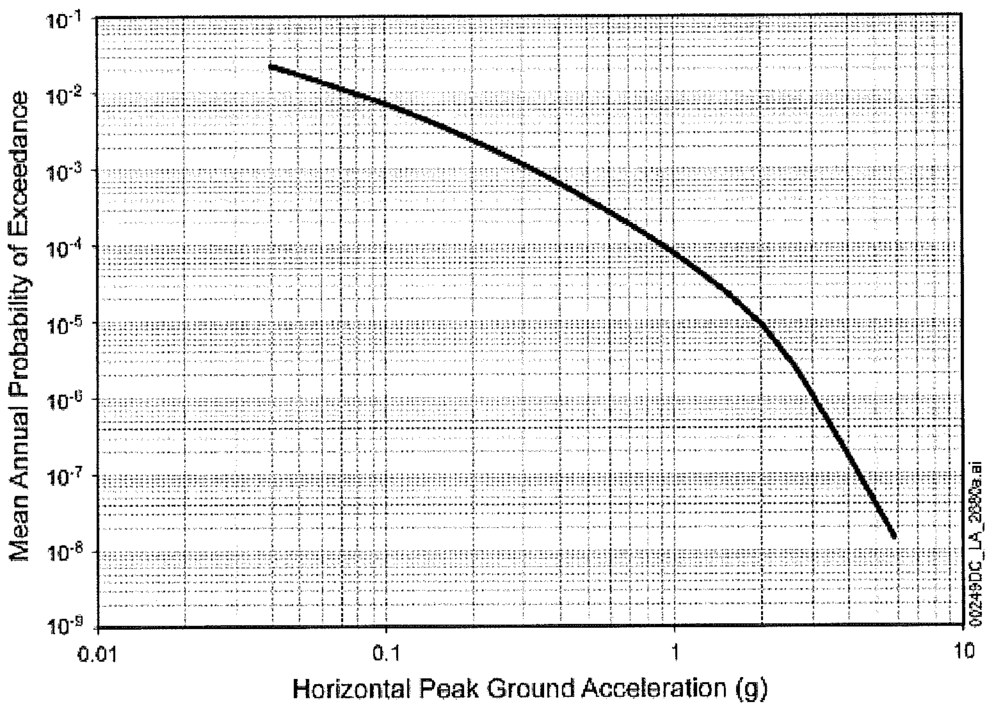


Figure 1.7-7. Seismic Hazard Curve Used in the Preclosure Safety Analysis for Surface Facilities

**Figure 6 - 1**
**DOE Seismic Hazard Curve Adapted for Post-closure Use [reproduced from Stepp et al. (2001), Figure 1.7-7]**

Logically, the closest, most active earthquake sources to Yucca Mountain should be responsible for the largest ground motion levels, and EPRI's analysis compared the ground motion levels of these sources to those of the Yucca Mountain PSH model (EPRI, 2006b). Therefore, EPRI considers the Solitario Canyon Fault (SCF) to be the most important fault upon which to base future seismic activity estimates. EPRI also considers one "background fault" in its analyses (EPRI, 2006b).

Figure 6-2 shows EPRI's estimates of the annual frequency of exceedance for PGA and PGV for the SCF and a background earthquake. Each horizontal line of three matching symbols on Figure 6-2 reflects the range of magnitudes estimates for the SCF (EPRI 2006b, Table 2-1). The open circles on the graphs represent the mean PGA and PGV for the $10^6$ year return period from the Yucca Mountain PSHA (Stepp et al., 2001). The analysis shows the PGA to be about 0.7 to 1g for the SCF at the $10^{-6}$/yr annual frequency of exceedance, ($10^6$ year return period), considerably less than the 3g estimated from the Yucca Mountain PSH model for the same return period. A PGV of 70 to 160 cm/sec is estimated for the SCF at the same annual frequency of exceedance or return period, considerably less than the 400 cm/sec derived from the Yucca Mountain PSHA. Similar results are obtained for the background earthquake (Figure 6-2).

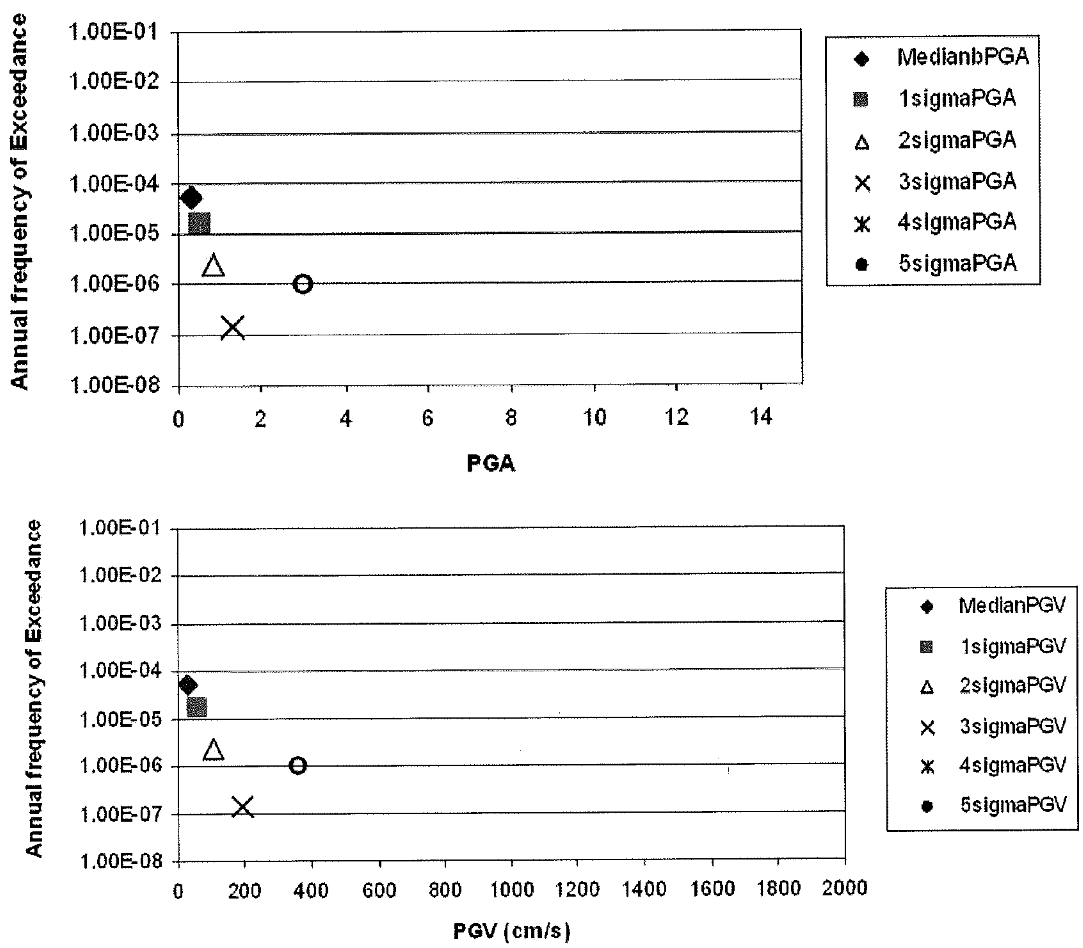


**Figure 6 - 2**
**EPRI's hazard estimates for the Solitario Canyon Fault (upper figure) and background earthquake (lower figure) sources. The open circles show for comparison the mean values for the 10-6/year annual frequency of exceedance (106 year return period) from the Yucca Mountain probabilistic seismic hazard model (Stepp et al. 2001).**

Therefore, EPRI has chosen to apply a 0.75 m/s peak ground velocity (PGV) with a $10^5$ year recurrence interval, so that repeated seismic events have been stylized as 10 large events over a $10^6$ year period, spaced out equally in time (EPRI, 2006b). These large events are those that have been judged most likely to produce changes in the repository that may alter its long-term performance.

#### 6.1.4.2 DOE Overestimated Waste Package Damage due to Seismicity and Rockfall Events

It is EPRI's position that waste package damage is limited due to seismic and rockfall events for cases involving either the presence or absence of drip shields. EPRI reaches this conclusion even for very large events that occur when the waste package outer barrier is degraded; small events, even if frequent, are expected to produce minimal damage to the waste packages. Smaller events occurring with greater frequency are less likely to be of importance to the Total System Performance Assessment (TSPA).

EPRI (2005b; 2006b) considered the effects on WP integrity for the following cases:

- WP-to-WP collisions due to seismic ground motion with PGVs of either 0.75 m/s or 2 m/s, drip shields in place, either flat-on or oblique WP-to-WP contact;
- Dynamic rockfall directly onto the center of a WP, drip shields absent;
- Static rock rubble loading directly on a WP, drip shields absent, Alloy 22 outer shell either present or absent.

EPRI (2005b) notes however that DOE's own analyses suggest that little rockfall will occur for the first 20,000 years:

> The DOE approach to modeling time-dependent rock degradation in the lithophysal units at Yucca Mountain is judged by EPRI to be reasonable and utilizes the most up-to-date knowledge on time-dependent rock mechanics and numerical techniques. ... DOE's results indicate little rockfall is expected out to 20,000 years after waste emplacement due to time-dependent processes alone. Other [DOE ]results ... also indicate that, when combined with thermal loading and seismicity, time-dependent loss of rock cohesion up to 20,000 years is not a major contributor to rockfall. Note, however, that the DOE approach involves basing the UDEC time-dependent model on an exponential formulation of the stress corrosion law without a lower threshold stress limit and use of material properties for heated rather than ambient temperature tuff. These are clearly conservative assumptions, hence, DOE's results ... represent pessimistic upper bounds on possible rockfall for the period of 10,000 to 20,000 years after repository closure.

Therefore the drip shields are not needed to protect the WPs from rockfall for the first 20,000 years following permanent closure or more.

##### *WP-to-WP Collisions*

Two sets of impact analyses for adjacent waste packages are discussed in EPRI (2006b): an analysis of a collision into an unyielding surface at 2 m/s and an analysis of a collision into an unyielding surface at 0.75 m/s. Use of an unyielding surface is conservative in that this assumes two adjacent waste packages are traveling in opposite directions, each with a velocity of either 2 or 0.75 m/s.

For 2 m/s PGV, plastic deformation leading to residual stresses does not develop in the WP outer Alloy 22 shell for a flat-on impact between two waste packages (EPRI, 2006b). Some yielding develops on the inner stainless steel lid and around the connection of the inner lid with the inner stainless steel shell, but this would not affect the performance of the waste package. For an oblique impact where a waste package is tilted at 4 degrees such that the impact is along an edge of the outer lids, some yielding develops in the outer lid under the reduced impact area. Yielding with plastic deformation and residual stresses also develops at the connection of the middle lid to the outer Alloy 22 shell. Such yielding leads to a potential for tearing of the weld at the middle lid connection if the waste package experiences impacts at this PGV multiple times over the life of the waste package. An extrapolation of these results would indicate that the potential for tearing the middle lid connection and yielding in the outer lid should be reduced to a very small probability below an impact of about 1 m/s.

For a PGV of 0.75 m/s, some minor plastic deformation develops on the outer shell in a small area under the concentrated load for the oblique (worst-case) impact orientation. However, no residual damage occurs in the inner or middle lids or in the closure connections for these lids. Thus, it can be concluded that even multiple impacts at this 0.75 m/s impact velocity for the worst-case orientation would not lead to eventual tears or failure of the inner lid as a containment boundary. Although some plastic deformation of the outer shell is predicted for a PGV of 0.75 m/s, this deformation results from compressive loading, so neither immediate structural failure nor delayed SCC penetration is expected. In addition, the extent of damage is so small that even repeated impacts are not expected to lead to a breach in containment.

When the WP inner SS and TAD outer SS shells are intact, DOE reaches a similar conclusion: "Note that for the CSNF WP with intact internals [SCC] damage [due to WP-to-WP collisions] occurs only at the 4.07 m/s PGV level (the probability is zero for all other PGVs" (DOE, 2008b, pg. 6.6-13). For more reasonable PGV values (EPRI, 2005b; 2006b), even DOE finds there will be *no* WP-to-WP damage during seismic events. Hence, both DOE and EPRI conclude the presence or absence of drip shields has no effect on WP damage due to WP-to-WP collisions during seismic events.

DOE also considers a scenario in which the outer containment barrier (OCB, the Alloy 22 shell) could be punctured by sharp WP internals caused by degraded internals. While DOE conservatively concludes that OCB punctures are more likely than SCC failures due to the rubble loading, at more reasonable seismic energy values (PGV less than approximately 1 m/s), even DOE shows essentially no WP damage due to either SCC or internal puncture (DOE, 2008b, Figures 6.6-14 and 6.6-17). Thus, DOE's conservative internal puncture analyses would also inappropriately heighten the value of including drip shields in the repository design.

### *Dynamic Rockfall*

For dynamic loading, EPRI (2005b) conservatively assumed that a large rock block is ejected directly onto the top of a bare WP (i.e., without the DS present), as shown in Figure 6-3. EPRI used an Alloy 22 thickness of 20 mm. The rock block EPRI modeled was assumed to be 7.49 metric tons with a volume of 3.11 $m^3$. This size of rock is the largest size in a representative grouping considered to have a reasonable probability of occurring for the maximum PGV of 2 m/s that EPRI has determined should be associated with a future seismic event near the Yucca Mountain site. This block was assumed to be ejected with a downward velocity of 2 m/s. Furthermore, EPRI (2005b) conservatively assumed that the rock block struck the unprotected WP on a knife edge (see Figure 6-3). EPRI has concluded that even in the event of the postulated occurrence, the WP internals would not be degraded in a manner such that they would fail to provide sufficient structural support to protect the contents. EPRI (2005b) concludes that:

> [A] rockfall impact event with the largest size rock in a representative grouping considered to have a reasonable probability of occurring for the maximum PGV of 2 m/s associated with a future seismic event will have very little effect on the longevity of the Alloy 22 WP outer shell. The response of the Alloy 22 material under the impact will likely remain in the linear regime, even with some corrosive thickness reduction, and thus, residual stresses that could accelerate the degradation from stress corrosion cracking will not be present. It seems especially evident that if residual stresses near the yield strength of the material are needed for stress corrosion cracking, then such a rockfall event will most certainly not affect the performance or longevity of the waste package.

Hence, it is EPRI's position that dynamic rockfall directly onto a WP – without the presence of a DS – will not cause any additional damage compared to the case for which a DS was present. Thus, drips shields are not needed to protect a WP from dynamic rockfall.

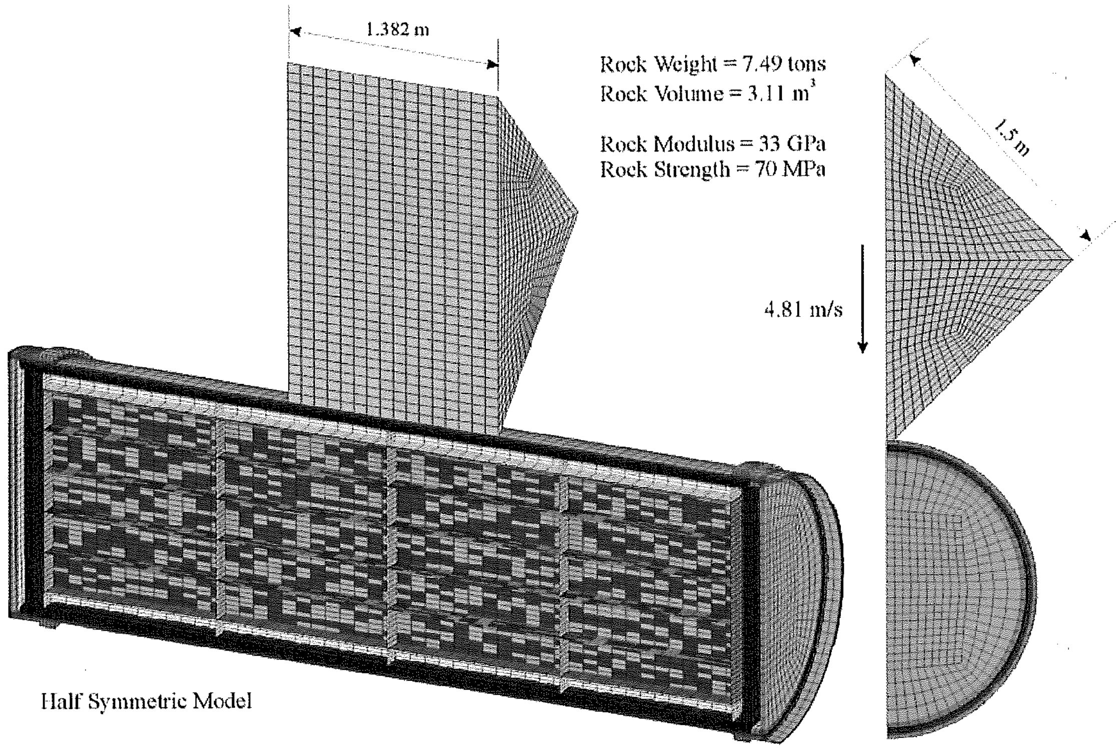


**Figure 6 - 3**
**Finite Element Model and Analysis Setup for Impact due to Rockfall (taken from Figure 12-1 in EPRI (2005))**

Analyses were performed to assess the effect of multiple seismic events on the integrity of the engineered barrier system (EBS) (EPRI, 2006b). The analyses are intended to approach a reasonable expectation case, although it is acknowledged that a number of conservatisms remain in the analysis, as a PGV of 0.75 m/s would not be expected to displace the DS. Hence, this analysis does not include the presence of drip shields. Furthermore, it is very conservatively assumed that each large block described above that is ejected leads to the dynamic structural failure of a single WP. The impact of this conservatism is increased when it is assumed that no drip shields are emplaced.

### *Static Rock Load*

EPRI (2005b) estimates that the maximum bulking height for rubble would be in the range of 5 to 20 meters. EPRI uses this amount of bulking to assess the static load and structural response of the WP.

For EPRI's static rubble analysis (EPRI, 2005b), EPRI considers the structural response of degraded waste packages due to static loads from rubble that would pile up on top of the waste package from a chimney-type collapse of a portion of the emplacement drift. No credit is taken for the drip shield and the Alloy 22 waste package outer barrier (WPOB, the outer Alloy 22 shell). Only the bare stainless steel WP inner shell is considered to be in place as the last structural barrier for protecting the spent fuel.[1] This bounding assumption was made to evaluate whether the structural strength of the inner 316 SS WP shell is sufficient to withstand the maximum credible load of rock resting on the WP. If the rubble static load can be withstood by just the SS inner shell, then it could be concluded that the rubble will not cause early WP failure due to structural failure.

EPRI (2005b) concludes that:

> [A] "bare" WP inner shell can survive the static loads that could develop from a collapse of the emplacement drift at Yucca Mountain for a conservative minimum of a 30-m-high pile of rock rubble. As the bare stainless steel inner shell will remain linear for 30m of rubble, it is extrapolated that a waste package with all or part of the Alloy 22 outer shell present (pristine or partially degraded) will also remain linear for a static load of at least 30m of rubble. The loading from a 30m column of rock conservatively calculated as necessary to mechanically fail a degraded WP far exceeds the loading from a 5-20m column of rock that can possibly be developed in degraded drifts at the Yucca Mountain repository due to rockfall and bulking.

Thus, EPRI's position is that drip shields are also not needed to protect the WP from early structural failure due to the maximum expected rubble height.

This conclusion is echoed by DOE:

> The probability of rupture [structural failure] for the 23-mm-thick OCB with intact internals was determined to be zero. ... Damage for WPs with intact internals was not calculated for WPs surrounded by rubble. A WP becomes surrounded by rubble after DS framework and DS plates have failed during a seismic event. This is expected to occur at late times after repository closure. ... Therefore, CSNF WPs are not likely to have degraded internals at the time of DS failure. (DOE, 2008b, pg. 6.6-14)

However, given that DOE assumes DS failure occurs fairly late in the period of regulatory interest such that some WP corrosion failure may have already occurred, DOE conservatively assumes that groundwater has previously penetrated the WP and degraded the WP internals to

---

[1] This compares to DOE's estimate of the minimum WPOB thickness to be considered for rubble load analyses: "[T]his estimate indicates that the 17-mm-thick OCB provides a reasonable representation for seismic response at the end of the period for assessment of repository performance." (DOE, 2008b, pg. 6.6-12)

the point at which DOE assumes the internals provide no structural support (DOE, 2008b, pg. 6.6-14). Thus, it is not possible to compare EPRI and DOE WP structural failure rates due to the presence of rubble as DOE has conservatively assumed the SS internals to the WP provide no structural support.

Cracking of the WP outer barrier due to the static load of the maximum rubble height could occur if the necessary prerequisites for SCC are met; namely: a tensile stress greater than the threshold stress for SCC, a suitable aqueous environment, and a corrosion potential ($E_{CORR}$) greater than the threshold value for cracking. In EPRI (2006b), only a fraction of the WPs subject to static loading are consider to fail by SCC. First, only those WPs subjected to a static load from a rock pile >10 m in height are considered to sustain a tensile load greater than the threshold for SCC. This height is a conservative estimate based on the height of the rock pile necessary to induce plastic strain for <u>an unprotected inner stainless steel vessel</u> (40 m for uniform loading of the vessel over a 120° arc), taking into account the stress concentration resulting from point or line loading. This latter effect is simulated using a "stress-concentration factor" of four, based on analyses performed by DOE (BSC, 2004). This estimate conservatively ignores the strength of the Alloy 22 outer barrier itself in determining the necessary height of the rock pile.[2] Second, of those WPs covered by a rock pile >10 m in height, only 71% are assumed to be exposed to an appropriate aqueous environment. Third, only a fraction of the WPs that meet both the threshold stress and environment prerequisites will also exhibit a sufficiently positive $E_{CORR}$ for SCC. EPRI (2006b) concludes that the overall fraction of WP subject to a rock pile >10 m in height that are susceptible to SCC is, therefore, 0.017 (71% of environments multiplied by the 0.024 probability that $E_{CORR}$ exceeds the threshold potential for SCC).

### *Conclusion of EPRI Seismic and Rockfall Analyses*

A total of 64 waste packages are predicted to fail as a result of the repeated seismic events, 18 as a result of dynamic rock impacts and 46, out of a total of 2734 that will be covered by a rock pile greater than ten meters in height, as a result of seismic-induced SCC of the outer barrier (EPRI, 2006b). All of these failures are predicted to occur during the first seven seismic events, with no further drift degradation predicted after 650,000 yrs. The number of dynamic failures decreases with time as the number of large ejected blocks diminishes with each subsequent event. In contrast, the number of static load failures tends to increase with time as more of the drift collapses.

In conclusion, it is EPRI's opinion that a series of conservatisms in DOE's seismic hazard and subsequent rockfall and WP damage analyses has led DOE to believe that drip shields offer some protection to the underlying WPs such that WP failure rates are reduced. EPRI analyses (EPRI, 2005b; 2006b) performed for more reasonable seismic energies and rockfall dynamic and static loads, although still maintaining some conservatism, conclude that excluding drip shields from the repository would have no effect on WP longevity.

### 6.1.4.3 DOE Finds Drip Shields can Cause WP-to-WP Collision Damage

According to DOE, the presence of drip shields also has the effect of potentially increasing the amount of WP damage due to seismic events. DOE analyses indicate that if the drip shield is present during a significant seismic event, then some WPs will be damaged due to WP-to-WP

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[2] Corrosion resistance of the Alloy 22 is not ignored, however.

collisions (DOE, 2008b) Section 6.6 of DOE(2008a) discusses DOE's approach to estimating DS and WP damage due to seismic events. The seismic events considered in the TSPA-LA (DOE, 2008a) are

> Dynamic loads on WPs free to move during a seismic event have the potential to result in a rupture (tear) of a WP if the local strain exceeds the ultimate tensile strain. Dynamic loading from a single impact may not produce tensile strains in the Alloy 22 outer corrosion barrier (OCB) that exceed the ultimate tensile strain. However, the extreme deformation from a major seismic event could weaken the OCB, potentially resulting in a ruptured OCB from a subsequent extreme seismic event. ...
>
> The probability of rupture for WPs with degraded internals surrounded by rubble is zero because the strain on the OCB is always below the ultimate tensile strain for Alloy 22. ... However, a severely deformed OCB may be punctured by the sharp edges of fractured or partly degraded internal components. The WP internals are assumed to degrade as structural elements after the OCB is first breached.

In contrast, EPRI (2006b) finds that for a reasonable maximum PGV values, no WP-to-WP collision damage is expected to occur.

Therefore, EPRI concludes that DOE has significantly overestimated the PGV and PGA that would occur during reasonable maximum seismic events. This leads to an overestimate of rockfall such that the value of the drip shields in preventing WP damage due to rockfall has been overstated. However, even if significant seismic activity and, hence, rockfall occurs directly onto an unprotected WP, it is EPRI's position that, at most, only a handful of WPs will fail earlier than if drip shields are used.

### *6.1.5 DOE Overestimated the Likelihood and Rate at which Alloy 22 could Degrade due to Localized Corrosion*

It is EPRI's position that DOE has overestimated both the localized corrosion initiation conditions and penetration rate for Alloy 22. Overestimates of these conditions and rates would artificially accentuate the importance of the presence of drip shields.

As described below, DOE conservatively applied a crevice initiation model in two different ways. Crevice initiation was assumed to occur anywhere on the WP surface, even though DOE recognizes crevice initiation will be much more localized:

> Crevices may form on the waste package surface at occluded regions, such as in between the waste package and the emplacement pallet Alloy 22 surfaces and potentially beneath mineral scales, corrosion products, and rocks. It is not expected that the entire waste package surface will be subjected to crevice-like conditions; therefore, application of the crevice repassivation potential model as a criterion for the initiation of localized corrosion to the area subjected to seepage, is conservative. (DOE, 2008b, Section 2.3.6.4.3.1.3)

Furthermore, DOE conservatively assumed there is no critical temperature below which no localized corrosion would occur:

> ... The modeling approach did not incorporate a critical temperature below which no localized corrosion would occur, regardless of other conditions in the bulk chemical

> exposure environment. In fact, the empirical rules used to implement the corrosion initiation model (Section 2.3.6.4.4.1) include evaluation of corrosion initiation down to exposure temperatures as low as 20°C. (DOE, 2008b, Section 2.3.6.4.3.1.3)

EPRI (2007b, Section 5.9.5) finds that crevice initiation is highly unlikely – even under aggressive chemical conditions: "...it is unlikely that multiple-salt deliquescent brines could form on WP surfaces in drifts at Yucca Mountain, and, if such brines were to form and be stable for some reason, that they would be incapable of initiating and sustaining localized corrosion of the Alloy 22 outer boundary." Only a small fraction of the possible water chemistries could potentially support localized corrosion. This water accounts for only 1% of all of the possible waters at YM so that, on average, localized corrosion is only possible in 1 out of every 100 realizations in EPRI's WP degradation model (EBSCOM). Initiation in EBSCOM is treated using a threshold temperature for localized corrosion.

Thus, EPRI's opinion is that DOE's assumption that crevice corrosion can occur over the entire WP surface is conservative.

Once crevice corrosion is initiated, DOE then applied a conservative localized corrosion penetration rate. DOE assumes a constant penetration rate with time and also applies a rate for aggressive chemical conditions:

> ... a range of potential localized corrosion rates is determined for two highly aggressive environments: (1) 10 wt % $FeCl_3$ test solution (12.7 μm/yr) ... and (2) concentrated HCl solutions at elevated temperatures (where passive film is degraded), with corrosion rates between 127 and 1,270 μm/yr. ... *The use of an Alloy 22 corrosion rate of 12.7 μm/yr measured in a $FeCl_3$ solution containing about 2.1 m chloride ions at 75°C is a suitable analogue crevice solution for estimating the lower bound for metal dissolution ...* because this represents a transpassive corrosion condition. [emphasis added, From DOE, 2008b, Section 2.3.6.4.2.3]

In contrast, EPRI analysis finds that pits will stifle, i.e., crevice corrosion rates will drop to *zero* before the crevice has penetrated the Alloy 22 (EPRI 2004).

Furthermore, DOE implies that crevice corrosion will have only a minor effect on mean dose rates even if the drip shields fail early:

> ... although the Alloy 22 localized corrosion abstraction ... is part of the TSPA model, there are no modeling cases in which the detailed results of the localized corrosion abstraction result in a dose consequence. ... The only modeling case impacted by localized corrosion is the drip shield early failure modeling case, where it is assumed that the waste packages underneath the failed drip shields are failed by localized corrosion. ... *Because the occurrence rate is so low for early drip shield failures, this assumption is conservative, but only slightly.* [emphasis added, From DOE, 2008b, Section 2.4.2.3.2.1.2]

Thus, EPRI concludes that DOE has overestimated both the potential for crevice initiation and the localized corrosion rate. Given DOE's overestimations, the longevity of the WPs has been underestimated. This underestimation results in an inappropriately high relative importance of the drip shields to delay onset of localized corrosion.

### 6.1.6 DOE Neglected Cladding and Inner Stainless Steel Waste Package

### *Performance*

DOE has conservatively assumed that the CSNF cladding will not provide any sort of barrier to the delay or release rate of radionuclides from the UO2 waste form [DOE 2008b, Section 2.4.2.3.2.3.2.3]. Neither has DOE taken credit for the performance of the inner stainless steel canisters within the waste packages or the outer stainless steel shell of the TAD. Without taking any credit for the performance of cladding or the inner stainless steel barriers, the performance of drip shields would seem to be more important than it really is.

EPRI does find that there is sufficient basis for taking credit for the performance of the CSNF cladding in its TSPA model (EPRI, 2000). Available data on the corrosion of zircaloy CSNF cladding were evaluated to derive an estimated cumulative failure curve as a function of time (Figure 6-4). It was assumed that approximately 2% of the cladding was failed prior to emplacement in a repository. After eventual failure of the waste package/EBS, two corrosion modes for the cladding were considered: (1) general corrosion under dry (moist air) conditions, and (2) general corrosion under dripping conditions. At 10,000 years after EBS failure, about 20% of cladding was projected to have failed under dripping conditions and no additional cladding failures were predicted to occur under dry conditions (EPRI, 2000).

Therefore, EPRI concludes that DOE's failure to take credit for the performance of the cladding is overly conservative. Failure to take credit for this additional, available engineered barrier to function as both a barrier and a delay mechanism results in an artificial increase in the relative importance of drip shields.

While it is certain that the stainless steel shells in the waste packages will provide some delay of radionuclide release and reduction of release rates, neither DOE nor EPRI have attempted to quantify this performance. Taking credit for this performance would also diminish the relative importance of the drip shields.

### *6.1.7 General DOE use of the More Conservative of Available Models*

DOE also notes that in general, it uses the more conservative of multiple models that provide a reasonable representation of available data. Several of these conservatisms have caused DOE to underestimate the performance of the EBS components other than the drip shields. These several conservatisms, taken together, represent a significant compounding of each individual conservatism. Because the performance of an entire series of EBS components has been underestimated, together these underestimates have caused DOE to conclude that the addition of drip shields is a necessary component of the EBS.

EPRI disagrees that the drip shields are a necessary component of the EBS. EPRI analyses assuming no drip shields, shown in Figure 6-4b, indicate that the dose rates to the RMEI out to 1,000,000 years after repository closure is still significantly less than the proposed EPA dose limits.

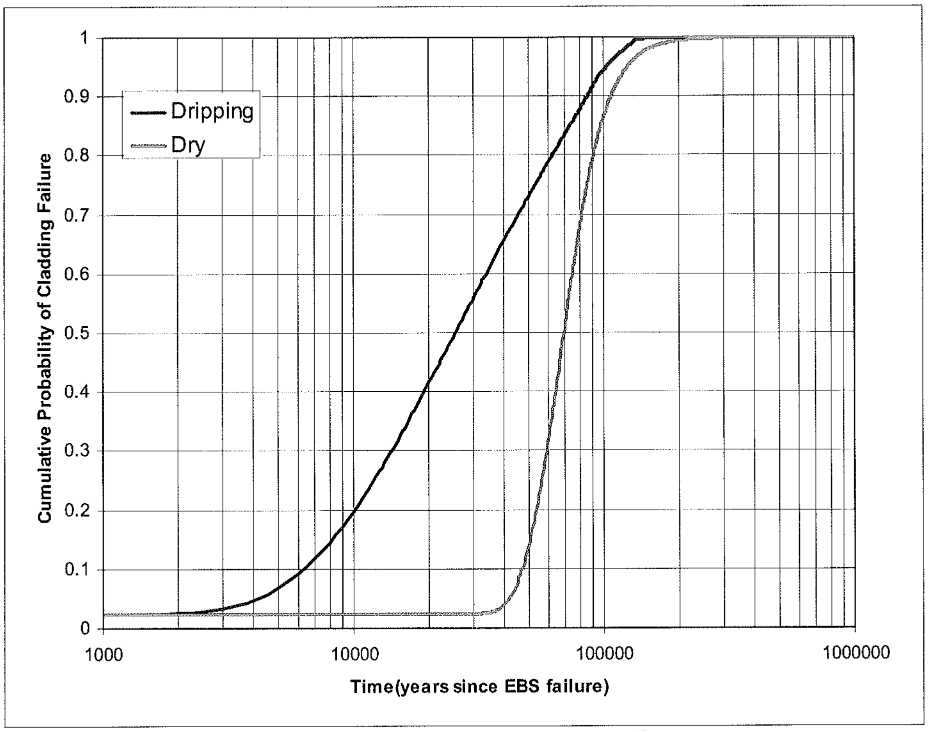


**Figure 6 - 4**
**Derived Cumulative Failure Curves for Zircaloy Cladding (EPRI, 2000)**

### *6.1.7 General DOE use of the More Conservative of Available Models*

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### *6.1.8 Peak Dose Sensitivity with and without Drip Shields*

EPRI performed a TSPA analysis using its IMARC code to compare EPRI's Base Case (drip shields present) and a sensitivity study for which EPRI assumed the drip shields were not present. Figure 6-5 shows the IMARC results for the Base Case (Figure 6-5a) and that for no drip shields (Figure 6-5b). There is a moderate increase in doses at early times associated with the waste package that is assumed to be initially failed owing to manufacturing defects. It is noteworthy that even in the EPRI analyses, the assumption of one initially failed waste package is a conservatism as the expected value of waste package failures from manufacturing defects is significantly below one. The change in peak dose without the presence of the drip shields is negligible, and is still well below the limits established in the proposed EPA/NRC standards.

Based on all the considerations in Section 6.1, EPRI concludes that drip shields are unnecessary.

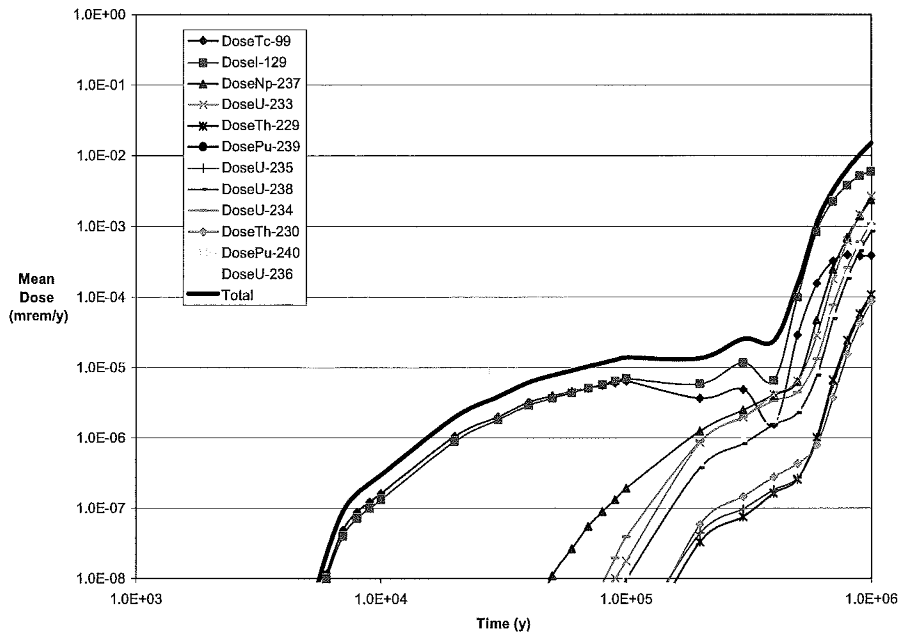
## 6.2 Impacts of Drip Shield Installation

The YMSEIS (DOE, 2008d) assumes that the annual individual dose associated with installation of the drip shields is 9.75 mrem per year, with a staffing of 10 persons per year, resulting in a total dose of 97.5 person-mrem per year. The repository closure phase is assumed to last for 10 years, although it is not clear from the YMSEIS whether the drip shield installation operations will take place during the entire 10-year operations-closure phase. If drip shield installation takes five years, the total dose would be 487.5 person-mrem. If it takes ten years, the total dose for drip shield installation would be 975 person-mrem. (BSC, 2007)

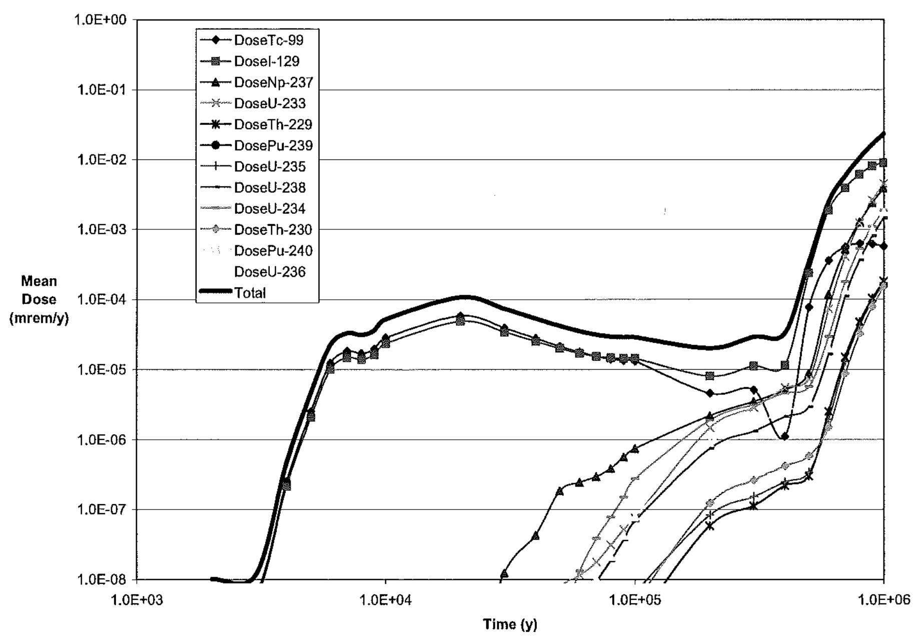
Non-radiological impacts are estimated in a similar fashion. For a five-year period for drip shield installation, the resulting estimates for worker impacts are 4.1 TRC, 2.7 LWC, and 0.009 fatalities. For drip shield installation over the entire ten-year closure period, the estimated non-radiological worker impacts would be 8.2 TRC, 5.4 LWC, and 0.018 fatalities.

**Table 6 - 3**
**Summary of Worker Impacts Associated with Drip Shield Installation**

| Assumed Duration of Drip Shield Installation (years) | Total Worker Dose (person-mrem) | Non-Radiological Impacts (Cases) |
|---|---|---|
| 5 | 487.5 | 4.1 TRC<br>2.7 LWC<br>0.009 fatalities |
| 10 | 975 | 8.2 TRC<br>5.4 LWC<br>0.018 fatalities |




(a)




(b)

**Figure 6 - 5**
**Comparison of EPRI's Base Case (a) and No Drip Shield (b) TSPA Results**

By advocating the use of drip shields, DOE is creating substantial resource demands for titanium (Ti), a material of significant strategic importance and of limited domestic availability.[3] DOE estimates that its projected schedule for drip shield manufacture will result in consumption of 22% of present day annual U.S. production of Ti for a limited period of time. Moreover, manufacture of the drip shields incurs occupational risks to involved workers. The YMSEIS estimates that 11,500 drip shields will be used under the Proposed Action. And as a heavy component, the YMSEIS also assumes that 25 drip shields will be shipped per rail car, with a total of 460 shipments. The YMSEIS assumed a shipping distance of 3,464 km, resulting in potential pollution health effect fatalities of 0.028 and vehicle fatalities of 0.036 – or total fatalities of 0.064 associated with the transport of drip shields from manufacturing facilities to the proposed repository (DOE 2008b, Transportation File, Attachment 12, Other materials).

In addition to the fatalities associated with transport of the drip shields, offsite manufacturing of 11,500 drip shields is estimated to require 3.5 million labor hours. The YMSEIS analysis of off-site manufacturing health and safety impacts assumed 9.1 injuries per 100 full-time worker years and 3.29 fatalities per 100,000 worker years. This results in 159 injuries and 0.609 fatalities associated with off-site manufacturing of the drip shields. (DOE 2008b, Offsite Manufacturing File, Attachment A.) These injuries or fatalities could be avoided if there was no need for the manufacture of Drip Shields for placement within the repository.

[3] Although not studied in this report, the resource demand for palladium may also be substantial.