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# Overview of total system model used for the 2008 performance assessment for the proposed high-level radioactive waste repository at Yucca Mountain, Nevada

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ABSTRACT

A summary is presented for the total system model used to represent physical processes associated with the seven scenario classes (i.e., nominal conditions, early waste package (WP) failure, early drip shield (DS) failure, igneous intrusive events, igneous eruptive events, seismic ground motion events and seismic fault displacement events) considered in the 2008 performance assessment for the proposed repository for high-level radioactive waste at Yucca Mountain, Nevada. The total system model estimates dose to an exposed individual resulting from radionuclide movement through the repository system and biosphere. Components of the total system model described in this presentation include models for (i) climate analysis, (ii) land surface infiltration and associated unsaturated zone flow, (iii) multi-scale thermal hydrology and engineered barrier system (EBS) thermal–hydrologic environment, (iv) EBS physical and chemical environment, (v) WP and DS degradation, (vi) drift seepage and drift wall condensation, (vii) waste form degradation and mobilization, (viii) water and radionuclide movement in the EBS and underlying unsaturated and saturated zones, (ix) radionuclide movement in the biosphere and resultant human exposure, and (x) processes specific to early WP and DS failures, intrusive and eruptive igneous events, and seismic ground motion and fault displacement events.



## 1. Introduction

Performance assessment (PA) for the proposed repository for high-level radioactive waste at Yucca Mountain (YM), Nevada, employs models for physical processes to describe the evolution of the repository over time and to quantify measures of repository performance such as expected dose to the reasonably maximally exposed individual (RMEI) specified in the U.S. Nuclear Regulatory Commission's (NRC's) licensing requirements for the YM repository [1–3]. As outlined in Ref. [4], these models collectively constitute one of the three basic mathematical entities that underlie the determination of expected dose in the 2008 YM PA. The other two entities are probability spaces that characterize uncertainty in the occurrence of future events (i.e., aleatory uncertainty) and uncertainty resulting from the state of knowledge about the repository system (i.e., epistemic uncertainty). Formally, the assembly of models can be represented by a function $D(\tau \mid \mathbf{a}, \mathbf{e}_M)$, where $\tau$ indicates time and $\mathbf{a}$ and $\mathbf{e}_M$ are elements of the probability spaces for aleatory uncertainty and epistemic uncertainty, respectively.

Models used in the 2008 YM PA were required to account for all processes and features with potential to significantly affect repository performance, to be consistent with the current state of knowledge of the system, and to be accompanied with evidence of

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model validity sufficient for technical and regulatory review. The processes and features to be represented in the models were identified through a structured screening process [5,6]. Closely-related processes and features were grouped to form the technical scope of individual models. Development of individual models generally progressed from conceptual descriptions of models in terms of processes and associated assumptions, to mathematical expressions of conceptual models specifying dimensionality, initial and boundary conditions, and finally to numerical implementation of mathematical expressions in software for computation.

Due to the complexity of the YM repository system, models were generally developed within the hierarchy illustrated in Fig. 1. At the most detailed levels, data from relevant scientific literature, field observations and laboratory experiments were assembled to describe ranges of values for physical quantities such as the porosity of a geologic stratum or the solubility of a radionuclide. These values (or ranges of values) were employed in the formulation of process models such as the model for flow through the unsaturated rock above and below the disposal area and the quantities of radionuclides that could be mobilized in waters entering the disposal areas. However, calculation of dose to the RMEI directly from the process models was impractical. Accordingly, many process models were abstracted and represented in the calculation of dose by response surfaces or by a few discrete values. These abstracted models were assembled into the total system model indicated at the top of Fig. 1 for the calculation of dose.

As observed in Fig. 1, development of appropriate process models for the 2008 YM PA presented a significant challenge to produce technically defensible models that support a computationally tractable

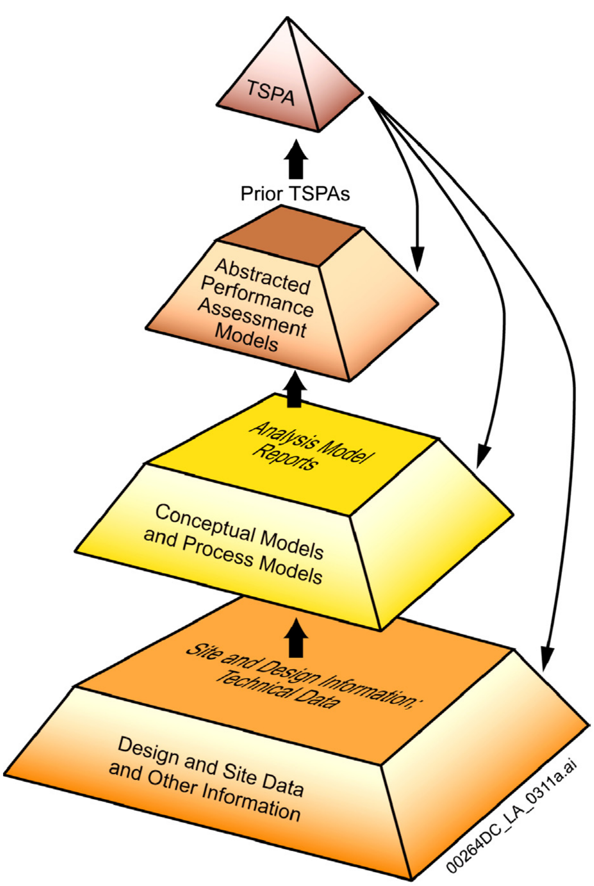


**Fig. 1.** Iterative process employed to synthesize data, conceptual and process models, and model abstractions into the total system model for the 2008 YM PA ([10], Fig. 2.3-1).

total system model. Consistent with NRC requirements [1–3,7], features and processes need not be evaluated in detail where the omission of such treatment would not significantly affect the time or magnitude of radionuclide releases. Accordingly, development of process models was managed from a system-level perspective, where the necessity and utility of enhancements to process models was judged by considering the potential effects on estimates of system performance. Moreover, because the numerical measure of system performance is expected annual dose, aspects of spatial variability in the repository system are often represented by spatial averages or by representative values where such representation is consistent with the calculation of expected values, to reduce the computational complexity of the total system model.

Fig. 2 illustrates the total system model used to estimate performance of the YM repository in the nominal scenario class. Abstractions of the process models were assembled and linked using the GoldSim software [8,9]. For other scenario classes (i.e., early waste package (WP) failure, early drip shield (DS) failure, igneous intrusive, igneous eruptive, seismic ground motion and seismic fault displacement scenario classes), similar models were assembled using abstractions of process models that were modified to account for the effects of the events represented by each scenario class ([8], Figs. 6.1.4-3–6.1.4-6). A total of seven models were thus assembled, one for each scenario class.

This paper provides (i) a summary description of the proposed repository and (ii) summary descriptions of the models indicated in Fig. 2 that represent the major features and processes of the YM repository system. The summary descriptions are at a high level and provide neither a detailed description of the repository system, nor formal mathematical descriptions of the models for physical processes used in the 2008 YM PA. This presentation intends to provide a perspective on the nature and scale of the physical process models that underlie the 2008 YM PA without the massive amount of mathematical detail that would be required to fully describe these models. However, extensive references are provided to detailed descriptions of the models used in the 2008 YM PA in two technical reports [8,10] and the many model specific technical reports cited therein. Summary descriptions of the physical process models used in the 2008 YM PA are also available in a sequence of conference presentations [11–13].

This article is part of a special issue of *Reliability Engineering and System Safety* on the 2008 YM PA and is intended as an introduction to following articles in the issue that provide additional analysis details and specific analysis results [14–24]. In addition, ten preceding articles provide historical background on the development and evolution of PA procedures for the proposed YM repository [25–34].

## 2. Summary description of repository system

Yucca Mountain is located in an arid region of the southwestern United States, about 90 mile northwest of Las Vegas, NV ([10], Fig. 1-1). The mountain is made up of a series of north–south oriented ridges roughly 350 m above the adjacent basin floor, with crests at about 1700 m in elevation ([10], Section 1.1.1.2). Yucca Mountain comprises successive layers of fine-grained volcanic tuff. The Topopah Springs Tuff, which includes the repository host rock units, was deposited approximately 13 million years ago ([10], Section 1.1.5.1). In the present climate, annual precipitation at Yucca Mountain is typically 200 mm/yr ([10], Table 1.1-19).

The proposed repository would be mined into YM roughly 200 m below the surface and roughly 300 m above the present-day water table ([10], Fig. 5-40; Section 1.3.1.1). The repository is projected to remain roughly 200 m above the water table during future climates ([10], Section 2.3.2.5.2). The waste emplacement