TOTAL SYSTEM PERFORMANCE ASSESSMENT (TSPA) FOR THE SITE RECOMMENDATION

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ABSTRACT

The U.S. Department of Energy (DOE) has been evaluating the feasibility of disposing high level radioactive wastes at a potential repository at Yucca Mountain, Nevada. These wastes consist of spent fuel from commercial nuclear reactors around the U.S. as well as defense and other high level wastes in the form of vitrified glass or spent fuel stored at DOE facilities. An important milestone in the decision making process is the determination of the suitability of the Yucca Mountain site as a long-term repository for these wastes. The DOE has been conducting numerous scientific and engineering investigations at the site for the last 20 years to evaluate the suitability of the site. If the site is found suitable, the Secretary of Energy may decide to recommend the site to the President.

An important element in the determination of site suitability is the evaluation of the performance of the site and the associated engineered barriers following repository closure.

A total system performance assessment (TSPA) for the Yucca Mountain repository system has recently been completed. This TSPA has been documented by the Civilian Radioactive Waste Management System Management and Operating (CRWMS M&O) contractor in a technical report entitled *Total System Performance Assessment for the Site Recommendation* (1). The purpose of this paper is to briefly summarize the approach, results and conclusions contained in this document.

INTRODUCTION

The U.S. Department of Energy (DOE) has been evaluating the feasibility of disposing high level radioactive wastes at a potential repository at Yucca Mountain, Nevada. These wastes consist of spent fuel from commercial nuclear reactors around the U.S. as well as defense and other high level wastes in the form of vitrified glass or spent fuel stored at DOE facilities. An important milestone in the decision making process is the determination of the suitability of the Yucca Mountain site as a long term repository for these wastes. The DOE has been conducting numerous scientific and engineering investigations at the site for the last 20 years to evaluate the suitability of the site. If the site is found suitable, the Secretary of Energy may decide to recommend the site to the President.

An important element in the determination of site suitability is the evaluation of the performance of the site and the associated engineered barriers following repository closure. This evaluation includes an assessment of the likely ability of the waste disposal concept to meet the applicable radiation protection standards. The method and criteria for evaluating postclosure suitability were proposed by the DOE in 10 CFR part 963 (64 FR 67054). An element of the requirements for the suitability evaluation is the completion of a total system performance assessment and a comparison of the projected performance with the applicable standards to assess compliance.

A total system performance assessment (TSPA) for the Yucca Mountain repository system has recently been completed. This TSPA has been documented by the Civilian Radioactive Waste Management System Management and Operating (CRWMS M&O) contractor in a technical report entitled *Total System Performance Assessment for the Site Recommendation* (1). This TSPA is the first draft of the type of analyses that would be completed for the Site Recommendation Report. It is currently undergoing an international peer review jointly coordinated by the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA). The purpose of this paper is to briefly summarize the approach, results and conclusions contained in this document. The document is available on the web at www.ymp.gov or a hard copy may be requested by writing DOE at:

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Yucca Mountain Site Characterization Office
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APPROACH

The objective of the TSPA is to provide an assessment of repository performance at the potential Yucca Mountain Site as part of the site recommendation process. Assessing the performance of the system requires the following:

- Assimilating all the available scientific data and analyses that describe the geological setting into which the design concept is to be placed
- Defining the design concept that is to be used
- Describing the behavior of the potential repository system in a traceable, transparent manner
- Identifying the standards by which the performance of the repository estimated using TSPA will be judged.

The total system is comprised of geological and engineering components. Therefore, the TSPA uses the available scientific information about naturally occurring physical and chemical processes at the Yucca Mountain site. In addition, the TSPA includes the design concepts and scientific information about physical and chemical processes involving the engineered components.

The general TSPA approach is illustrate in Figure 1. Starting with a basic design concept, information about the features, events and processes (commonly referred to as FEPs) germane to the characterization of the site and associated engineered barriers is collected by project scientists. This information is used to develop models of the relevant processes, first at the conceptual level and then at the detailed or process level and finally at a simplified or abstracted level suitable for inclusion in the probabilistic TSPA model. Throughout this process the uncertainty in the understanding is quantified to the extent possible, or appropriately bounded in cases of high complexity. The role of the performance assessment is then to integrate these processes and to evaluate the significance of the uncertainty with respect to the ability of the system to meet the regulatory objectives.

TOTAL SYSTEM PERFORMANCE ASSESSMENT MODEL

The components included in the TSPA model for the Yucca Mountain repository system are schematically illustrated in Figure 2. This figure illustrates the relevant attributes of the repository system, as follows:

- Limiting water contacting waste package - this includes processes that affect water movement above the repository horizon (such as the climate, net infiltration and unsaturated zone hydrology) and the possible ingress of water into the emplacement drifts by seepage.
- Prolonging waste package lifetime – this includes processes that affect the degradation rate of the engineered barriers, including the environments in the emplacement drifts and the corrosion processes that affect the lifetime of the drip shield and waste package.
- Limiting radionuclide mobilization and release – this includes processes in the waste package such as the degradation of the spent fuel cladding and the alteration of the waste form when it is exposed to moisture, as well as the mobility and transport characteristics of the different radionuclides contained in the waste.
- Slowing radionuclide migration away from the engineered barrier system (EBS) – this includes processes in the drift, the unsaturated zone and the saturated zone that tend to delay or disperse the radionuclides that may be released from the engineered barriers.
- Addressing the effects of potentially disruptive processes and events – this includes analysis of the potential significance of low probability events such as igneous activity.

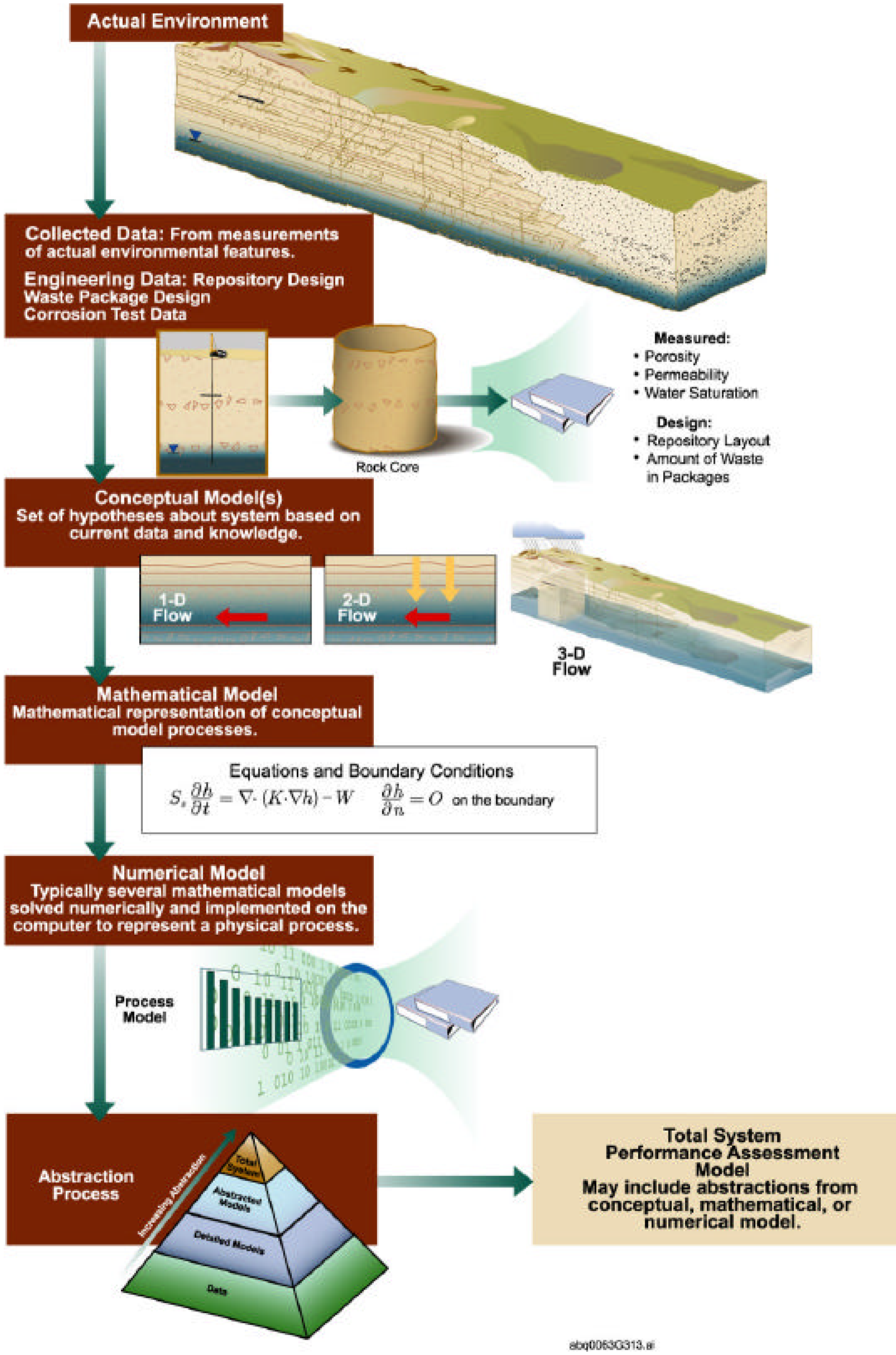

Fig. 1. General Approach in the Development of a Total System Performance Assessment

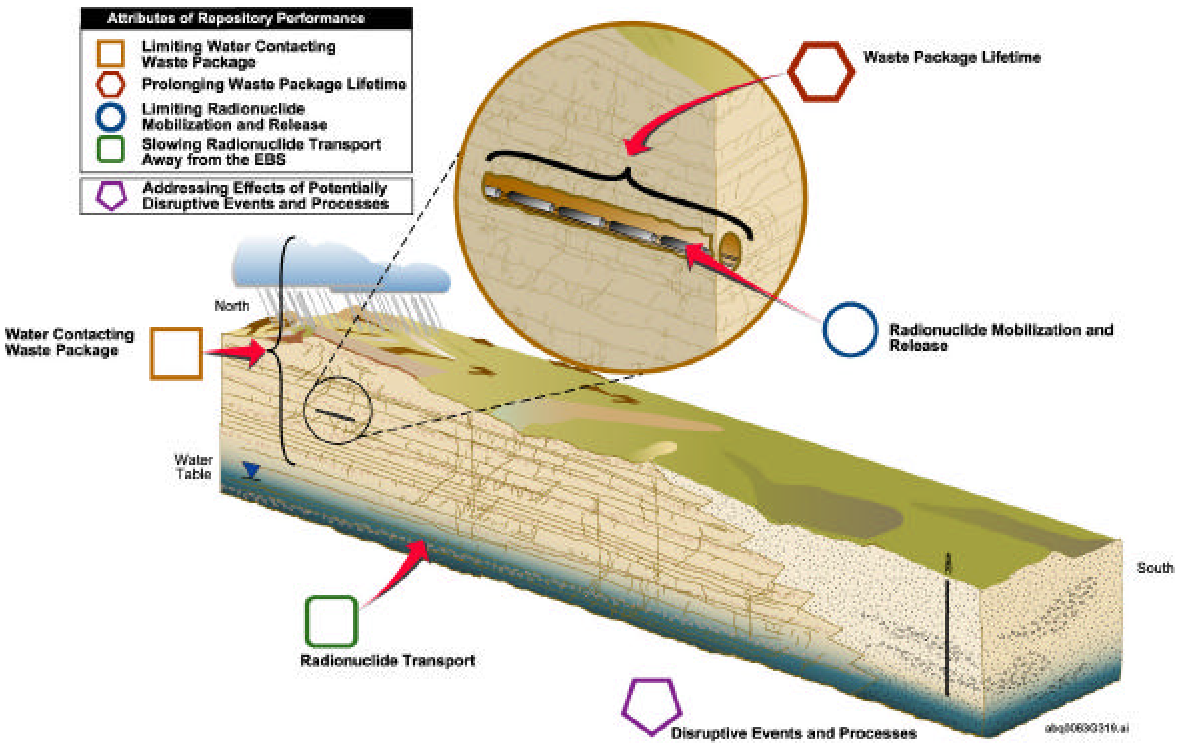

Fig. 2. Schematic Illustration of the Yucca Mountain Site and the Principal Attributes of the Repository System Affecting Performance

Figure 3 illustrates the interconnection and flow of information between the process component models of the TSPA. This figure also illustrates that the total group of possible FEPs are screened to identify those that are significant to repository performance. The screened FEPs are then combined into relevant scenario classes, including the nominal scenario class which describes the probable performance and its uncertainty in the absence of low probability disruptive events and the igneous activity scenario class which describes the probable performance attributed to a low probability igneous event. Also illustrated are the various performance measures of interest to post closure performance. The results of the analyses are presented in the next section.

As noted above, the scientific basis for the individual component models is founded on site-specific investigations supported where possible by analog information available in the scientific literature. The information available to support the models is briefly summarized in the document *Total System Performance Assessment for the Site Recommendation* (1) and the supporting references, in particular a series of Process Model Reports as depicted below:

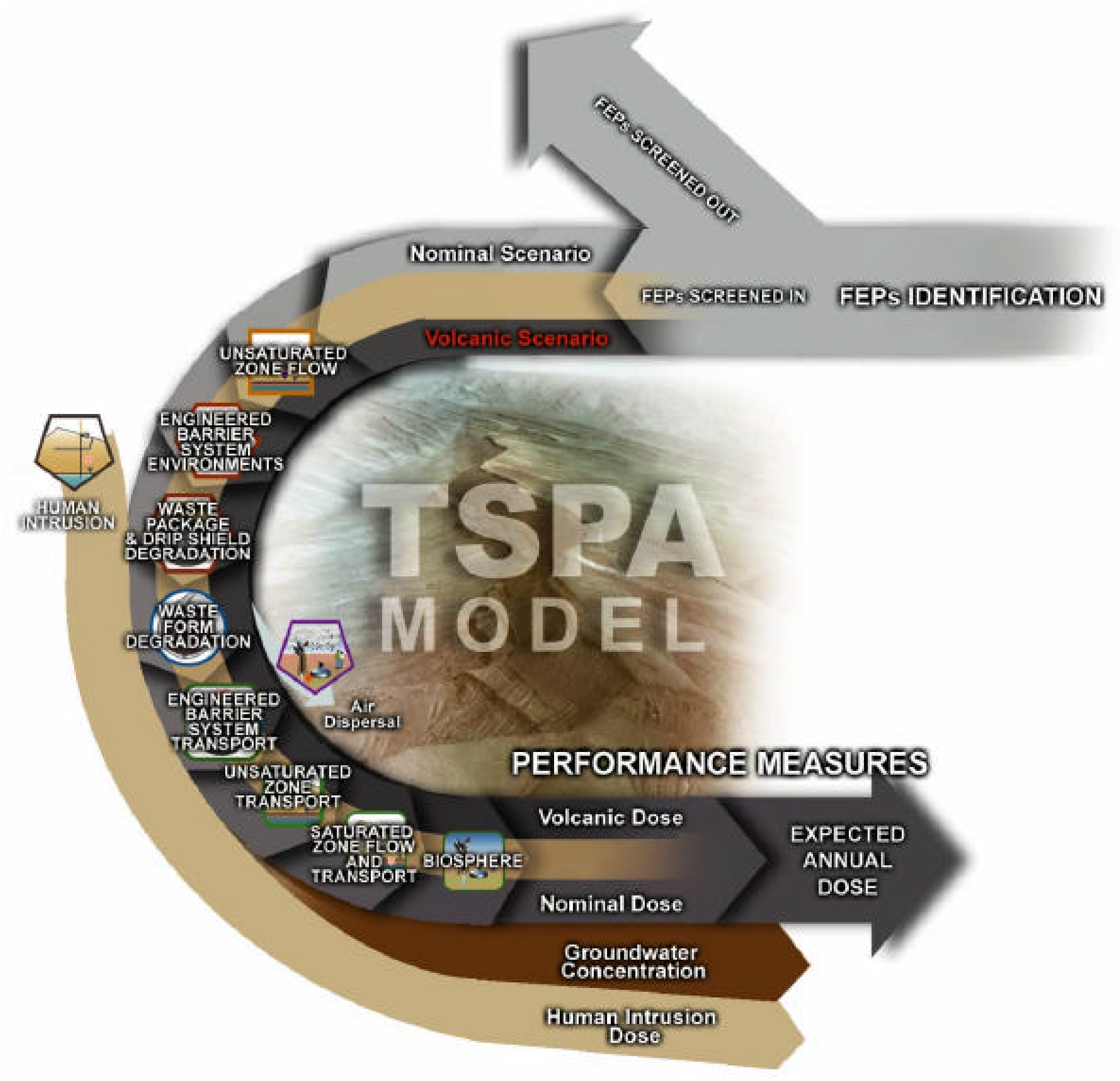

Fig. 3. General Schematic of the Component Models Included in the TSPA and the Principal Performance Measures Included in TSPA-SR

Process Model Component	Process Model Report Documentation
Unsaturated Zone Flow	Unsaturated Zone Flow and Transport (4)
Engineered Barrier System Environments	Near Field Environment (5)
Waste Package and Drip Shield Degradation	Waste Package Degradation (6)
Waste Form Degradation	Waste Form Degradation (7)
Engineered Barrier System Transport	Engineered Barrier System Degradation, Flow, and Transport (8)
Unsaturated Zone Transport	Unsaturated Zone Flow and Transport (4)
Saturated Zone Flow and Transport	Saturated Zone Flow and Transport (9)
Biosphere	Biosphere (10)
Volcanism	Disruptive Events (11)

RESULTS

Using the TSPA model and approach summarized above, the individual protection results and the corresponding uncertainty in these results is depicted in Figure 4 for the nominal performance scenario class and in Figure 5 for the igneous activity scenario class. Figure 6 illustrates the temporal evolution of the total radionuclide inventory with the engineered and natural barriers. This figure indicates the large fraction of the total inventory that remains within the waste package due to the containment by the engineered barriers, the low mobility of many radionuclides, and the very small fraction of mobile radionuclides that may be transported to the receptor group over very long time periods.
Several points are worth summarizing on these projections:

- These projections have included the uncertainty in the dose attributed to the quantified uncertainty discussed in the process models, abstraction models and their included parameters presented in Section 3 of *Total System Performance Assessment for the Site Recommendation* (1). As a result, a distribution of potential doses has been developed reflecting this uncertainty.
- Additional unquantified uncertainty exists, the impacts of which have not been captured in the results presented. These unquantified uncertainties reflect in large part the conservative assumptions included in the analyses to increase the defensibility in particularly complex processes. Appendix F of *Total System Performance Assessment for the Site Recommendation* (1) summarizes the significance of the conservative assumptions included in the analyses. The result of this conservatism is to under-estimate the possible performance.

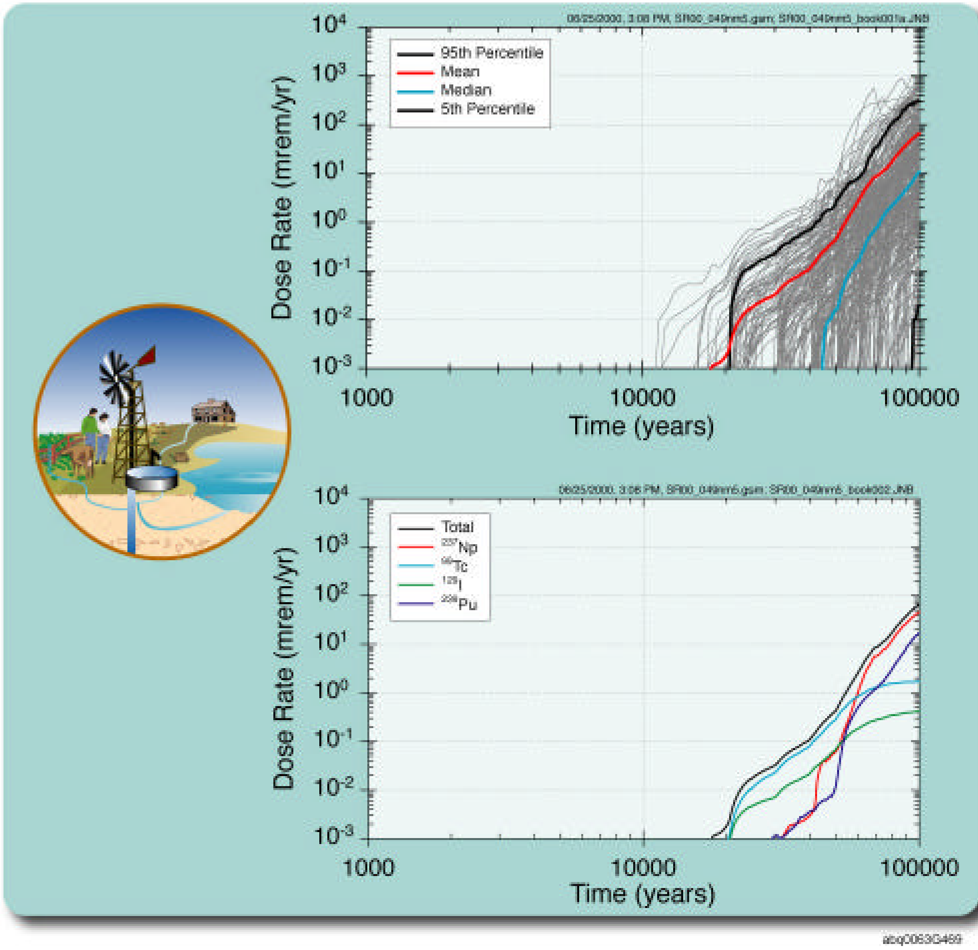

Fig. 4. Individual Protection Performance Results for Nominal Scenario Class

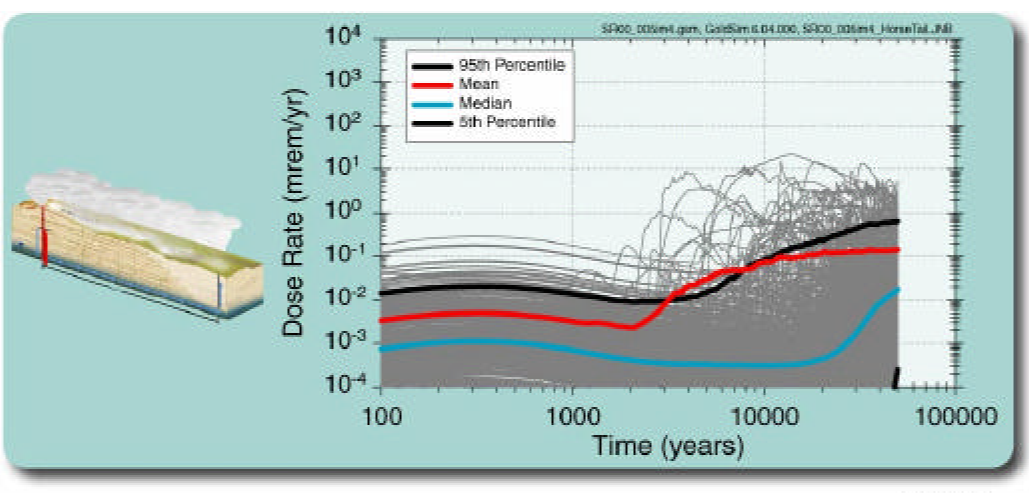

Fig. 5. Individual Protection Performance Results for Igneous Activity Scenario Class

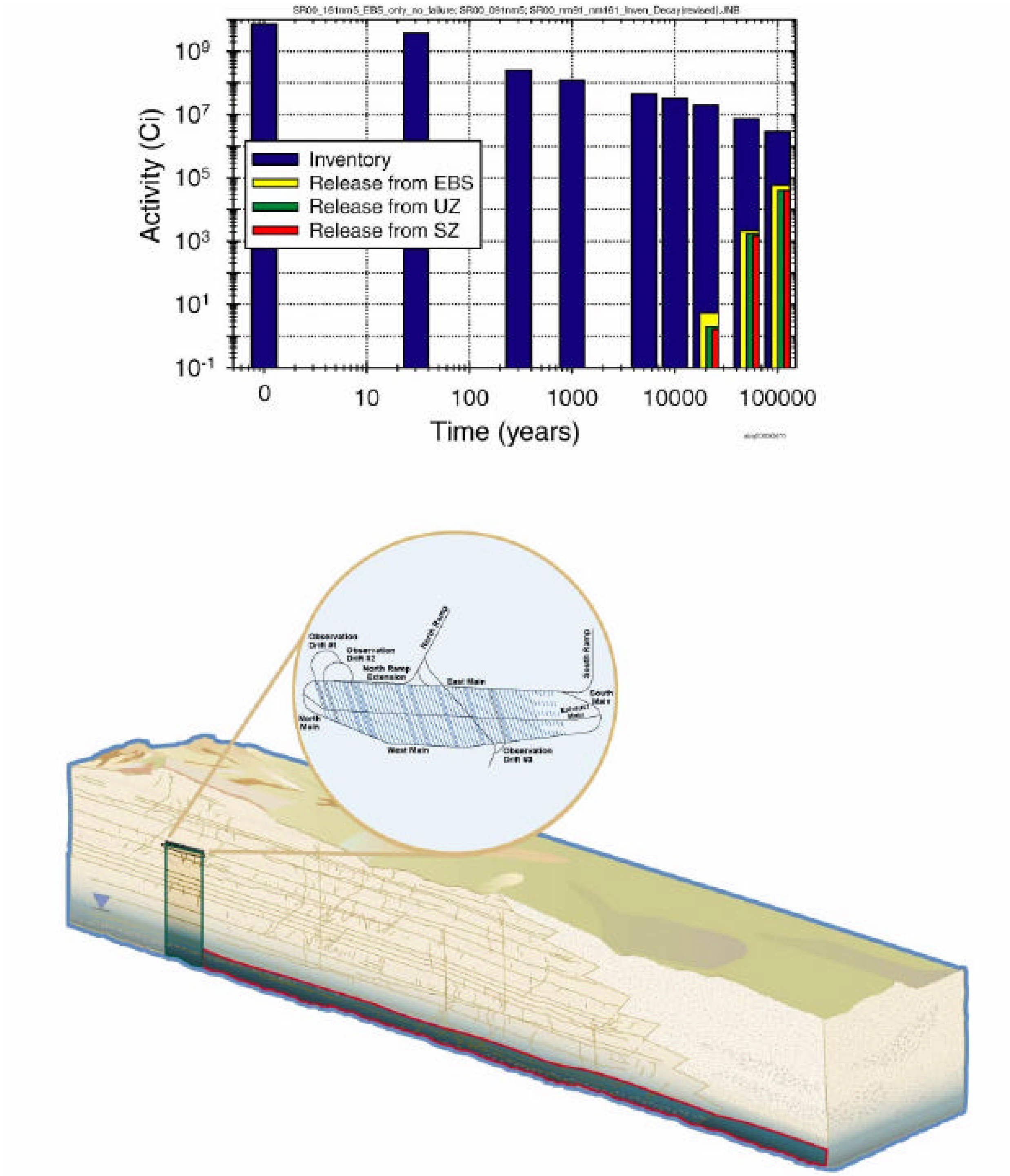

Fig. 6. Distribution of Radionuclide Activity Released from Different Barriers for the Nominal Scenario Class

- Projections are made beyond the 10,000-year regulatory time period specified for the standards proposed in 40 CFR Part 197 (3). These projections are important to evaluate the robustness of the system response and the contribution of both natural and engineered barriers to the overall system performance during the time period when the containment of the engineered barrier is being degraded. These post-10,000 year projections will also be used in the Environmental Impact Statement to consider the effects of the peak dose, as required by the EPA in proposed 40 CFR Part 197 (3).
- Projections are made for the dose to the individual residing 20 kilometers downgradient from the potential repository, in the vicinity of Lathrop Wells.
- These projections are applicable to both the average member of the critical group (using the definition of proposed 10 CFR Part 63 (2)) and the reasonably maximally exposed individual (using the definition of proposed 40 CFR Part 197 (3)). It is important to recognize that both of these individuals reside within a group of individuals likely to be most exposed to the risks associated with the long-term performance of the potential repository (given that the group of individuals is assumed to reside over the plume of contaminated groundwater). The exact characteristics of this individual (whether s/he is the "average member" or the "reasonably maximally exposed individual") are similar. In both instances the individual: (a) has a diet that includes the consumption of amounts of locally grown produce, milk, and meat, consistent with the diet of current residents of Amargosa Valley; (b) lives in the vicinity of Lathrop Wells; (c) has a lifestyle consistent with the existing population of Amargosa Valley; and (d) drinks 2 liters of water per day derived from the contaminated groundwater.
- The projected doses for the volcanic event scenario class reflect probability-weighted doses as required in proposed 10 CFR Part 63 (2); that is the probability of the event is multiplied by the dose consequence to yield the dose risk. This allows combining the nominal and volcanic event scenario classes to yield the total system dose response.

Total system performance assessments are by their very nature uncertain projections of the possible behavior of the individual component models describing the relevant processes affecting the containment and isolation of radioactive wastes from the biosphere. This uncertainty is explicitly included in the models and resulting analyses in the form of discrete probability distributions that encompass the range of possible outcomes.

There remains uncertainty in the individual process models and their abstraction into the TSPA model. Much of this uncertainty has been quantified and is included in the TSPA model. The TSPA results reflect this quantified uncertainty. For example, the full distribution of individual dose rates illustrated on Figure 4 indicate a range of possible dose rates that extends over about 6 orders of magnitude between the 5th and 95th percentile. This range is a direct indication of the degree of uncertainty incorporated in the individual models used as input to the TSPA model.

In addition to the quantified uncertainty in the TSPA model, there is also unquantified uncertainty that has been generally represented by using a more bounded or conservative representation of a particular process model. These conservatisms result when there is insufficient information available or significant complexity exists that is not amenable to quantification of the attendant uncertainty (although elicitation approaches could be used if one desired to quantify the uncertainty in these conservative judgments).

An important use of the performance assessment methodology is to evaluate the significance of the uncertainty associated with projections of such long term risks. A detailed discussion of the results of the uncertainty analyses may be found in *Total System Performance Assessment for the Site Recommendation* (1).

CONCLUSIONS

In conclusion, a systematic approach based on detailed scientific investigations has been developed and applied to the evaluation of the performance of the Yucca Mountain repository system. This evaluation has considered the relevant features, events and processes that are potentially important to long-term performance. It has also evaluated the significance of the inherent uncertainty in the projections of performance over such long time periods.

Both the EPA and the NRC have recognized that uncertainty about the future performance of the repository will remain even after site characterization is complete. The NRC perspective is articulated in proposed 10 CFR Part 63, which states, "Proof that the geologic repository will be in conformance with the objective for postclosure performance is not to be had in the ordinary sense of the word" (64 FR 8640 [101680], Section IX, p. 8650). In place of such proof, the NRC regulation makes the determination of compliance with the standards contingent upon a regulatory finding of "reasonable assurance," which would be made on the basis of the record before it. Similarly, the EPA explicitly states that "unequivocal numerical proof of compliance is neither necessary nor likely to be obtainable" (64 FR 46976 [105065], p. 46997). The EPA prescribes a "reasonable expectation" approach for demonstrating compliance with its standard.

As the National Research Council ((12), p. 13) and others have noted, there are residual uncertainties with deep geologic disposal that cannot easily be quantified and incorporated into performance analyses. Nevertheless, their potential impact must be, to the extent practicable, addressed and, if important, mitigated to provide confidence in post-closure safety. Examples of residual uncertainties associated with geologic disposal that are difficult to quantify include:

- The potential for currently unknown processes to affect performance

- The possibility that incompletely characterized processes have been incorporated in the TSPA in a manner that results in the underestimation of radionuclide releases; examples of incompletely characterized processes include thermal, chemical, hydrologic, and mechanical processes that are coupled in complex ways that cannot be completely tested at the scale of a repository, and processes that are difficult to observe and test, such as colloidal transport of radionuclides
- Uncertainty associated with the projections of engineered barrier performance over geologic time periods (e.g., 10,000-years) based on data from short-term (e.g., several years) laboratory testing
- Uncertainty associated with the large spatial scale of the three-dimensional groundwater flow system, which makes it difficult to characterize flow paths and processes.

Substantial effort has been made to identify, characterize, and mitigate the potential impacts of residual uncertainties that could significantly affect long-term performance. Where possible, more tests have been conducted to collect additional information that would provide insight to analysts. Where additional testing was not feasible (e.g., it is not possible to run tests over the same time period as the repository must perform), or of limited benefit (e.g., no amount of excavation or drilling could completely characterize the natural system) modelers used conservative assumptions to "bound" their analyses of uncertain processes. In addition, use has been made of empirical observations and qualitative lines of evidence from natural analogues to address uncertainties.

Addressing the uncertainty inherent in the models used for post-closure performance assessment has been an integral ingredient in the development and implementation of the component models and parameters used in the TSPA model. In addition, examining the significance of quantified uncertainty has been an important objective of the TSPA analyses themselves. Ongoing efforts to quantitatively evaluate the significance of unquantified uncertainties will add additional insights to support the determination of the degree of conservatisms included in the "base case" models.

Finally, these analyses and the supporting documentation, as well as future updates and refinements to the models and analyses, will serve as part of the information used to determine the suitability of the Yucca Mountain repository system and to support the Secretary of Energy's decision of whether to recommend the site to the President.

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