# PERFORMANCE ASSESSMENT AS A MANAGEMENT TOOL FOR PRIORITIZING NUCLEAR WASTE PROGRAM RESEARCH AND DEVELOPMENT ACTIVITIES[1]

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## ABSTRACT

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. Some of these applications include:

- Environmental assessment of proposed high-level waste (HLW) disposal sites
- Development and demonstration of Spent Nuclear Fuel (SNF)/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
- Development and implementation of PA for the Waste Isolation Plant (WIPP) transuranic (TRU) waste repository
- Development and implementation of Total System Performance Assessment (TSPA) for the Yucca Mountain Repository Project

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 and guide research aimed at reducing uncertainties for objective estimations of risk; and compliance directed safety assessments.

PA is unquestionably the premier compliance demonstration tool; however, it also provides unique capability for evaluation of new concepts and is a management tool for the prioritization of research and development activities within R&D 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.

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# I. BACKGROUND

In the early 1980s, Sandia National Laboratories (SNL) developed a PA methodology for the evaluation of total waste management systems (Figure 1) which is now widely accepted within the international community. The PA methodology provides a framework for organizing all of the relevant information from the initial research and development (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.

PA is a term used in the U.S. to denote a probabilistic risk analysis (PRA) for evaluating the long-term performance of a nuclear waste disposal facility [1]. PA has provided the basis for: 1) understanding and forecasting the long-term behavior of a nuclear waste disposal system[4]; 2) estimating the ability of the disposal system and its various components to isolate the waste; 3) the development of, and testing implementation of regulations; 4) implementation of programs to estimate the safety that the system can afford to individuals and to the environment, and 5) ultimately, to demonstrate compliance with the attendant regulatory requirements [2].

As a type of PRA, the formulation for PA is that defined by Kaplan and Garrick [3] where risk analysis is an answer to three questions:

<u>What can happen?</u>, (i.e., What can go wrong?)? This question is 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

<u>How likely is such an outcome to happen?</u> This second question is answered from available evidence on the frequency of such events, where data exists, or, when there is little or no data available, from analyses of probability and uncertainty, including the use of expert judgment.

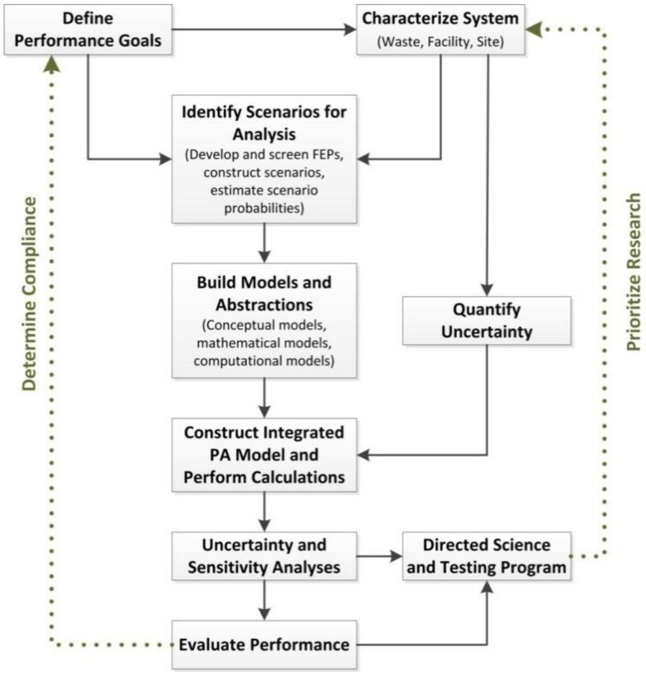

**Figure 1 - SNL Performance Assessment Methodology**

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[4] A waste disposal system as referred to in this paper is the combination of natural barriers (i.e., geologic formations) and engineered barriers (i.e., man-made barriers, such as waste containers) working individually and jointly to isolate the waste in a manner that it does not reach the environment accessible to humans.

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 thousands to 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? or What is the level of confidence in the answers to the first three questions?

To a large extent, the credibility of the analysis and its results hinge on the manner in which uncertainties are identified and objectively quantified. Uncertainty arises from the models themselves, and because of incomplete knowledge of the present system, inability to forecast future events, assumptions and abstractions made in designing the analysis, and the inherent complexity of natural systems [2].

The PA methodology provides a framework for organizing the relevant information and analyzing it in a transparent and traceable fashion. In addition to a tool to demonstrate compliance with regulatory requirements, it is also a prominent management tool for decision making with respect to what is important in the context of the decision. PA is not typically viewed in this context; however, our experience has demonstrated that, when used in an iterative manner, it can very effectively be used to ensure that R&D activities are directed at reducing those uncertainties that impact the decision of interest. Without such a management tool, the tendency is for the scientific endeavor supporting a nuclear waste disposal project to be open-ended.

### I.A PA Applied To Evaluate Potential Disposal Concepts

National policy can change direction, as in the case of Yucca Mountain (YM) in the U.S. Subsequently, new or previously deferred alternatives merit evaluation. SNL has recently conducted three feasibility and scoping PAs for alternative SNF and HLW disposal approaches: disposal in deep boreholes [4]; disposal in a clay/shale repository [5]; and disposal in a granite repository [6]. In such cases results are understandably less than definitive, yet provide a basis to reflect on the utility of the analyzed system.

For example, calculations by SNL estimated the peak dose from a hypothetical deep borehole system containing 150 Metric Tons of spent fuel to be more than a billion times below current regulatory limits for releases from geologic repositories. This encouraged two high-level policy bodies to recommend further R&D to help address uncertainties about deep borehole disposal; to allow for a more comprehensive (and conclusive) evaluation of the practicality of licensing and deploying this approach; and to urge regulatory agencies to develop a regulatory framework for borehole disposal [7,8].

### I.B PA Applied To Active Disposal Concepts

The Waste Isolation Pilot Plant (WIPP) is located east of Carlsbad, New Mexico. WIPP is the first deep geologic repository certified in the U.S. to safely and permanently dispose of transuranic (TRU) waste. The waste is placed underground in a geologically stable salt formation in disposal rooms at a depth of 655 meters (2,150 feet). WIPP received the first shipment of TRU waste in March 1999. The U.S. Environmental Protection Agency (EPA) required compliance demonstration document is known as the Compliance Certification Application (CCA).

The first CCA, submitted in October 1996 [9], was based on a PA predicting the performance of the disposal system over 10,000 years using computer models of the disposal system and random sampling of uncertain parameter values. The PA examined potential release scenarios, quantified their likelihoods, estimated potential releases to the accessible environment, and evaluated the potential consequences. The WIPP PA integrates process models for initial radioactivity and subsequent decay of multiple waste streams, gas generation due to metal container corrosion and microbial degradation of organic waste components, disposal room closure, brine and gas flow within the repository, actinide solubility and mobilization in brines, direct releases (contaminated solids and brine) to the surface from drilling intrusions and long-term releases due to far-field transport of contaminated groundwater. The initial CCA PA estimate releases well below the regulatory release limits (Figure 2). Two subsequent re-certifications of WIPP, one in 2004 [10], and another in 2009 [11] reflected similar results.

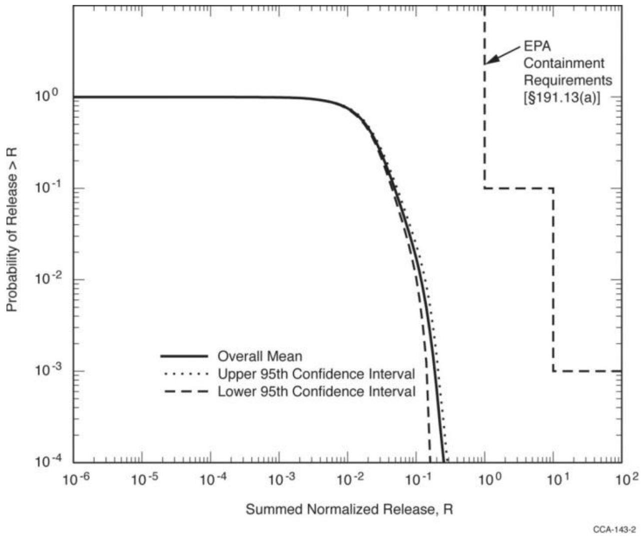

**Figure 2 - WIPP CCA Results**

Until the U.S. government's pending withdrawal of the license application for Yucca Mountain (YM) in March 2010 [12], the YM site had been under evaluation since 1987 as the nation's first repository for the disposal of military and civilian SNF and HLW. The unsaturated volcanic tuff site is located northwest of Las Vegas, Nevada. A license application was submitted to the NRC for authorization to construct the YM repository in June 2008 [13], and subsequently withdrawn as the current Administration's position is that Yucca Mountain is not a workable option.

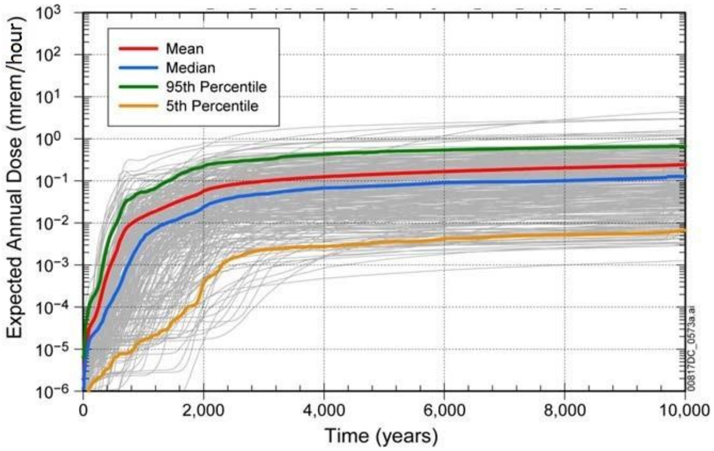

**Figure 3 - Yucca Mountain PA**

The YM license application was based on a TSPA, a system-level model that integrates submodels for the various components of the natural and engineered barriers. The TSPA model relies on simplifications, or abstractions, 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. TSPA evolved over many years with the version supporting the license application (TSPA-LA), including four discrete scenario classes: 1) 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; 2) an igneous disruption scenario class in which a volcanic event causes magma to intersect the emplacement region, with or without an accompanying eruption; 3) a seismic disruption scenario class, in which ground motion or fault displacement damages waste packages and drip shields; and, 4) a nominal scenario class in which none of these three types of events occurs. Each event-based scenario class was subdivided into separate modeling cases to simulate the consequences of specific events. The total mean annual dose for 10,000 years was developed by summing the mean annual doses for each modeling case. The TSPA-LA results were well below the regulatory limits established in the NRC and EPA regulations (Figure 3) [13].

## II. PERFORMANCE ASSESSMENT AS A MANAGEMENT TOOL TO PRIORITIZE R&D

Our work with PA clearly emphasizes its value as a compliance demonstration tool for the long-term isolation of radioactive waste. We have demonstrated the use of total system analysis to: 1) evaluate compliance with regulatory requirements; 2) quantify performance margin and barrier capability ; 3) identify most sensitive models and parameters; 4) evaluate design options/alternatives; 5) evaluate consequences of features, events and processes; 6) determine significance of data, parameter and model uncertainties; and, 7) most pertinent to this paper, prioritize information and testing needs and risks to support decision making

A site characterization program necessarily evolves over time, beginning with evaluations of feasibility, to progressive evaluations of viability, and culminating in those activities required for regulatory compliance. Initially, a broad-based site characterization program is needed to develop an understanding of the system and identify uncertainties and to develop appropriate conceptual models leading to selection of appropriate mathematical and computational models to evaluate performance. Every experiment and model should be viewed in the context of contribution to compliance.

As knowledge and understanding of the disposal system improve, PA modeling is iteratively conducted in parallel with the science and testing program. This enables identification of the most sensitive parameters and prioritization of information and testing needs. However, it is important that early modeling results not be used to prematurely terminate experimental programs based on the premise that it is not needed to demonstrate compliance. Although models may represent some processes in a simplified fashion, a detailed understanding of those processes, requiring detailed models, is also necessary to provide a credible and defensible basis for model simplification. It is also important that scientists involved in site characterization and testing activities work closely with the analysts involved in model and parameter abstraction and simplification because this can be a complex process, requiring an understanding of processes on both the small (experimental) scale and large (site or PA) scale.  Furthermore, those scientists most familiar with the range of parameter values and the consequences of selecting different values are best able to evaluate the impact of selecting a single value to represent the range, for example.

The PA is used in an iterative manner to identify the most sensitive models and parameters, determine the significance of data, parameter and model uncertainties, and evaluate consequences of features, events and processes (FEPs).  The scenario assumptions and parameters with greatest impact on performance measures can be identified and prioritized.  New information is used to refine requirements, performance measures, alternatives, and models, thus reducing important sources of uncertainty with each analysis iteration.  As the PA matures and the systems are better understood, it is not the perspective of experimental scientists, but rather the total system PA methods (i.e., FEP analysis and screening, uncertainty analysis, modeling, and sensitivity analysis) that provide the context for prioritizing and evaluating additional data needs.

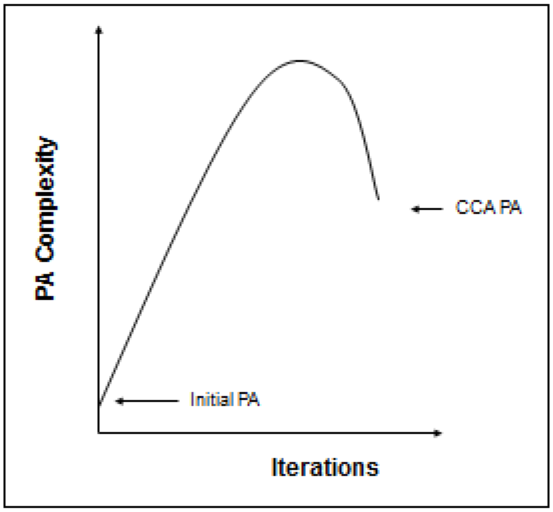

**Figure 4 - Evolution of WIPP PA Complexity**

On WIPP there were five formal iterations of the PA methodology prior to the initial CCA. Figure 4 illustrates the attendant reduction in complexity with assessment maturity.  The last iteration was a DOE designed and implemented a performance-based decision-aiding tool called the Systems Prioritization Method (SPM) to assist in the transition from “science to compliance” [14].  SPM brought all of the project scientists together and evaluated the effects of proposed technical activities on project budget, schedule, and compliance with U.S. EPA radioactive waste disposal regulations.  The results of SPM were used to inform the experimental program to ensure that data and other information was focused on assessing the adequacy of the technical baseline for certification.  As a result, new technical programs were initiated, some existing programs were refocused on reducing specific uncertainties, and other programs were cancelled when the uncertainties they addressed were determined to be acceptable without further data collection.  SPM also served to inform stakeholders of the experimental program supporting the certification and to gain their confidence in the adequacy of the technical baseline.

On YM, there were five formal iterations of the PA methodology preceding the analysis supporting the license application.  In these, PA was systematically used to affirm the design approach, identify opportunities to reduce costs, and ensure that the design incorporated best practices.  In this way, costs could be optimized by increasing benefit and reducing unnecessary resources.  PA was used in an iterative manner for the analysis of the post-closure nuclear safety design bases, which includes information that identifies the specific functions to be performed by a structure, system, or component of the facility and the specific values or ranges of values chosen for controlling parameters as reference bounds for design.  The analyses identified and characterized important waste isolation features of the engineered and natural barrier systems, explicitly taking into account the uncertainties in characterization and modeling. These analyses provided the technical bases, or justification, for the safety design specifications, including the choice of materials, properties, configurations, orientations, conditions, licensing specifications, and other design characteristics.

A post-closure nuclear safety design bases analyses, predicated on PA results, identified core parameter characteristics for features and components important to barrier capability, which would be candidates for evaluation in the performance confirmation program. This program includes monitoring and testing activities to support continuing evaluation of the adequacy of the assumptions, data, and analyses supporting the safety case. This includes confirmation that subsurface conditions and geotechnical and design parameters are as predicted and that barriers (both natural and engineered) are functioning as intended and anticipated following permanent closure. Probabilistic modeling and sensitivity studies assisted in the development and refinement of the candidate list of performance confirmation monitoring and testing activities for both the WIPP and YM programs. It is important to note that not all performance confirmation activities are derived from PA analyses. For example, activities to evaluate certain specific design elements are derived directly from regulatory requirements.

Another valuable SNL experience from both WIPP and YM was managing the transition of a technical organization from “science to compliance.” During the “science” phase both projects focused the technical organization on: 1) the scientific and research work needed to understand the behavior of the disposal system; and, 2) the use of that information in the total system analysis. In the “compliance” phase the emphasis shifted to: 1) the use of the scientific and technical information and of the total system analysis in the preparation of the safety case (i.e., CCA for WIPP and the LA for YM); and, 2) the defense of the safety case and its technical basis within the processes established by the pertinent regulatory authority.

The mathematical and computational models must assess the long-term performance of the disposal system in a manner that is acceptable for regulatory decision-making about deep geologic disposal of radioactive wastes. Part of this process is informing the regulator on the approach, the analysis, and the results. At WIPP, during the certification phase, SNL scientists worked closely with the EPA and assisted them in their verification of the compliance analysis, which was essentially a re-running of the codes using EPA-defined parameters and assumptions. At YM, prior its termination, SNL scientists responded to hundreds of requests for additional information from the NRC.

## III. CONCLUSIONS

The SNL PA methodology for the evaluation of waste management systems has gained wide acceptance within the international community. It has been used to inform development of regulatory requirements, evaluate different geologic media for a repository, guide preliminary site selection, prioritize R&D to support site characterization, evaluate disposal designs, increase understanding of influential processes and phenomena; identify, prioritize, and guide research aimed at reducing uncertainties; and, ultimately, to demonstrate that a disposal system meets or exceeds the performance objectives established by the relevant regulations for the long-term protection of human health and the environment.

This paper has focused on illustrating how PA can be used to prioritize needed R&D, by indicating which features, events or processes, and scenarios, have the greatest impact on repository performance, or in reducing uncertainty, and which warrant the highest priority on limited resources.

## ACKNOWLEDGEMENTS

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