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U.S. Nuclear Regulatory Commission
ATTN: Mrs. Deborah A. DeMarco
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Washington, DC 20555

Subject: Programmatic Review of Paper

Dear Mrs. DeMarco:

The enclosed paper, which will be submitted for presentation at the 2003 International High-Level Radioactive Waste Management Conference, to be held March 30–April 2, 2003 in Las Vegas, Nevada, is being submitted for programmatic review. The title of the paper is:

> *Review Methodology for Preclosure Safety Analysis of Proposed Geologic Repository* by B. Dasgupta, A. Chowdhury, R. Benke, and B. Jagannath

NRC will review the preclosure safety analysis in the potential license application for the proposed geologic repository at Yucca Mountain. This paper discusses the risk-informed performance-based review methodology which is based on Yucca Mountain Review Plan. The paper also describes the PCSA Tool developed by CNWRA and NRC staff to assist in the preclosure review. An example is presented to demonstrate the review process. Please advise me of the results of your programmatic review. Your cooperation in this matter is appreciated

Sincerely yours,

Budhi Sagar
Technical Director

BS/cp

cc:

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B. Dasgupta, A. Chowdhury, R. Benke, and B. Jagannath

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Review Methodology for Preclosure Safety Analysis of Proposed Geologic Repository

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Abstract – *The Yucca Mountain site specific regualtio at 10 CFR Part 63 requires DOE to demonstrate, through preclosure safety analysis that the proposed geologic repository can be designed and operated in accordance with the preclosure performance objectives. NRC will use the Yucca Mountain Review Plan and PCSA Tool to review the DOE preclosure safety analysis. In this paper, the methodology to be used by NRC to review the preclosure safety analysis for the proposed geologic repository is described.*

I. INTRODUCTION

The proposed geologic repository at Yucca Mountain (YM) will be designed for the permanent disposal of about 70,000 metric tons uranium (MTU) of spent nuclear fuel and high-level nuclear waste (HLW). In its license application (LA) to construct and operate the proposed geologic repository, the U.S. Department of Energy (DOE) is required to present a preclosure safety analysis for the period before permanent closure. During the preclosure period, the proposed facility will receive and handle casks containing the waste in sealed disposal canisters or in the form of spent fuel assemblies. Using a combination of manual and remote operations, the waste will be transferred into disposal waste packages and transported underground for emplacement into drifts. U.S. Nuclear Regulatory Commission (NRC) staff will review the license application to ensure that the proposed activities will meet preclosure requirements of the regulation at 10 CFR Part 63 to protect the public and workers. The Yucca Mountain Review Plan (YMRP)[1] provides NRC staff with guidance for reviewing DOE analysis. The YMRP will be used by the staff to review the LA for construction authorization and, if approved, subsequent amendments to receive and possess waste.

This paper describes the risk-informed, performance-based review methodology applicable to analyses of repository safety before permanent closure. The DOE approach to the preclosure safety analysis has been outlined in their Preclosure Safety Analysis Guide[2]. The NRC and Center for Nuclear Waste Regulatory Analyses (CNWRA) have developed a software package called PCSA Tool [3] to assist in its review . The application of the PCSA Tool is demonstrated through an example in the paper.

II. REGULATORY REQUIREMENTS

The risk-informed, performance-based regulation at 10 CFR Part 63 provides the general scope, requirements, and objectives of the preclosure safety analysis to ensure radiological safety of the public and workers during the period before permanent closure. As required in 10 CFR 63.21(c)(5), any license application must include a preclosure safety analysis to demonstrate compliance with the performance requirements in 10 CFR 63.111(a), (b), and 63.204, which in part are stated in terms of limiting radiation doses to the workers and the public. Preclosure safety analysis is defined in 10 CFR 63.2 and 63.102(f), as a systematic examination of the repository site and the facility design, and evaluation of potential hazards, initiating events, event sequences, and dose consequences to workers and the public. The regulatory requirements for preclosure safety analysis are specified in 10 CFR 63.112. The preclosure safety analysis identifies structures, systems, and components (SSCs) that would be relied on to meet the performance objectives in 10 CFR 63.111 and hence, designated as important to safety.

III. YUCCA MOUNTAIN REVIEW PLAN

The YMRP is a site-specific guide for conducting a risk-informed and performance-based review. A risk-informed performance-based approach uses risk insights, engineering analysis and judgement, and performance history in conducting the review. The YMRP outlines a risk-informed review philosophy that (i) permits a NRC

determination of whether the DOE has demonstrated through its preclosure safety analysis that the repository as designed can be constructed and operated to meet the specified performance objectives throughout the preclosure period; (ii) enables NRC staff to focus the review on the design of the SSCs important to safety in the context of the ability of the design to meet the performance objectives; and (iii) permits NRC staff to proportionately focus its review on high-risk significant SSCs.

The review of preclosure safety analysis is addressed in YMRP in section 4.1.1, which has eight subsections. Each subsection provides guidance (review methods and acceptance criteria) on what information staff reviews, the review basis, how review is accomplished, what demonstrates compliance with regulations, and example of potential conclusions regarding the applicable sections in 10 CFR Part 63. For preclosure safety analysis, the YMRP follows a sequence of evaluations that involves assessment of the (i)site description; (ii)description and design of structures, systems, components, equipment, and operational process activities, (iii)identification of hazards and initiating events, (iv)identification of event sequences, and (v)consequence analysis for evaluation of (a)compliance demonstration for Category 1 and Category 2 event sequences, (b)identification of structures, systems, and components important to safety, (c)design of structures, systems, and components important to safety, and (d) meeting the as low as is reasonably achievable (ALARA) requirements. The sequence of evaluation is depicted in Figure 1 where associated YMRP sections are also indicated.

The risk-informed performance-based review approach allows the applicant the flexibility in how it chooses to meet the performance-criteria. The PCSA Tool, which implements the risk-informed review methodology of the YMRP, provides capabilities to facilitate staff identification of safety related SSCs for detailed review and staff determination of whether DOE preclosure safety analysis demonstrates compliance with performance objectives in 10 CFR Part 63.

IV. PCSA TOOL

The PCSA Tool computer code combines the useful components of the integrated safety analysis (ISA) methodologies used in the chemical industry, and the probabilistic risk assessment (PRA) capabilities and tools used in the safety assessment of nuclear power reactors.[4] The tool will be used by the NRC to assess, through selected independent confirmatory analyses, DOE evaluation of potential hazards, event sequences and radiological consequences, and identification of those SSCs that are required to ensure safety to public and workers.

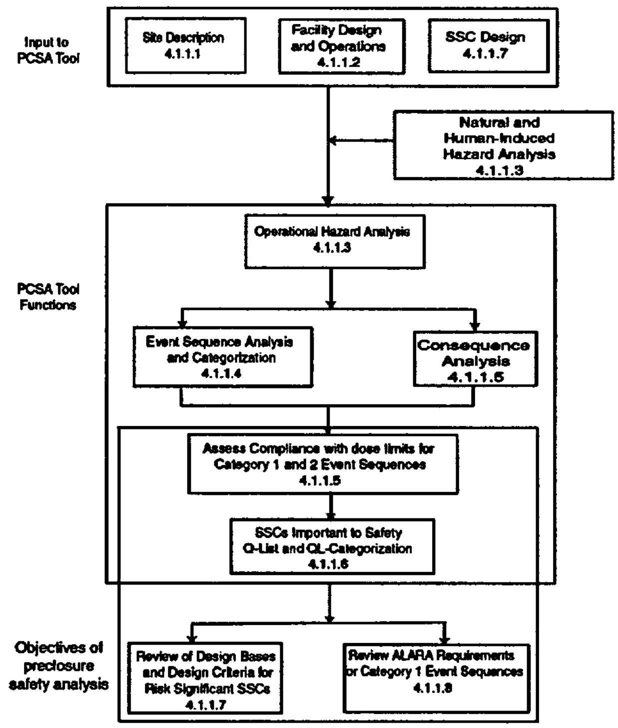

Figure 1. Preclosure review methodology using the YMRP and PCSA Tool. The section number of the YMRP is presented for each component of the methodology.

The PCSA Tool has been designed to :(i) store and retrieve data and information in a database, (ii) perform calculations using off-the-shelf and specially designed software, and (iii) document review results. The executive module of the PCSA Tool interfaces with the databases and analytical tools. The project database allows segmenting the repository into several functional areas for the creation of input data, storage of output data from model analyses, display of graphical results, and report generation. The results from all the functional areas can be combined for assessment of preclosure safety. The tool also include a database for the component failure rates obtained from actuarial data and literature.

Details of the facility design, operations, human activities, and waste stream and characterization are input to the PCSA Tool. The modules in the tool are designed for operational hazard analysis, event sequence analysis, consequence analysis, safety assessment, and identification of SSCs important to safety. The operational hazard analysis module of the tool uses several standard qualitative hazard

analysis methodologies, such as Failure Modes and Effects Analysis, What-If analysis, and Human Reliability Analysis. Justifications for credible naturally occurring hazards (e.g., seismic, flood, fire, etc.) and human-induced hazards (e.g., aircraft crash, nearby industrial hazards, etc.) are reviewed outside the tool. The operational hazard analysis forms the basis for postulating initiating events and event sequences that have the potential to cause radiological consequence to the public and facility workers. Event trees and fault trees are used to develop event sequence scenarios that can lead to radiological release.

The frequency analysis module uses a code called SAPHIRE[5], developed for the NRC for use in PRA of nuclear power reactors. Preclosure safety analysis considers probability of potential hazards and event sequences taking into consideration the range of uncertainty associated with the data that support probability calculations. The tool groups the event sequences into category 1 and 2 based on the likelihood of their occurrence. The regulation at 10 CFR 63.2 defines Category 1 as those event sequences that have the potential to occur at least once during the preclosure period, and Category 2 are those event sequences that have the probability of occurrence of at least one in ten thousand during the preclosure period. If the preclosure period is assumed to be 100 years, the limiting frequencies are 1×10^{-2}/yr for Category 1event sequences and 1×10^{-6} /yr for Category 2 event sequences.

The consequence module of the PCSA Tool uses the RSAC code[6] to calculate radiological consequences to an off-site member of the public from an atmospheric release of radioactive material using point estimate and probabilistic approaches. The tool also uses the MELCOR code[7] to estimate building discharge fraction, which serves as an input to the public dose calculation. Inhalation, ingestion, ground surface, and submersion doses are calculated and combined to estimate the total effective dose equivalent to whole body and also to individual organs. The probabilistic approach is incorporated to assess the uncertainty and variability in the consequence analysis. In addition, the tool also has the capability to evaluate worker doses.

The safety assessment module of the PCSA Tool combines the frequencies and consequences of event sequences to evaluate compliance with regulatory dose limits for Category 1 and Category 2 event sequences. The PCSA Tool can invoke two different approaches for evaluating compliance with the public dose performance requirements for Category 1 event sequences. The two approaches calculate (i) the frequency-weighted annual dose and (ii) the summation of doses from combinations of multiple event sequences within a single year of operation. The preclosure safety assessment is based on total effective dose equivalent to members of the public from Category 1 event sequences and normal operations. In addition to the two safety assessment approaches, the conditional dose (i.e., not frequency weighted) from each Category 1 event sequence must be compared to the annual dose limit of 1.5×10^{-4} Sv (15 mrem) specified in 10 CFR 63.204. The performance requirement for Category 2 event sequences is based on an event dose limits (5×10^{-2} Sv [5 rem] total effective dose equivalent plus other organ dose) to an offsite member of the public. The total effective dose equivalent, as well as the doses to individual organs, are compared in the PCSA Tool with the performance requirements in 10 CFR Part 63 for Category 2 event sequences. The tool is also used to identify structures, systems and components (SSC) that are relied on for compliance with the performance objectives.

V. RISK-INFORMED PERFORMANCE-BASED REVIEW

In its preclosure safety analysis, DOE would identify the potential natural and operational hazards, assess potential events and event sequences and their consequences [2]. The DOE preclosure safety analysis would also identify SSCs and personnel activities intended to prevent each event sequence or mitigate its consequences. The analysis provides information to establish design bases and design criteria of each SSCs and also to classify each SSC into one of four quality levels for the purpose of graded implementation of QA controls on these SSCs. In general, the DOE preclosure safety analysis is an iterative process and integral to the facility design and operations [2]. DOE preclosure safety analysis would evolve as the repository design matures to a potential license application. The NRC will review the preclosure safety analysis for the final design that DOE will submit with any license application.

The overall review methodology in the YMRP, including relationship to the PCSA Tool, is shown in Figure 1. As shown in the figure, three sections of the YMRP (4.1.1.1, 4.1.1.2 and to 4.1.1.7) serve as input to preclosure safety analysis review and the PCSA Tool is capable of performing assessments that directly relate to four sections of YMRP (4.1.1.3 through 4.1.1.6). The preclosure review activities in sections 4.1.1.3, 4.1.1.4 and 4.1.1.5 systematically address the risk triplets: "What can go wrong?", "How likely is it?", and "What are the consequences ?" The risk-insight information generated from this review would be used to review performance of the repository design to meet the regulatory dose limits (section 4.1.1.5) and identification of risk-significant SSCs that are required to comply with performance objectives (section 4.1.1.6). In addition, risk-insight information would

also be used to identify risk-significant event sequences and focus in-depth review of these, for example, DOE consideration of sources of uncertainty in event sequence and consequence analysis.

The PCSA Tool will be used to review DOE preclosure safety analysis through limited independent analysis using site specific data and facility description, design information and operations. The data from the site and facility descriptions would be evaluated for adequacy in the context of the information required to review the preclosure safety analysis. The analysis using PCSA Tool will help focus review of design of risk significant SSCs and evaluate the compliance with the ALARA requirements for safety of public and workers.

The PCSA Tool will be used to focus on the potential gaps in the DOE assessment of operational hazards and initiating events that may result in radiological consequences, and determine the appropriateness of DOE inclusion and exclusion of hazards in preclosure safety analysis. The tool would be used to evaluate the frequency or probability of occurrence of initiating events including consideration of uncertainties. The tool can generate and independently analyze event scenarios for those initiating events potentially not identified by DOE. Independent evaluation of event sequence frequencies considering uncertainty of failure rates of components in event tree and fault tree analysis would be conducted using the tool during the review. The tool also would be used to evaluate human reliability in the manual and remote operations in handling waste and reliability of hardware and software used in the surface and subsurface operations.

The tool would be used to perform independent analysis of consequences taking into consideration variability and uncertainty. These consequence analyses would be used to review the DOE evaluation of consequence to the workers and members of the public from normal operations and category 1event sequences, and to the public from category 2 event sequences. To verify compliance with the regulatory requirements, the tool uses mean values for frequency and consequence for all event sequences.

The SSCs important to safety are identified in PCSA Tool through a dose-based importance analysis in which the performance of the system is reevaluated assuming that the SSC under evaluation has failed to perform its intended function. The preclosure safety analysis results will be used by NRC to review the design bases and design criteria established by DOE for SSCs important to safety.

VI. EXAMPLE

In this section, an example is presented to demonstrate the risk-informed performance-based review process using PCSA Tool. The spent fuel and vitrified high-level radioactive waste from nuclear power plants and other facilities would be transported to the Yucca Mountain. The proposed geologic repository would have surface and subsurface facilities. The main operations in the surface facility would be receiving, preparing, packaging, and transporting waste, while in the subsurface waste would be transported and emplaced in the underground drifts. The waste would arrive at the facility by rail or truck in transportation casks. The repository would receive commercial spent nuclear fuel as individual assemblies, and the DOE spent nuclear fuel and high level waste in disposable canisters.

Based on the DOE site recommendation design[8], upon arrival at the surface facility the waste would undergo several handling operations before it is emplaced in underground drifts. The cask containing waste would be lifted from the carrier and routed either through the dry or wet transfer system to repackage waste. In the dry transfer system, the disposable canisters would be either transferred from the transportation cask directly into the disposal containers or temporarily staged before it is transferred. In the wet transfer system, the cask or dual purpose canisters would be opened to remove individual fuel assemblies under water in a pool. The fuel assemblies would be placed in fuel assembly baskets, which would be moved to a blending pool for storage. The assemblies would be removed from the pool environment and dried before loading assemblies in disposal containers. Each fuel assembly would be lifted out of the fuel basket and placed in the disposal containers. The disposal containers from the dry and wet transfer systems would be welded and tested before placement on the subsurface transporter for movement to the underground.

An hypothetical example shows how the PCSA Tool would be used to perform a compliance review of the DOE preclosure safety analysis. This example is presented for illustrative purposes only and covers the review process up to and including a hypothetical compliance assessment for Category 1 and 2 event sequences. Although DOE facility description and design are used, data contained in this example do not correspond to preliminary designs of the Yucca Mountain Project. A generic applicant and regulator are used and any reference to "applicant", henceforth, does not refer to the DOE. . The example presented here is at a much simpler level and does not reflect the finer level of detail involved in the underlying review.

The example discussed here deal with potential drop events during the transfer operations of waste from transportation casks to disposal containers. The applicant would conduct an operational hazard analysis based on the facility design and identify hazards and initiating events. For example, the applicant would identify canister drops due to failure of lifting devices such as over head crane as an potential hazard in canister transfer system. Similarly, drop of fuel assemblies and fuel assembly baskets caused by failure of handling machines in the pool could potentially result in radiological consequence to the public and workers. A list of five hypothetical drop events (A-E) is shown in Table 1. Based on the identified hazards, the applicant would further develop event scenarios and conduct event sequence frequency analyses. Each scenario assumes an initiating event that may or may not result in the breach of fuel cladding and its container (e.g., canister). It is also assumed that the containment structure would perform its function and the mitigation of radiological consequence to the public would depend on the availability and functioning of HEPA filters. Each event scenario has three possible event sequences: (i) no cladding or canister breach, resulting in no consequence, (ii) breach of cladding/canister, consequence mitigated by HEPA filter, and (iii) breach of cladding/canister, HEPA not available to mitigate consequence. Frequency estimates, frequency categorization, and dose to the public for each event sequence are shown in Table 1. Event sequences resulting in no radiological consequences are not shown in Table 1.

Table 2 summaries hypothetical results of an applicant's Category 1 event sequences for compliance analysis. The sum of the frequency-weighted doses from all Category 1 event sequences (i.e., the average annual dose due to the Category 1 event sequences during facility operations) will be compared to the annual dose limit. The conditional consequences from each Category 1 event sequence will also be compared to the annual dose limit. Based on the applicant's analysis, five Category 1 event sequences were identified.

The review can be made risk informed by calculating the percent contribution of each event sequence relative to the sum of the frequency-weighted doses and focusing the review on the event sequence(s) that contribute the most (see Table 2). All event sequences will be reviewed, but independent assessments may not be conducted for all event sequences. In this example, the canister drop event sequence (A1) contributed the most to the sum of the frequency-weighted doses, and thus, the regulator performed independent assessments on that event sequence, whose results are also presented in Table 2. For event sequence A1, the regulator's assessment resulted in an increased frequency and decreased consequence compared to the applicant's results. As part of being risk informed, the change in the contribution to the sum of the frequency-weighted doses was evaluated and found to decrease {$(0.03/\text{yr})(2\times10^{-6}\,\text{Sv}) = 6\times10^{-6}\,\text{Sv/yr}$ is less than the applicant's result of 8×10^{-6} Sv/yr}. An independent assessment on the frequency of event sequence E1 (fuel assembly basket drop on fuel assembly basket) resulted in a smaller frequency when compared to that of the applicant. The change in the frequency weighted dose from that assessment is also listed in Table 2.

In this example, reviews of the hazard analysis identified event sequence F1 not included by the applicant (human error causing a fuel assembly basket collision with another fuel assembly basket, event F in Table 1). Because its contribution to the sum of the frequency-weighted doses was unknown, an independent assessment of the event sequence frequency and consequence were conducted by the regulator and are shown in Table 2.

Each of the independent assessments (i.e., the conditional doses and sum of frequency-weighted doses) should be compared to the performance objective dose limits. Results from the independent assessments do not have to be the same. For our example, the independent assessments performed on the A1 and E1 event sequences changed the magnitude of contributions to the sum of the frequency-weighted doses by -2×10^{-8} Sv/yr and -2×10^{-9} Sv/yr (minus sign represents reduction), respectively. The independent assessments on the event sequence F1 in Table 2, not included by the applicant, resulted in a change of $+2\times10^{-9}$ Sv/yr. Overall, the sum of the frequency-weighted doses for Category 1 event sequences is reduced by roughly 20 percent (from 1.1×10^{-7} Sv/yr to 0.9×10^{-7} Sv/yr) in our example, when the results of regulator's independent assessments replace those from the applicant. Differences between the results of the applicant's and regulator's assessments could lead to requests for additional information from the applicant.

As shown by Table 1, there are only two Category 2 event sequences. The conditional doses for each Category 2 event sequence will be compared to the dose limits for individual Category 2 event sequences. As part of risk informed review, greater attention will be given to those Category 2 event sequences with frequencies that are near the boundaries of Category 1 and Category 2 event sequences, and Category 2 and beyond Category 2 event sequences that result in the largest consequences.

VII. SUMMARY

NRC will use YMRP and PCSA Tool to review a potential DOE license application for construction authorization for the proposed geologic repository at Yucca Mountain, Nevada. The YMRP implements site specific risk-informed performance-based regulation at 10 CFR Part 63. YMRP provides guidance to ensure appropriate review of a DOE preclosure safety analysis, which must demonstrate the repository design will meet the specified performance objectives throughout the preclosure period and SSCs important to safety have been identified. Risk insight gained from the review permits staff to proportionately focus its review on high-risk significant SSCs that are important to safety. The PCSA Tool allows the staff to conduct and document independent and confirmatory analyses for part or the entire repository system. The tool has the capability to conduct hazard analysis, event frequency analysis, and consequence analysis including verification of compliance demonstration and identification of SSCs important to safety. The tool provides flexibility to review in detail all or selected aspects of the safety analysis. The review process for preclosure safety analysis has been demonstrated with an example.

VIII. ACKNOWLEDGEMENT

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Table 1: Hypothetical events and event scenario analysis in a potential application

Event	Scenario Description	Assemblies Breached	Event Sequence	Frequency (1/yr)	Frequency Category	Dose (Sv)
A	Canister drop on floor	17	A1. With HEPA	0.02	1	4×10^{-6}
			A2. HEPA Failed	2×10^{-7}	Beyond Category 2	‡
B	Fuel Assembly (FA) drop on floor	1	B1. With HEPA	0.2	1	3×10^{-8}
			B2. HEPA Failed	2×10^{-6}	2	3×10^{-5}
C	FA basket drop on floor	4	C1. With HEPA	0.05	1	1×10^{-7}
			C2. HEPA Failed	5×10^{-7}	Beyond Category 2	‡
D	FA drop on another FA	2	D1. With HEPA	0.18	1	5×10^{-8}
			D2. HEPA Failed	1.8×10^{-6}	2	5×10^{-5}
E	FA basket drop on another FA basket	8	E1. With HEPA	0.05	1	2×10^{-7}
			E2. HEPA Failed	5×10^{-7}	Beyond Category 2	‡
F	Operator error FA basket collision	4	Event not identified by applicant			
‡ dose not calculated for event sequence with frequency less than Category 2 limit						

Table 2: Review of compliance requirements for Category 1 event sequences

Event Sequence Identification	Potential Application		Independent Assessment				
	FWD (Sv/yr)	Contribution to FWD (Percent)	Frequency (1/yr)	Dose (Sv)	FWD (Sv/yr)	Contribution to FWD (Percent)	Change in FWD (Sv/yr)
A1	8×10^{-8}	72.7	0.03	2×10^{-6}	6×10^{-8}	66.4	-2×10^{-8}
B1	6×10^{-9}	5.5	✳	✳	✳	6.6	✳
C1	5×10^{-9}	4.5	✳	✳	✳	5.5	✳
D1	9×10^{-9}	8.2	✳	✳	✳	10.0	✳
E1	1×10^{-8}	9.1	0.04	✳	8×10^{-9}	8.8	-2×10^{-9}
F1	Not included		0.03	8×10^{-8}	2×10^{-9}	2.7	2×10^{-9}
Sum of Frequency Weighted Dose (FWD) (Sv/yr)	1.1×10^{-7}		9.0×10^{-8}				-2×10^{-8}
✳ denotes regulatory review conducted but no independent assessment by the regulator							