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Summary discussion of the 2008 performance assessment for the proposed high-level radioactive waste repository at Yucca Mountain, Nevada

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ABSTRACT

A deep geologic repository at Yucca Mountain (YM), Nevada, for the disposal of spent nuclear fuel and high-level radioactive waste was proposed by the U.S. Department of Energy (DOE). This paper summarizes the historical development of the 2008 YM performance assessment (PA), and explains how the methods and results of the 2008 PA address regulatory requirements specified by the United States Environmental Protection Agency (EPA) and the United States Nuclear Regulatory Commission (NRC). Topics covered include (i) screening of features, events and processes, (ii) development of scenario classes, (iii) descriptions of barrier capability, and (iv) compliance with applicable quantitative standards for individual protection, individual protection following human intrusion, and ground water protection. This article is part of a special issue of *Reliability Engineering and System Safety* devoted to the 2008 YM PA and provides a brief summary of information presented in detail in multiple articles in this issue and interprets the results in the context of applicable EPA and NRC regulations.

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1. Introduction

The United States Department of Energy Office of Civilian Radioactive Waste Management (DOE-OCRWM) submitted a license application on 3 June 2008 to the United States Nuclear Regulatory Commission (NRC) seeking authorization to construct a repository at Yucca Mountain (YM), Nevada, for the permanent disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) [1,2]. On 8 September 2008, the NRC accepted the DOE's application for technical review and docketed it to begin the formal regulatory process of review and hearings. Between September 2008 and January 2010 the NRC staff submitted 602 requests for additional information to the DOE regarding clarification and supplementation of the content of the license application, and the DOE provided written answers to each request [3]. On 3 March 2010, the DOE filed a motion with the NRC's Atomic Safety and Licensing Board requesting the withdrawal of the license application, noting that "a geologic repository at Yucca Mountain is not a workable option for long-term disposition" of SNF and HLW [4]. As of the date at which this article is being written, the future of the proposed YM repository is uncertain.

This article provides a summary discussion of the 2008 YM PA that was developed to support the DOE's license application [5]. As described in detail in other articles in this special issue [6–19], the 2008 YM PA provides quantitative estimates of long-term performance of the repository, including estimates of future radiation doses to a hypothetical "reasonably maximally exposed individual" (RMEI). Analyses for the proposed YM repository are supported by more than two decades of scientific investigations [20–28], and as discussed elsewhere in this issue [29], the 2008 YM PA builds on prior iterations of system-level analyses [30–35] beginning in the early 1990s and continuing through the 2002 Yucca Mountain Site Recommendation [36] and Final Environmental Impact Statement [37].

2. Regulatory framework

The management of SNF and HLW is governed in the United States by the provisions of the Nuclear Waste Policy Act of 1982 (NWPA), as amended [38]. As required by the NWPA, the United States Environmental Protection Agency (EPA) has issued public health and environmental radiation protection standards for YM at 40 Code of Federal Regulations (CFR) Part 197 [39,40], and the NRC has issued regulatory requirements at 10 CFR Part 63 that establish criteria for the implementation of the EPA standards [41–43]. The NRC provides additional guidance relevant to evaluating compliance with 10 CFR Part 63 in the Yucca Mountain Review Plan [44].

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Acronyms

CFR	United States Code of Federal Regulations
DOE	United States Department of Energy
DS	drip shield
EPA	United States Environmental Protection Agency
FEP	feature, event, and/or process
HLW	high-level radioactive waste
mrem/yr	millirem per year
mSv/yr	millisievert per year
NRC	United States Nuclear Regulatory Commission
NWPA	United States Nuclear Waste Policy Act
OCRWM	Office of Civilian Radioactive Waste Management
PA	performance assessment
pCi/L	picocurie per liter
RMEI	reasonably maximally exposed individual
SNF	spent nuclear fuel
TSPA	total system performance assessment
WP	waste package
YM	Yucca Mountain

The EPA and NRC regulations define the overall framework for the 2008 YM PA as an analysis that identifies and evaluates relevant features, events, and/or processes (FEPs) that could affect repository performance, and then estimates performance taking into account uncertainties associated with significant FEPs and weighting their consequences by their probabilities of occurrence. In practice, this regulatory direction is implemented as a probabilistic uncertainty analysis using numerical models for components of the repository and the geologic setting that are linked into a system-level model suitable for Monte Carlo uncertainty analysis [6].

In addition to defining the overall method to be used in PA for the proposed YM repository, the EPA and NRC regulations also define quantitative limits on long-term performance that are to be met for demonstrations of regulatory compliance. Specifically, 10 CFR 63.311 defines an individual protection standard, consistent with the EPA standards at 40 CFR 197.25, that limits the mean annual dose to the RMEI during 10,000 years after repository closure to 0.15 mSv/yr (15 mrem/yr) and to 1 mSv/yr (100 mrem/yr) for the period between 10,000 and 1,000,000 years after repository closure. The rule also provides separate standards for (i) mean annual doses to the RMEI following an assumed and stylized human intrusion event (10 CFR 63.321) and (ii) allowable releases of radioactive material to ground water (10 CFR 63.331).

The EPA and NRC regulations define the scope of long-term analysis for the proposed YM repository by specifying criteria for determining which FEPs must be included in PAs. Both EPA and NRC regulations state that PAs "shall not include consideration of very unlikely features, events, or processes, i.e., those that are estimated to have less than one chance in 100,000,000 per year of occurring." Impacts of FEPs that have a higher probability of occurrence need not be evaluated if overall repository performance in the initial 10,000 years after disposal "would not be changed significantly" by their occurrence (40 CFR 197.36(a)(1) and 10 CFR 63.342(a)). NRC requirements call for the use of "multiple barriers, consisting of both natural barriers and an engineered barrier system" (10 CFR 63.113(a)). Although no quantitative limits apply to the performance of components of the multiple barrier system, the DOE is required to describe the capability of barriers and to provide the technical basis for that description, consistent with the PAs used to demonstrate compliance with the system-level standards.

As required by the NRC at 10 CFR 63 Subpart G, all scientific and engineering work that directly supports the PA for the license application must be performed and documented in accordance with appropriate quality assurance standards [45].

3. Structure of 2008 YM PA

When viewed at a high level, the 2008 YM PA is based on three basic entities: (i) a probabilistic characterization of aleatory uncertainty (i.e., perceived randomness in the possible future occurrences that could affect the YM repository), (ii) a model that predicts dose to the RMEI and additional system properties conditional on specific realizations of aleatory uncertainty (i.e., the total system performance assessment, or TSPA, model), and (iii) a probabilistic characterization of epistemic uncertainty (i.e., a lack of knowledge with respect to the appropriate values for quantities used in the 2008 YM PA for system properties, the determination of dose to the RMEI, and the characterization of aleatory uncertainty that are assumed to have constant but uncertain values) ([6] Sect. 3, [46–49]).

The required analysis content for the license application was determined by following the five-step approach shown in Fig. 1. First, a comprehensive list of potentially relevant FEPs was identified based on insights from past YM PAs and programs of other nations and international organizations; then, the FEPs were evaluated and screened according to criteria specified by the NRC, e.g., at 10 CFR 63.114 [50,51]. Of the 374 FEPs identified for

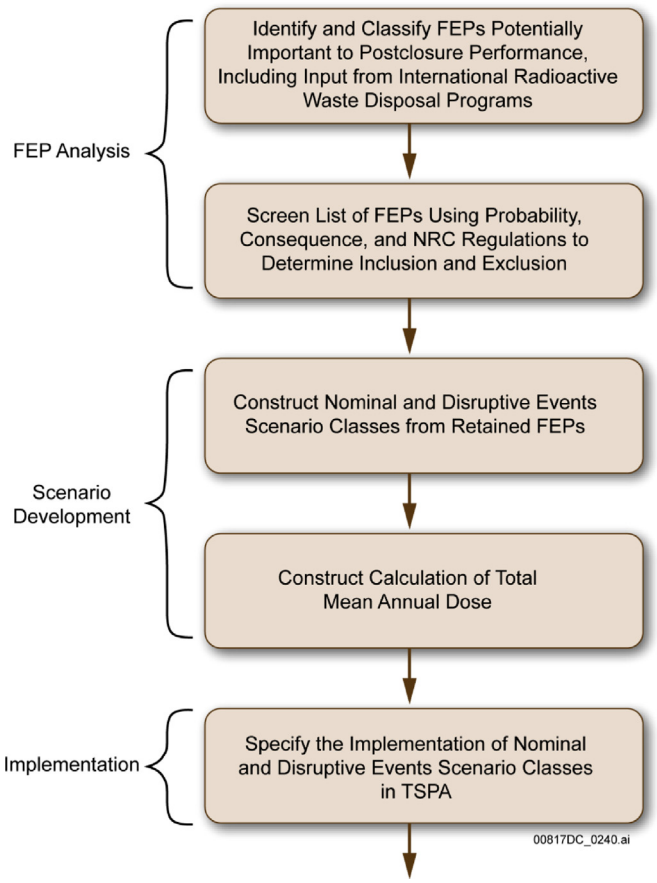

Fig. 1. Steps in the Development of Scenarios for the 2008 YM PA ([5], Fig. 6.1.1-1).

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