The Role of Performance Assessment through the Multiple Phases of a Nuclear Waste Management Program

E.J. Bonano[1], G.A. Freeze[1], and G. Appel[2]
[1] Sandia National Laboratories[3], Albuquerque, NM 87185, USA
[2] Nuclear & Regulatory Support Services (NRSS), Albuquerque, NM 87109 USA

ABSTRACT

In many countries, regulations for the management of nuclear waste require a performance (safety/risk) assessment to demonstrate the safety asserted to be provided by the sites/facilities proposed for handling, storing, and disposing of the wastes. However performance assessment can play a bigger role than solely demonstration of compliance with applicable safety standards in support of a regulatory decision (i.e., licensing of a waste management facility). Performance assessment can be an effective management tool during all phases of a waste management program: from development of national nuclear waste management policies; to programmatic environmental impact assessments associated with design and siting evaluations, site selection, and site characterization; to licensing and operation of facilities.

International experience has demonstrated that nuclear waste management programs are long-term efforts, lasting at least two to three decades from initial policy development to licensing and commencement of waste management and disposal operations. These experiences have also demonstrated that consistent attention to, and integration of, initial component studies are necessary to provide a comprehensive total system analysis for programmatic environmental impact assessments and for licensing.

For nearly 40 years, Sandia National Laboratories has developed and applied a performance assessment methodology in numerous U.S. and international nuclear waste management programs. These applications range from development and feasibility testing of environmental health standards to preliminary evaluation of waste disposal sites, to establishing the basis for demonstration of compliance, to informing licensing (compliance demonstration) decisions. In many of these applications the performance assessment methodology has also served as a management tool for confirming the added value of research and development investments.

This paper presents examples to illustrate how performance assessment has been used as an effective management tool through multiple phases of a nuclear waste management program.

INTRODUCTION

For nearly 40 years Sandia National Laboratories (SNL) has been developing and applying its performance assessment (PA) expertise by informing key decisions concerning radioactive waste management both in the United States (U.S.) and internationally [1]. Some of these applications include:

[3] Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. This paper is Sandia publication SAND2011-6679C.

- Development and demonstration of Spent Nuclear Fuel (SNF)/High Level Waste (HLW) PA methodology for the U.S. Nuclear Regulatory Commission (NRC)
- Support to the U.S. Environmental Protection Agency (EPA) and NRC for the development of protection standards and regulatory requirements for SNF/HLW disposal
- Development and demonstration of low-level waste (LLW) PA for NRC
- Environmental assessment of proposed HLW disposal sites
- Development and implementation of PA for the Waste Isolation Pilot Plant (WIPP) transuranic (TRU) waste repository certification
- Development and implementation of Total System Performance Assessment (TSPA) for the Yucca Mountain (YM) Repository licensing

From these efforts evolved a generic PA methodology that has been used as an effective management tool to evaluate different disposal design concepts and sites; assess regulatory requirements; identify and prioritize research aimed at reducing uncertainties for objective estimations of risk; and support compliance directed safety assessments.

PA is unquestionably the premier compliance demonstration tool; however, it also provides a unique capability for evaluation of new concepts and is a management tool for the prioritization of research and development activities (R&D) within such efforts. In this paper we discuss the use of the SNL PA methodology as a management tool in the context of nuclear waste management programs.

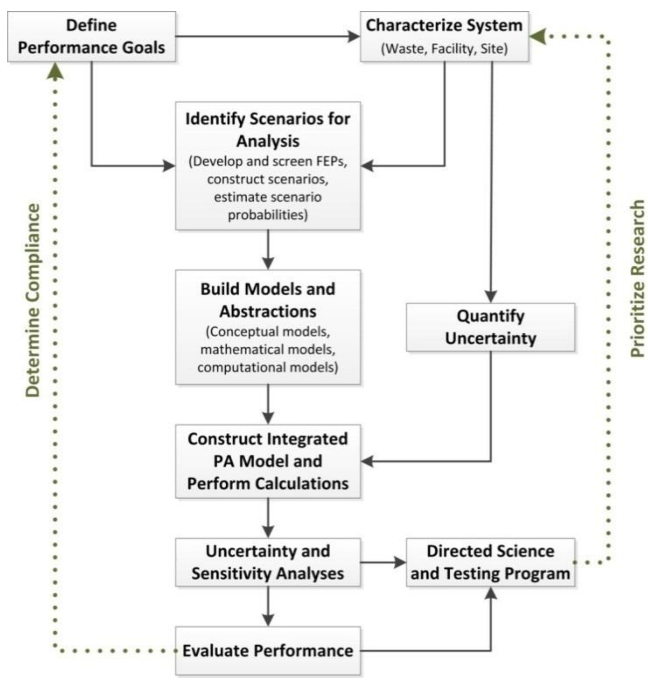

Figure 1 - SNL Performance Assessment Methodology

The PA methodology (Figure 1) provides a framework for organizing all of the relevant information from the initial R&D phase through final regulatory approval phase of the facility. Data and information are captured from multiple sources and organized in a logical manner to support decisions, explicitly taking into consideration uncertainties in the information, and providing transparency, traceability, and reproducibility to the analysis. The PA methodology provides a mechanism for analyzing the behavior of components of a complex system both in isolation and in conjunction with other components.

THEORY

As a type of probabilistic risk assessment (PRA), the formulation for PA is that defined by Kaplan and Garrick [2] where risk analysis is defined as an answer to three questions.

- What can happen (i.e., What can go wrong?)? - This first question customarily is answered in the form of scenarios (combinations of events or processes that could occur and act on features) representing plausible future states of the disposal system.
- How likely is such an outcome to happen? - This second question is answered from available evidence on the frequency of such scenarios, where data exists, or, when there is little or no data available, from analyses of probability and uncertainty, including the use of expert judgment.
- If it does happen, what are the consequences? - This third question is answered for each scenario to assess the range of possible outcomes by exercising a suite of appropriate conceptual and mathematical models.

Because of the large temporal and spatial scales required to analyze radioactive waste disposal systems (i.e., tens of kilometers and hundreds of thousands of years), uncertainty permeates PA applications. Hence, SNL PAs explicitly consider a fourth question:

- What is the uncertainty in the answers to the first three questions? – The answer to this fourth question helps to identify the level of confidence in the answers to the first three questions.

The practical application of the PA methodology enables response to changes in national policy direction, as in the case of Yucca Mountain in the U.S. Subsequent to such changes, new or previously deferred approaches and alternatives merit evaluation and PA serves as a tool to evaluate and manage the direction of attendant policy changes. In the U.S., there are significant challenges and obligations regarding defensible, sustainable solutions for managing commercial and government-owned SNF, defense HLW, naval SNF, and other long-lived nuclear waste (e.g., greater than Class C waste (GTCC)). All these wastes need some form of final geologic disposal, regardless of the outcome of the current legal/administrative debate with respect to Yucca Mountain [3].

To fulfill U.S. obligations, a coordinated program for developing and implementing long-term solutions for the safe and secure management of nuclear wastes from the nation's commercial nuclear power enterprise and defense activities will need to be pursued. Within such a program, the PA methodology provides a framework for organizing the relevant information and analyzing it in a transparent and traceable fashion. PA is a prominent management tool for such decision making with respect to what is important in the context of far reaching and complex waste management decisions, in addition to its value as a tool to ultimately demonstrate compliance with regulatory requirements.

The coordinated program's overall objective should be to anticipate and address the challenge of developing and implementing sustainable nuclear waste management solutions related to transportation, storage and disposal. More specifically, the program must address technical, regulatory and social issues regarding the transportation, storage, and disposal of the waste inventories (existing and proposed) which are presently federal government responsibilities, including commercial SNF, government-owned and naval SNF, HLW, and related wastes such as GTCC. Management of these wastes comprises the functional systems and inventories of the back-end of the nuclear fuel cycle.

The coordinated program should be designed, planned and implemented from initial policy development to the licensing and operation of nuclear waste management facilities. It should be founded on active participation and buy-in from all stakeholders (i.e., federal, state and local units of governments; regulators; industry; and potential host communities).

Key attributes of such a program will be:

- Define and align activities and milestones as the program progresses from basic generic R&D to domain-relevant R&D, and eventually to site-specific characterization, to system evaluation and modeling, and to demonstration of compliance and licensing;
- Plan for known programmatic transitions (e.g., policy development, programmatic environmental impact assessments, licensing and operation of facilities);
- Adapt to new combinations of social, economic, and political events and context (e.g., elections, and government agency driven policy changes);
- Address maintenance and retention of core competencies and capabilities; and
- Maintain a robust organizational culture that assures appropriate transparency and broad credibility.

Both U.S. and international experiences have demonstrated that the nuclear waste management process, from initial policy development to licensing and operation of facilities, is inherently long (25 years or longer). Because of this long timeframe, early policy and programmatic decisions must be:

- Objective, transparent, coherent and sustainable, and explicitly recognize that science will continue to evolve; new technologies will be developed and proven feasible; and social, economic, and political values will change over that timeframe; and
- Flexible, recognizing that national and international trends, coupled with a changing threat environment requires systems that can be adapted to changing needs.

These experiences have also demonstrated that consistent attention and integration of component studies are necessary to provide the required comprehensive total system analyses for programmatic environmental impact assessments and eventually for licensing.

Any coordinated program will evolve in phases: (1) policy development, (2) programmatic environmental impact assessments, and (3) licensing and operation of facilities, all of which should be enabled by using a PA methodology throughout the development process. Figure 2 shows these phases, including likely key activities and expected outcomes under each phase.

Phase 1 – Policy Development

Phase 1 consists of the activities needed to support the development of a new national policy for the management of nuclear wastes. These activities should address the following broad range of policy and process related topics.

- Stakeholder Participation and Site Selection Process;
- Waste Confidence Rule;
- Evaluation of Waste Management Alternatives;

- Licensing of Interim Storage Facilities;
- Resolution of Transportation Issues;
- Resolution of Nuclear Security Issues; and,
- Research & Development (R&D) Investments & Demonstration Projects

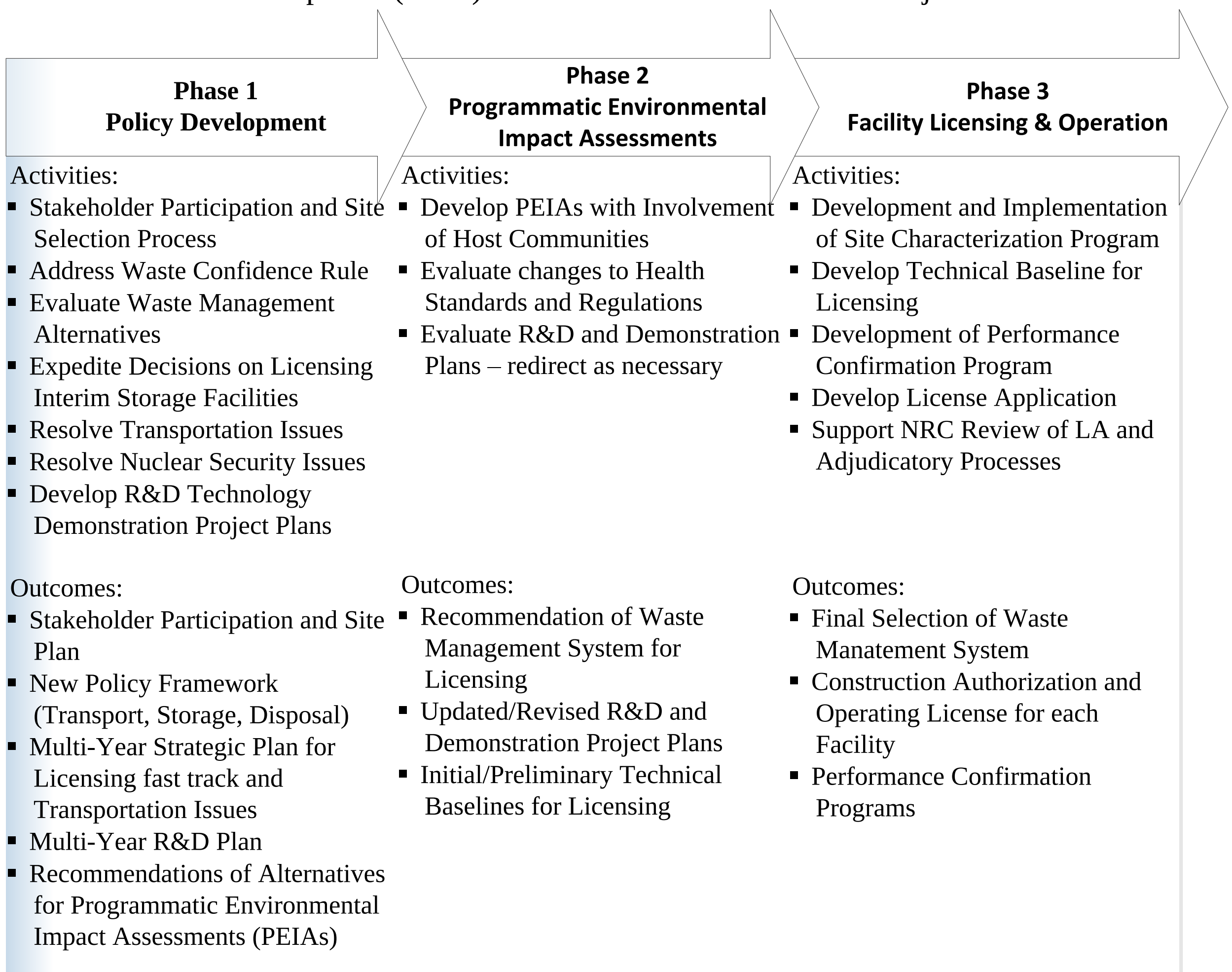

Figure 2 - Phases for the Development and Implementation of New National Policy for the Back End of the Nuclear Fuel Cycle

<u>Phase 2 – Programmatic Environmental Impact Assessments</u>

As required by the U.S National Environmental Policy Act (NEPA) [4], Programmatic Environmental Impact Assessments (PEIAs) of the plausible alternatives recommended during Phase 1 will be necessary. It is assumed that the process for performing the PEIAs for potential interim storage and disposal facilities will be similar to the process in Section 112 of the U.S. Nuclear Waste Policy Act (NWPA) [5] for the preparation of Environmental Assessments (EAs). An EA should include specified evaluations, descriptions, and assessments; they are:

- An evaluation as to whether a candidate site is suitable for site characterization under established guidelines;

- An evaluation as to whether a candidate site is suitable for development of a repository (or an interim storage facility) under each guideline that does not require site characterization as a prerequisite;
- An evaluation of the effects of site characterization activities at the candidate site on the public health and safety and the environment;
- A reasonable comparative evaluation of a candidate site with other candidate sites and locations that have been considered;
- A description of the decision process by which a candidate site was recommended; and
- An assessment of the regional and local impacts of locating the proposed repository (or interim storage) at a candidate site.

Most of these evaluations, descriptions, and assessments can be greatly facilitated through the use of the PA methodology, most notably the PEIAs. The goal of the PEIAs will be to provide adequate information on the relevant attributes for each alternative to support a decision on a recommended path for development and eventual licensing.

<u>Phase 3 – Licensing and Operations</u>

During Phase 3 the technical and regulatory work is performed that is necessary to support the licensing and operation of the facilities and components for interim storage and permanent disposal comprising the recommended waste management system. Activities performed in Phase 3 include:

- Development and implementation of a site characterization program;
- Development of the technical baseline for the facilities comprising the waste management system necessary to prepare the safety analysis report for inclusion in a license application initially to receive authorization to construct the facilities and later to operate the facilities;
- Development and implementation of a long-term performance confirmation program for long-term storage facilities and disposal systems; and,
- Support the defense of the license application(s) within the NRC's licensing process in 10 CFR Part 2.

DISCUSSION

The following discussion provides examples of the application of SNL's PA methodology in the context of the phases for a coordinated waste management program outlined above.

<u>Phase 1 – Policy Development</u>

SNL's most recognized experience in developing and applying PA methodologies to radioactive waste management problems relates to the detailed compliance-oriented performance assessments for the WIPP and for the YM repository. However, SNL's PA experience extends to non-compliance related elements that are most germane to the objectives of Phase 1. Beginning in 1976, in support of several U.S. government agencies, SNL evaluated geologic media for the deep geologic disposal of HLW, supported the development of the basis for eventual regulations applied to the disposal of SNF, HLW and TRU, and applied its PA methodology to manage the R&D efforts for nuclear waste management.

SNL's initial PA work was applied to a hypothetical HLW repository in a generic bedded salt formation. As SNL's PA analyses for bedded salt progressed, SNL began to investigate whether the PA could be applied to the analysis of a HLW repository in other geologic media, specifically basalt and welded tuff [1]. As a result of this work, SNL successfully demonstrated that the PA methodology could be appropriately applied independent of geologic media and could be used by NRC to examine compliance with its regulatory requirements.

In the context of regulatory development, starting in 1976 SNL developed for NRC a probabilistic PA methodology for deep geologic repositories that allowed NRC to test the methods for demonstrating compliance with the requirements contained in proposed NRC and EPA regulations, 10 CFR Part 60 [6] and 40 CFR Part 191 [7], respectively. In the early 1980s, SNL analyzed an early working draft of the EPA standard to provide the NRC information for use in evaluating the rationale for the technical requirements in its proposed Rule 10 CFR 60. The analysis was used to respond to public comments on the proposed rule, and to evaluate the benefits of alternative criteria for the final rule. A series of parametric analyses were performed on the potential releases of radionuclides to the accessible environment in order to determine the impact on compliance with the draft EPA standard.

These SNL PA studies helped establish the regulatory basis for NRC regulations and EPA environmental standards for radioactive waste disposal by demonstrating the PA methodology as an effective tool for demonstrating and measuring compliance. These studies also provided effective feedback to the regulatory standards, helping to illustrate the efficacy of the criteria in achieving the intended goals, (i.e., protecting the environment and the health and safety of workers and the public).

Phase 2 – Programmatic Environmental Impact Assessments

The second phase of a coordinated program is often the first formal public presentation of analyses developed to implement a national policy for the management of nuclear wastes. The PA methodology is an exemplary tool for presenting the information in a transparent and traceable fashion while analyzing the information in an organized framework. SNL has successfully applied the PA methodology to both Environmental Assessments (EAs) and more rigorous Environmental Impact Statements (EIS), since the mid-1970s.

In early 1975, SNL was named as the scientific adviser for further site characterization of a proposed repository site in bedded salt in southeastern New Mexico and for development of a conceptual repository design and an EIS. Beginning with the work of Bingham and Barr [8] supporting the WIPP EIS [9], SNL's WIPP PA studies developed the science of the feature, event, and process (FEP) identification and screening methodology. The study conducted in support of the WIPP EIS was a significant effort directed at the development of a FEP list for a 1989 demonstration (pre-certification) PA. The list of relevant FEPs remained fairly constant until the list was formally updated with a complete re-evaluation of the FEPs for the 1996 compliance demonstration (CCA) PA [10]. In addition, the initial 1989 FEP list was used by program management to scope the size and duration of the R&D phase of the WIPP program and then, later, adjust planning as appropriate based on the iterative PA results.

Some of the earliest work related to FEPs and scenario development was conducted by Bingham and Barr [8] for the WIPP EIS and by Cranwell, Guzowski et al. [11], whose work on a scenario selection procedure as part of the NRC risk assessment methodology was initially provided to NRC. Both studies focused on bedded salt as the medium in which to develop and test their methodology.

SNL generated at least nine distinct iterations of PA for YM over the past 30 years. Various iterations were used for programmatic evaluations such as the 1986 EA [12], viability assessment (VA), site recommendation (SR), and draft and final EISs. Each of these PAs built on the conclusions of prior assessments evolving in both detail and emphasis. The 1986 EA for YM, conducted when it was one of five candidate sites being considered to host a repository, was simplistic by today's standards. Later PA iterations were more complex; they included as many as 1,000 parameters, a number of which were uncertain or variable. The parameter uncertainty was addressed using stochastic Monte Carlo analysis and the results were graphically summarized in "horsetail plots" (Figure 3a) showing time versus annual dose (i.e., annual dose histories) for hundreds to thousands of realizations, depending on the scenario. These results of the multiple-realization simulations were displayed along with statistical measures of the output. The mean (representing the arithmetic average of data points from each realization at each time step) was the performance measure established by the regulations. The median of the output along with 5th and 95th percentile of the output was also frequently plotted in graphical representations of the results.

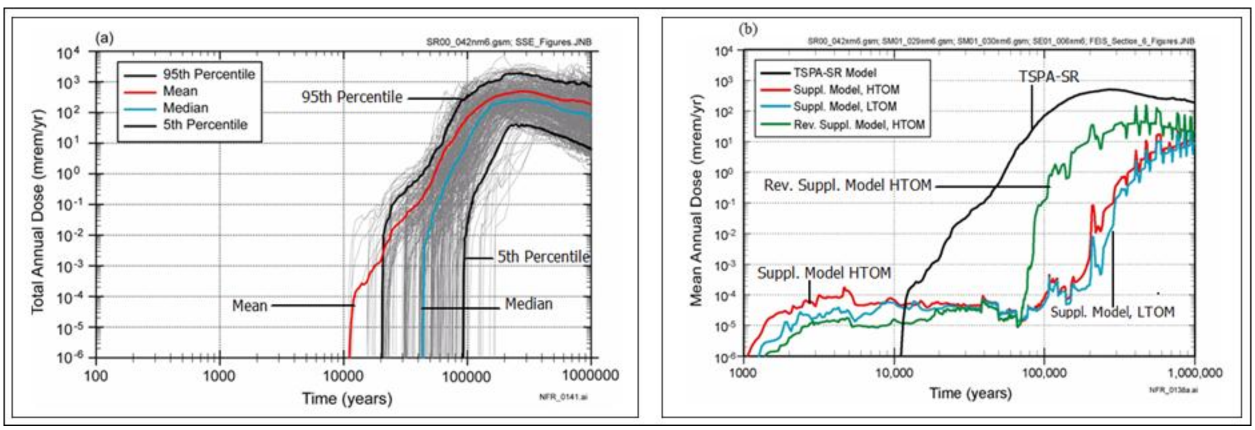

Figure 3 - (a) Typical Presentation of PA Results; (b) PA Results for YM EIS

Figure 3b compares the results of several PA model iterations, presenting the mean annual dose for several different models including nominal scenario for TSPA-SR, supplemental model (both higher temperature and lower temperature operating modes), and revised supplemental model for the final EIS (higher temperature operating mode).

Phase 3 – Licensing and Operations

The third and final phase of a coordinated program involves crucial analyses to support the licensing and operation of the facilities for interim storage and permanent disposal of nuclear wastes. PA methodology results in this phase are articulated as direct demonstrations of compliance with regulatory requirements. SNL has performed detailed compliance-oriented performance assessments for the WIPP and the YM repository. This work has spanned decades and has steadily evolved in complexity and insight, contributing to regulatory development and insight, and management of ongoing R&D efforts, as well as the compliance demonstration per se.

Between 1986 and 1992, SNL conducted four analyses to show compliance of the WIPP with EPA's environmental radiation protection standards, 40 CFR Part 191 (Figure 4). Results of the 1992 WIPP PA led DOE to conclude that the site was suitable for the disposal of TRU waste, and DOE proceeded on a path to certification under the EPA regulations. As noted previously, WIPP PA studies developed the science of FEP identification and screening. PAs for WIPP also advanced the science of conducting uncertainty and sensitivity calculations on both subsystem and system models to identify critical parameters for further study. WIPP PA also identified potential advantages in having two system models, one for detailed studies of the importance of parameters and one for the streamlined calculations needed for compliance applications, and it showed that control and transparency of the data inputs to the calculations is critically important.

The Compliance Certification Application (CCA) was submitted to the EPA in October 1996 [10], and in 1999 WIPP became the first deep geologic repository certified in the U.S. to permanently dispose of TRU waste. SNL subsequently conducted two additional PAs as part of the recertification applications for the site in 2004 [13] and 2009 [14].

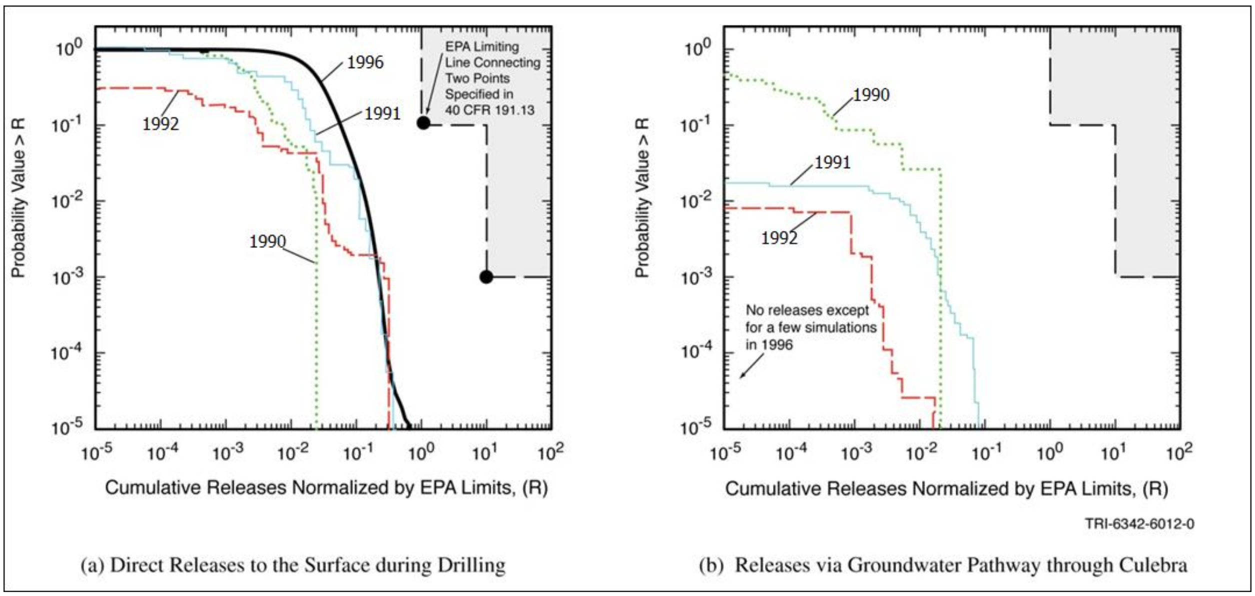

Figure 4 - Comparison of WIPP PA results 1990–1996

SNL was involved in multiple iterations of the YM PA for nearly three decades. This started with the previously mentioned EA for YM [12] and culminated in the 2008 YM Total System Performance Assessment – License Application (TSPA-LA) [15], submitted to the NRC as part of the Safety Analysis Report (SAR) for the license application [16]. SNL led only the earliest and latest YM PAs, but was continuously involved in its development and application. The YM TSPA model evolved over decades in response to site characterization understanding, design concept changes, and revisions in regulatory guidance.

At the conceptual level, the YM TSPA is identical to the WIPP PA. The mathematical framework is much the same; however, the difference is in the details, or process. The TSPA models are formulated as "abstractions" from more detailed process models. As a result, the TSPA is a system-level model that integrates submodels for each of the various components of the natural and engineered barriers. The TSPA model relies on the abstractions, or simplifications, of some of the major processes due to the complexity of those processes and the large number of system-level simulations required for the Monte Carlo uncertainty analysis.

For the 2008 TSPA-LA, four discrete scenario classes were analyzed probabilistically including:

- An early failure scenario class, in which one or more waste packages or overlying drip shields fails prematurely due to undetected manufacturing or emplacement defects,
- An igneous disruption scenario class in which a volcanic event causes magma to intersect the emplacement region, with or without an accompanying eruption,
- A seismic disruption scenario class, in which ground motion or fault displacement damages waste packages and drip shields, and
- A nominal scenario class in which none of the three previous disruptive events occurs. Each event-based scenario class was subdivided into separate modeling cases to simulate the consequences of specific events [17].

The total mean annual dose for 10,000 years and 1 million years was developed by summing the probability-weighted mean annual doses for each modeling case. The TSPA-LA results were well below the regulatory limits established in the NRC and EPA regulations as shown in Figure 5.

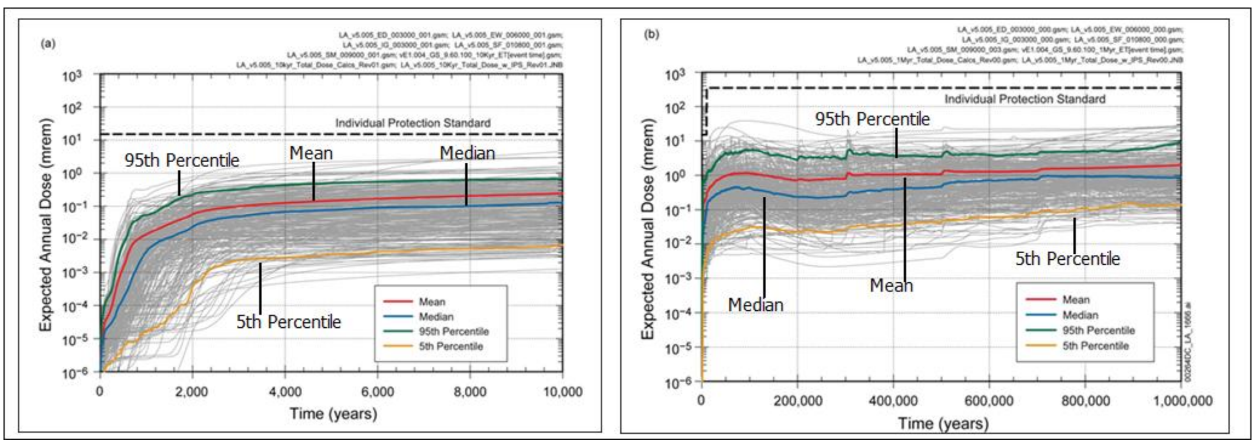

Figure 5 - TSPA-LA results: distribution of total expected annual dose for (a) 10,000 years and (b) 1 million years after repository closure, compared against the individual protection standard from 10 CFR 63.311

In July 2011 NRC released its technical evaluation of the content of the SAR volume that described repository safety after closure. The information in this volume is entirely derived from and supported by the TSPA-LA. NRC's document was prepared as part of the agency's closeout of the YM licensing review. Though the report contained no regulatory determinations, NRC concluded that the technical approach and results in the TSPA-LA, including the mean annual dose values and the performance of the repository barriers were reasonable.

CONCLUSIONS

A coordinated program to fulfill U.S. obligations to develop and implement long-term solutions for the safe and secure management of nuclear wastes from the nation's commercial nuclear power enterprise and defense activities needs to be pursued. The program's overall objective should be to anticipate and address the challenge of developing and implementing sustainable nuclear waste management solutions related to transportation, storage and disposal of U.S. nuclear wastes. All of these wastes need some form of final geologic disposal, regardless of the outcome of the ongoing legal/administrative debate. The practical application of the SNL PA methodology, developed and applied over the past four decades, enables response to such changes in national policy.

As demonstrated by the specific PA applications described in this paper, PA is invaluable in each phase of a nuclear waste management program: from policy development; to programmatic environmental impact assessments; and to licensing and operation of facilities. PA serves as an asset in evaluating new design and siting options or previously deferred approaches and alternatives and is a superior tool to manage the direction of nuclear waste management R&D. PA is often essential in formulating regulatory policy as well as assessing the environmental impacts of proposed actions. PA is unquestionably the premier means to demonstrate compliance with regulatory standards extending out over extraordinarily long timeframes. If iteratively applied throughout the phased development of a nuclear waste management program, the likelihood of technical success is assuredly increased.

REFERENCES

1. Sandia National Laboratories, Development of the Performance Assessment Methodology for Long-Term Environmental Programs: The History of Nuclear Waste Management. SAND2011-XXXX. (2011) (in publication).
2. Kaplan S. and Garrick J.B., Risk Analysis, Vol. 1, No. 1, p. 13 (1981)
3. Blue Ribbon Commission on America's Nuclear Future, Draft Report to the Secretary of Energy, July 29, 2011, Blue Ribbon Commission for America's Nuclear Future, p. 10, (2011).
4. United States National Environmental Policy Act of 1969 (NEPA), Public Law 91-190, (1969).
5. United States Nuclear Waste Policy Amendments of 1987 (NWPA), Public Law 100-203, (1987).
6. U.S. Nuclear Regulatory Commission, U.S. Code of Federal Regulations (CFR), Title 10, Part 60, 46 FR 13980, (1981).
7. U.S. Environmental Protection Agency, U.S. Code of Federal Regulations (CFR), Title 40, Part 191, 50 FR 38084, (1985).
8. Bingham, F.W., and G.E. Barr, SAND78-1730, Sandia National Laboratories, (1979).
9. U.S. Department of Energy, DOE/EIS-0026, (1980).
10. U.S. Department of Energy, DOE/CAO-1996-2184, (1996).
11. Cranwell, R.M., R.V. Guzowski, J.E. Campbell, and N.R. Ortiz, SAND80-1429, NUREG/CR-1667, Sandia National Laboratories, (1990).
12. U.S. Department of Energy, DOE/RW-0073, (1986).
13. U.S. Department of Energy, DOE/WIPP 04-3231, (2004).
14. U.S. Department of Energy, DOE/WIPP-09-3424, (2009).
15. Sandia National Laboratories, MDL-WIS-PA-000005 REV 00 ADD 01, (2008).
16. U.S. Department of Energy, DOE/RW-0573, (2008).
17. Bonano, E.J., Kessel, D., and Dotson, L., SAND2010-2237C, Sandia National Laboratories, (2010).