To be published in the *Proceedings of the NEA Workshop on Scenario Development, Madrid, Spain, May 10-12, 1999*, Nuclear Energy Agency of the Organisation for Economic Co-operation and Development

Feature, Event, and Process Screening and Scenario Development for The Yucca Mountain Total System Performance Assessment

SAND98-2831C

Peter Swift, George Barr, Ralston Barnard, and Rob Rechard
Sandia National Laboratories
Al Schenker
Los Alamos Technical Associates
Geoffrey Freeze and Peter Burck
Duke Engineering and Services

1.0 Introduction

Scenario development has two primary purposes in the design and documentation of post-closure performance assessments in a regulatory setting. First, scenario development ensures a sufficiently comprehensive consideration of the possible future states of the system. Second, scenario development identifies the important scenarios that must be considered in quantitative analyses of the total system performance assessment (TSPA).

To ensure clear documentation of the treatment of potentially relevant future states of the system in the Yucca Mountain license application (LA), the US Department of Energy (DOE) has chosen to adopt a scenario development process based on the methodology developed by Cranwell et al. (1990) for the US Nuclear Regulatory Commission (NRC). Although the process, described below, has been modified somewhat as a result of experience gained in the last decade, the underlying methodology is consistent with that outlined by the DOE in the 1988 Site Characterization Plan for the Yucca Mountain Project (YMP) (U.S. DOE, 1988). The approach is fundamentally the same as that used in many performance assessments, including the most recent analysis of the Yucca Mountain repository by the NRC (Wescott et al., 1995). The approach has also been used by the DOE for the Waste Isolation Pilot Plant (WIPP) (U.S. DOE, 1996), by the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-Operation and Development (OECD), and by other radioactive waste programs internationally (e.g., Skagius and Wingefors, 1992).

Section 2.0 of this report describes the scenario development process. Steps in the process are described in Section 2.1, and terms introduced in this section are defined in Section 2.2. The electronic database used to document the process is described in Section 3, and Section 4 provides a summary of the current status of the YMP scenario development work. Section 5 contains acknowledgments, and Section 6 contains a list of the references cited.

DISCLAIMER

2.0 The Scenario Development Process

There are five principal steps to the scenario development process, as outlined in Section 2.1 and illustrated in Figure 1. Documentation of the scenario development process will include documentation of each of these steps.

2.1 The Five Steps of Scenario Development

1. Identify and classify features, events, and processes (FEPs) potentially relevant to the long-term performance of the disposal system.

2. Screen the FEPs using well-defined criteria to distinguish between those FEPs that can be excluded from the TSPA and those that should be included in the analysis.

3. Use the retained FEPs to construct scenarios, or scenario classes (which are defined as sets of related scenarios), as appropriate.

4. Screen the scenarios (or scenario classes) using the same criteria applied to the FEPs to identify any scenarios that can be excluded from the TSPA.

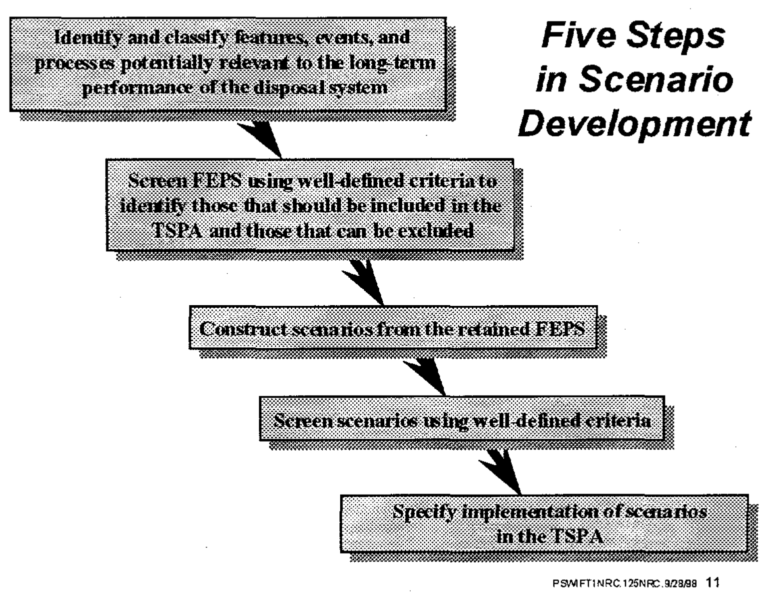

Figure 1: The Five Steps in Scenario Development

5. Specify the implementation of the scenarios (or scenario classes) in the computational modeling for the TSPA, and document the treatment of included FEPs.

These five steps differ slightly from those identified by Cranwell et al. (1990), in that FEP classification, which was the second step in their procedure, has been included with the first step, and the final step has been modified to clarify the linkage between scenario development and the TSPA analysis.

Section 2.1.1 Step 1: Identifying FEPs and Building the Initial FEP list

The NRC's proposed rule for the Yucca Mountain repository, 10 CFR part 63, defines performance assessment to be

> … a probabilistic analysis that:
>
> (1) Identifies the features, events, and processes that might affect the performance of the geologic repository; and
> (2) Examines the effects of such features, events, and processes on the performance of the geologic repository; and
> (3) Estimates the expected annual dose to the average member of the critical group as a result of releases from the repository. (Proposed 10 CFR § 63.2)
> (4) Step 1 of the scenario development process, the identification of FEPs potentially relevant to the performance of the Yucca Mountain repository, will help meet NRC expectations regarding the scope of the performance assessment.

The initial set of FEPs has been created for the Yucca Mountain TSPA by combining lists of FEPs previously identified as relevant to the YMP (e.g., by Wilson et al., 1994, CRWMS M&O, 1995, and other documents) with a draft FEP list compiled by an NEA working group. The NEA list is the most comprehensive list available internationally, and currently contains 1261 entries from Canadian, Swiss, and Swedish spent-fuel programs, intermediate and low-level waste programs of the UK, and the US WIPP program. The YMP initial FEP list currently (as of November 1998) contains 1573 entries.

The FEP list is open, and will continue to grow as additional FEPs are identified. Because one of the major goals of the process is to address the comprehensiveness of the TSPA, no FEPs are removed from the list at this stage. Consistent with the diverse backgrounds of the programs contributing to the NEA list, FEPs currently on the list were identified by a variety of methods, including expert judgement, informal elicitation, event tree analysis, stakeholder review, and regulatory stipulation. For the purposes of the Yucca Mountain scenario development effort, no specific technique is identified as a preferred method of FEP identification. All potentially relevant FEPs are included, regardless of origin.

This approach leads to considerable redundancy in the FEP list, because the same FEPs are frequently identified by multiple sources. To eliminate this redundancy and to create a more useful FEP list to carry forward into the screening process in Step 2, FEPs are identified in this stage as either Primary FEPs or Secondary FEPs. Primary FEPs are those FEPs for which the project proposes to develop detailed screening arguments. Secondary FEPs are either FEPs that are completely redundant (for example, the NEA list contains as many entries for meteorite impact as there were participating programs), or FEPs that can be aggregated into a single primary FEP for the purposes of the Yucca Mountain TSPA. Examples of secondary FEPs that can be aggregated into a single primary FEP for Yucca Mountain include almost all FEPs related to human disruption of the disposal system, given the proposed regulatory requirement regarding the treatment of human intrusion through a prescribed drilling scenario.

FEPs that are unarguably irrelevant to the Yucca Mountain system, such as those that are specific to repositories in salt host rock, are also identified at this stage, and are not carried through into Step 2 for the development of specific screening arguments.

Documentation is maintained at this stage of all mapping of FEPs into the primary and secondary categories, and of any FEPs identified as irrelevant. Screening work in Step 2 focuses on the primary FEPs. For comprehensiveness, traceability is maintained from the secondary FEPs to the related primary FEPs.

2.1.2 Step 2: Screening the FEP list.

Each FEP is screened for inclusion or exclusion in the TSPA on the basis of three basic criteria. First, each FEP is examined to determine whether or not it is of regulatory concern, given the specific regulatory requirements applicable to the Yucca Mountain TSPA. If the FEP is potentially of concern, it is then screened on the basis of its probability of occurrence or its consequence.

As described in Section 2.1.2.1, each of these screening criteria have their basis in regulatory requirements contained in the NRC's proposed rule 10 CFR part 63. FEPs are excluded from the TSPA only if they are specifically ruled out by regulation (e.g., deliberate human disruption of the site), if they can be shown to have a probability of occurrence less than 10^{-4} in 10^{4} yr, or if their occurrence can be shown to have no significant effect on the overall performance of the system. Because the regulatory requirements allow exclusion of FEPs on any one of these criteria, a FEP need not be shown to be both of low probability and low consequence to be excluded. The order in which the criteria are applied is, therefore, not essential.

In practice, FEPs are screened as shown in Figure 2: regulatory criteria are examined first, and then either probability or consequence may be examined next at the discretion of the analyst. This application of the analyst's judgment regarding the order in which to apply the criteria does not affect the final decision: FEPs that are retained on one criterion will then be considered against the other. Allowing the analyst to chose the most appropriate criteria to apply at this step prevents needless work developing quantitative probability arguments for low consequence events or complex consequence models for low probability events. For example, there is no need to develop detailed models of the response of the disposal system to the impact of a large meteorite if it can be shown that this event has a probability below the regulatory cutoff.

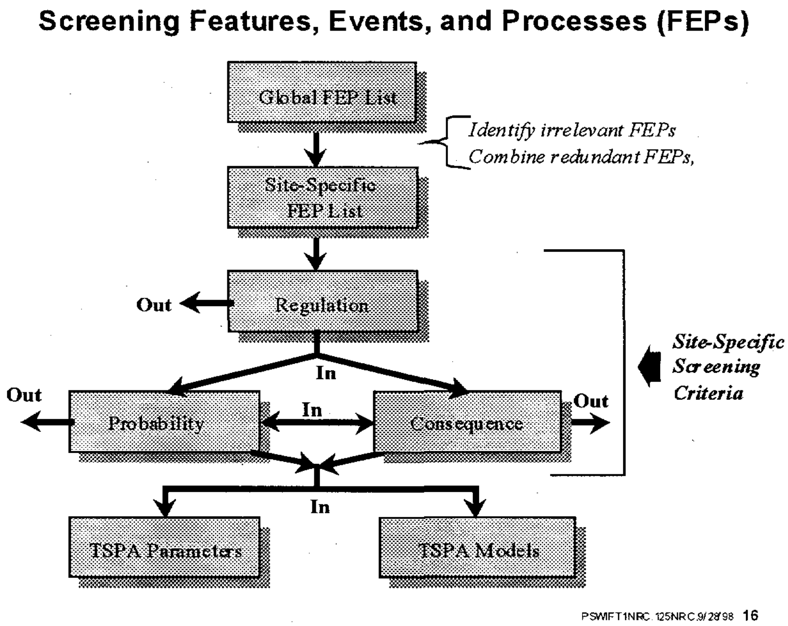

Figure 2. Schematic illustration of the FEP screening process.

Probability estimates for FEPs may be based on technical analysis of the past frequency of similar events (such as seismic events), or, in some cases, on expert elicitation. Probability arguments, in general, require including some information about the magnitude of the event in its definition. For example, the probability of meteorite impacts depends on the size of the meteorite of interest. Impacts of meteorites sufficiently large to create large craters at Yucca Mountain are much less probable than smaller impacts. Thus, meteorites large enough to affect the disposal system may be screened out on the basis of low probability (if a sufficiently low probability can be established), but small impacts that have no effect are more appropriately screened out on low consequence. Probability arguments are also sensitive to the spatial and temporal scales at which FEPs are defined (meteorite impacts are less likely in shorter time intervals and at smaller locations), and probability arguments should therefore be made at reasonably coarse scales.

The quantitative basis for consequence-based screening arguments can be established in a variety of ways, including TSPA sensitivity analyses, modeling studies outside of the TSPA, or, in the case of relatively straightforward arguments, through the use of reasoned arguments based on literature research. For example, consequences of many geomorphic processes such as erosion and sedimentation can be evaluated by considering bounding rates reported in geologic literature. More complicated processes such as criticality require detailed analyses conducted specifically for the Yucca Mountain Project. Low-consequence arguments are often made by demonstrating that a particular FEP has no effect on the distribution of an intermediate performance measure in the TSPA. For example, demonstrating that including a particular waste form has no effect on the concentrations of radionuclides transported from the repository in the aqueous phase may be sufficient to demonstrate that including this waste form would not change the overall performance measure. Explicit modeling of the characteristics of this waste form could therefore be excluded from the TSPA.

Documentation of the FEP screening step in the scenario development process will include a statement of the screening decision for each FEP (retained or excluded). For excluded FEPs, documentation will include the criterion on which it was excluded and the technical basis for the screening argument. Documentation of the treatment of retained FEPs in the models and parameters of the TSPA, as shown in the last steps of Figure 2, will be provided by Step 4.

2.1.2.1 Regulatory Screening Criteria in Proposed 10 CFR part 63

Proposed 10 CFR part 63 contains regulatory screening criteria relevant to many FEPs. Examples include the explicit requirements regarding assumptions about the critical group to be considered in the dose assessment (at § 63.115), and the specification of the treatment of human intrusion (at § 63.113(d)).

The probability criterion is explicitly stated at § 63.114:

> (d) Consider only events that have at least one chance in 10,000 of occurring over 10,000 years.

Because the probability of any specific event depends strongly on how it is defined, the probability criterion can only be applied at an appropriately broad scale. For example, the probability of seismic events should be evaluated over the entire 10,000-year period, rather being artificially lowered by defining 10,000 different seismic events each occurring in a different year.

Consequence criteria are provided at § 63.114(e) and § 63.114(f):

> (e) Provide the technical basis for either inclusion or exclusion of specific features, events, and processes of the geologic setting in the performance assessment. Specific features, events, and processes of the geologic setting must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission.

(f) Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission.

2.1.3 Step 3: Constructing Scenarios

The NRC has not defined the term "scenario" in draft proposed 10 CFR part 63. The Yucca Mountain TSPA has chosen to define a scenario as a subset of the set of all possible futures of the disposal system that contains futures resulting from a specific combination of features, events, and processes.

The primary reason for adopting this definition is pragmatic: one of the goals of scenario development is to define a limited set of scenarios that can reasonably be analyzed quantitatively while still maintaining comprehensive coverage of the range of possible future states of the system. There are an essentially infinite number of possible future states, and for scenario development to be useful, it must generate scenarios that are representative of the range of futures that are potentially relevant to the licensing of the facility.

Under the definition adopted for the Yucca Mountain TSPA, a scenario is not limited to a single, deterministic future of the system, and instead is a set of similar futures that share common FEPs. The number and breadth of scenarios depend on the resolution at which the FEPs have been defined: coarsely defined FEPs result in fewer, broad scenarios, whereas narrowly defined FEPs result in many narrow scenarios. There is no uniquely correct level of detail at which to define scenarios: decisions regarding the appropriate level of resolution for the analysis are made based on consideration of the importance of the scenario in its effect on overall performance and the resolution desired in the results. For efficiency, both FEPs and scenarios should be aggregated at the coarsest level at which a technically sound argument can be made that is adequate for the purposes of the analysis.

More coarsely defined scenarios may be referred to as scenario classes (sets of closely related scenarios), and more narrowly defined scenarios may be referred to as subscenarios. Mathematically, scenario classes and subscenarios share the same definition as scenarios: all are subsets of the set of all possible futures of the system. In practical application, however, distiguishing between coarsely defined scenario classes and more narrowly defined scenarios and subscenarios is useful. For example, both the DOE and the NRC have identified "igneous activity occurs at Yucca Mountain" as one of the most important disruptive scenario classes for the repository. Within this class, consequence analyses have focussed on specific scenarios and subscenarios involving processes such as ash plume eruption and lava intrusion.

Before scenarios are constructed, FEPs retained from Step 2 are identified as either expected FEPS (EFEPs) or disruptive FEPs (DFEPs). Expected FEPs are those that can be assumed, for the purposes of the TSPA, to have a probability of occurrence equal to 1.0 (although they may have uncertain consequences). DFEPs are those that have a probability less than 1.0 (but greater than the lower cutoff prescribed by the NRC) and have a significant effect on overall performance. All EFEPs are included in a nominal scenario, which is simulated by the base case model described in the TSPA documentation. Disruptive scenarios are constructed from all EFEPs and combinations of DFEPs, with the probability of each disruptive scenario calculated as the product of the probabilities of the included DFEPs.

Scenario construction can be displayed graphically using logic diagrams (Figure 3). Note that these diagrams do not imply any ordering of the events: they are simply a graphical way of displaying the possible combinations of the retained DFEPs. Documentation of

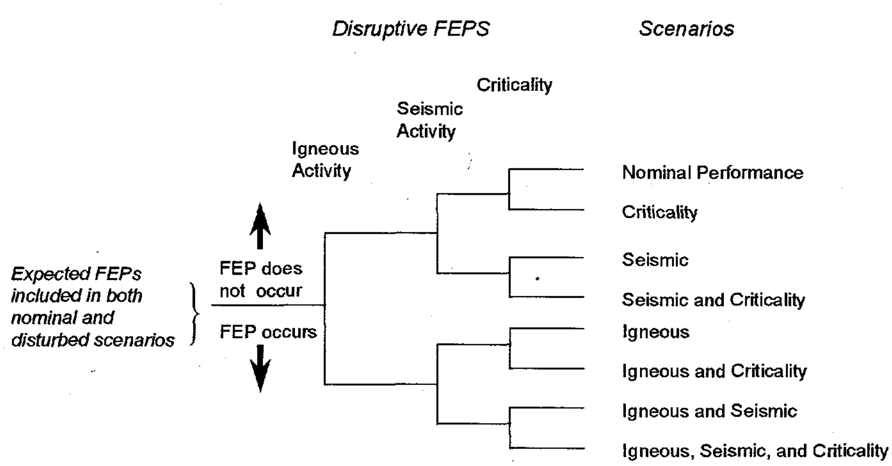

Figure 3. Logic Diagram for the Yucca Mountain TSPA for the 1998 Viability Assessment, showing the construction of scenarios using combinations of disruptive FEPs. Note that this figure is provided for illustration only. The scenarios shown here may not be the final set analyzed for the Yucca Mountain license application.

this step in the scenario development process will include demonstration that scenarios incorporate all combinations of retained DFEPs, and that probabilities of the scenarios have been correctly calculated based on FEP probabilities.

2.1.4 Step 4. Screening Scenarios

Scenarios constructed in step 3 are screened using the same regulatory, probability, and consequence criteria defined in step 2. For example, the probability criterion may be used to exclude scenarios that include some combinations of low probability FEPs.

If scenarios are to be screened out on the basis of low probability, the probability must be taken at an appropriately coarse level. Scenarios should not be defined artificially narrowly to reduce their probability below the NRC cutoff.

Documentation of this step in the scenario development process will include identification of any scenarios that have been screened from the analysis, and the technical basis for that screening decision.

2.1.5 Step 5 Specifying Scenarios for TSPA Analysis

All retained FEPs must be included in TSPA analyses either in the nominal scenario or in disruptive scenarios. EFEPs may be included in the nominal scenario either through explicit modeling or through the selection of parameter values. DFEPs are included explicitly in modeling of disruptive scenarios.

Documentation of step 5 will include identification of how each retained FEP has been treated in the TSPA. As shown in Figure 2, retained FEPs will be treated either through explicit incorporation in TSPA models or through uncertainty included in the assignment of parameter values used in the TSPA models.

2.2 Definitions

FEP: a feature, event, or process.

Feature: an object, structure, or condition that has a potential to affect disposal system performance.

Event: a natural or anthropogenic phenomenon that has a potential to affect disposal system performance and that occurs during an interval that is short compared to the period of performance.

Process: a natural or anthropogenic phenomenon that has a potential to affect disposal system performance and that operates during all or a significant part of the period of performance.

Future: a single, deterministic representation of the future state of the system. An essentially infinite set of futures can be imagined for any system.

Scenario: a subset of the set of all possible futures of the disposal system that contains futures resulting from a specific combination of features, events, and processes.

Scenario class: a set of scenarios that share sufficient similarities that they can usefully be aggregated for the purposes of a specific analysis.

Subscenario: a subset of a scenario (or a scenario class) created by defining one or more of the component FEPs more narrowly.

Retained FEP: a FEP that is identified by the screening process as requiring analysis in the quantitative total system performance assessment.

Expected FEP (EFEP): a retained FEP that, for the purposes of the total system performance assessment, is assumed to occur with a probability equal to 1.0 during the period of performance.

Disruptive FEP (DFEP): a retained FEP that has a probability of occurrence during the period of performance less than 1.0 (but greater than the cutoff of $10^{-4}/10^{4}$ yr defined by the NRC at 10 CFR § 63.114(d)).

Nominal scenario: the scenario that contains all expected FEPs and no disruptive FEPs.

Disruptive scenario: any scenario that contains all expected FEPs and one or more disruptive FEPs.

3.0 The Electronic FEP Database

The YMP performance assessment team is constructing an electronic database of FEPs. Each FEP identified in Step 1 of the process will be entered as a separate record in the database. Fields within each record will provide a description of the FEP, unique identification numbers, the origin of the FEP, identification as a primary or secondary FEP for the purposes of the YMP TSPA, and mapping to related FEPs. Fields will also provide summaries of the screening arguments, with references to supporting documentation, and, for all retained FEPs, statements of the disposition of the FEP within the TSPA modeling system.

The current YMP electronic FEP database has 1737 FEPs entered in preliminary form. The database has been developed in Claris Filemaker Pro Version 4.0, which is the same software adopted by the NEA working group for their FEP database. Working copies of the YMP FEP database are also available in Microsoft Access 97.

4.0 Current Status of the YMP Scenario Development Work

Work done for the viability assessment and previous preliminary TSPAs has identified igneous activity, seismic activity, and criticality as potentially important disruptive FEPs, and quantitative analyses have focussed on the nominal scenario and the major disturbed scenarios associated with these events.

Scenario development work for the Yucca Mountain license application is primarily focussed on documentation of Steps 1 and 2 of the five-step process at this time. This documentation may confirm that the scenarios selected for preliminary analysis are appropriate and sufficiently comprehensive to support the LA. However, ongoing work may identify FEPs for which additional analyses are needed to support a screening decision (either in or out), and additional EFEPs or DFEPs could be identified that will require modification of the scenarios analyzed in the TSPA.

Once the TSPA modeling system for the LA is mature, FEP work will focus on Step 5, providing the documentation for how all retained FEPs have been treated in the TSPA.

Scenario development is an iterative process, because new FEPs may be added to the initial list and screening decisions for existing FEPs may change as new information becomes available. Regulatory requirements that form the essential basis for all FEP screening may also change when the US Environmental Protection Agency (EPA) promulgates 40 CFR part 197 and when the NRC promulgates the final rule for 10 CFR part 63. FEP screening decisions and the resulting scenarios considered in the TSPA-VA are therefore preliminary. Screening arguments for excluded FEPs will continue to be developed during the preparation of the LA, and the treatment of the included EFEPs and DFEPs will change as the TSPA models and parameters are refined.

5.0 Acknowledgements

Kate Trauth and Jack Gauthier provided valuable technical reviews of this report. Work was done at Sandia National Laboratories for the Civilian Radioactive Waste Management System Management and Operating Contractor and for the US Department of Energy Yucca Mountain Site Characterization Project. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL8500.

6.0 References

Cranwell, R.M., Guzowski, R.V., Campbell, J.E., and Ortiz, N.R. 1990. *Risk Methodology for Geologic Disposal of Radioactive Waste: Scenario Selection Procedure*. NUREG/CR-1667, SAND80-1429. Prepared for the Division of High Level Waste Management, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. NNA.19900611.0073.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor). 1995. *Total System Performance Assessment – 1995: An Evaluation of the Potential Yucca Mountain Repository*. B00000000-01717-2200-00136, Rev. 01. TRW Environmental Safety Systems Inc., Las Vegas, NV for U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C. TIC Catalog Number 224028.

Skagius, K., and Wingefors, S. 1992. *Alligator Rivers Analogue Project Final Report, Volume 16: Application of Scenario Development Methods in Evaluation of the Koongarra Analogue*. ISBN 0-642-59942-4, DOE/HMIP/RR/92/086, SKI TR 92:20-16. Australian Nuclear Science and Technology Organisation. TIC Catalog Number: 231268.

U.S. DOE. 1988. *Consultation Draft Site Characterization Plan Overview, Yucca Mountain Site, Nevada Research and Development Area, Nevada*. DOE/RW-0161. U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C. TIC Catalog Number: 203432.

U.S. DOE. 1996. *Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant*. DOE/CAO-1996-2184. United States Department of Energy, Waste Isolation Pilot Plant, Carlsbad Area Office, Carlsbad, NM. Vols. I-XXI. TIC Catalog Number: 240511.

U.S. NRC. 1999. *Title 10 CFR Parts 2, 19, 20, 21, 30, 40, 51, 60, 61, and 63, Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain; Proposed Rule*. February 22, 1999. United States Nuclear Regulatory Commission. Federal Register, Vol. 64, no. 34, p. 8640-8679.

Wescott, R.G., Lee, M.P., Eisenberg, N.A., McCartin, T.J., and Baca, R.G., Editors. 1995. *NRC Iterative Performance Assessment Phase 2: Development of Capabilities for Review of a Performance Assessment for a High-Level Waste Repository*. NUREG-1464. Southwest Research Institute, Center for Nuclear Waste Regulatory Analyses, San Antonio, TX for Nuclear Regulatory Commission, Washington, DC. TIC Catalog Number: 221527.

Wilson, M.L., Gauthier, J.H., Barnard, R.W., Barr, G.E., Dockery, H.A., Dunn, E., Eaton, R.R., Guerin, D.C., Lu, N., Martinez, M.J., Nilson, R., Rautman, C.A., Robey, T.H., Ross, B., Ryder, E.E., Schenker, A.R., Shannon, S.A., Skinner, L.H., Halsey, W.G., Gansemer, J.D., Lewis, L.C., Lamont, A.D., Triay, I.R., Meijer, A., and Morris, D.E. 1994. *Total-System Performance Assessment for Yucca Mountain-SNL Second Iteration (TSPA-1993)*. SAND93-2675. Sandia National Laboratories, Albuquerque, NM. TIC Catalog Number: 102773.