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Summary of the Systems Prioritization Method as a Decision-Aiding Method for the Waste Isolation Pilot Plant

D. M. Boak, N. H. Prindle, R. A. Bills, S. Hora, R. Lincoln, F. Mendenhall, R. Weiner

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Summary of the Systems Prioritization Method as a Decision-Aiding Method for the Waste Isolation Pilot Plant

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ABSTRACT

In March 1994, the U.S. Department of Energy Carlsbad Area Office (DOE/CAO) implemented a performance-based decision-aiding method to assist in programmatic prioritization within the Waste Isolation Pilot Plant (WIPP) Project with respect to applicable U.S. Environmental Protection Agency (EPA) long-term performance requirements in 40 CFR 191.13(a) (radionuclide containment requirements) and 40 CFR 268.6 (hazardous constituent concentration requirements). This method, the Systems Prioritization Method (SPM), was designed by Sandia National Laboratories (SNL) to: 1) identify programmatic options (activities) and their costs and durations; 2) analyze combinations of activities (activity sets) in terms of their predicted contribution to long-term performance of the WIPP disposal system; and 3) analyze cost, duration, and performance tradeoffs. The results of the second iteration of SPM (SPM-2) were the basis for recommendations to DOE/CAO in May 1995 for programmatic prioritization within the WIPP project. This paper presents a summary of the SPM implementation, key results, and lessons learned.

ACKNOWLEDGMENTS

This paper is a summary of work done by many people who are specifically acknowledged in a number of reports now in preparation. The authors gratefully acknowledge their participation and important contributions to this project. We would like to specially acknowledge Walt Beyeler for his significant contributions to many aspects of SPM.

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ACRONYMS

CCDF	Complementary Cumulative Distribution Function
CAO	Carlsbad Area Office
CI	Compliance Indicator
DOE	U.S. Department of Energy
EA	Engineered Alternative
EPA	U.S. Environmental Protection Agency
PDC	Probability of Demonstrating Compliance
RCRA	Resource Conservation and Recovery Act
SNL	Sandia National Laboratories
SPM	Systems Prioritization Method
SPM-1	Systems Prioritization Method – First Iteration
SPM-2	Systems Prioritization Method – Second Iteration
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant

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INTRODUCTION

Systems Prioritization Method (SPM) is a decision-aiding tool developed by Sandia National Laboratories (SNL) for the U.S. Department of Energy Carlsbad Area Office (DOE/CAO) to assist in programmatic prioritization within the Waste Isolation Pilot Plant (WIPP) Project. SPM was designed to 1) identify programmatic options (activities) and their costs and durations; 2) analyze combinations of activities (activity sets) in terms of their predicted contribution to the WIPP disposal system with respect to applicable U.S. Environmental Protection Agency (EPA) long-term performance requirements in 40 CFR 191.13(a) (radionuclide containment requirements) and 40 CFR 268.6 (hazardous constituent concentration requirements promulgated pursuant to the Resource Conservation and Recovery Act (RCRA)); and 3) analyze cost, duration, and performance tradeoffs.

The second iteration of SPM (SPM-2), completed in March 1995, analyzed the most viable combinations of scientific investigations, engineered alternatives (EAs), and waste acceptance criteria (WAC) for supporting the final compliance certification application for WIPP.[1] The results were the basis for programmatic recommendations to DOE/CAO in May 1995. This paper summarizes SPM, its implementation and key results. The section following this introduction discusses the SPM approach. The results of SPM-2 follow. The statistical regression analysis that was performed to determine pareto-optimal (greatest benefit for the least cost) activity set(s) for meeting DOE/CAO objectives is then summarized. A discussion of the lessons learned appears in the next section, and the paper closes with a summary.

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[1] For a full account of SPM-2, see Volumes I, II, and III of the SPM-2 final report (Prindle et al., 1996a; Prindle et al., 1996b; and Prindle et al., 1996c). See also Helton et al. (1996) for a detailed description of the computational procedures used in SPM-2.

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THE SPM APPROACH

The goal of SPM was to provide information about how potential activities—21 scientific investigations, three EAs, and two WACs—when viewed singly or in combination, could contribute to a demonstration of compliance with the EPA long-term performance requirements for the WIPP disposal system. For each combination of activities (activity sets), SPM calculated the probability of demonstrating compliance (PDC) if the activity set was implemented, along with the activity set's projected cost and duration. The PDC, cost, and duration were contained in a decision matrix that was analyzed to find programmatic options that maximized incremental PDC while minimizing activity set cost and duration. SNL performance assessment models were used to estimate how the disposal system might perform if activities were implemented, and this evaluation was the basis for calculating each activity set's PDC. SPM analyzed roughly 46,700 activity sets. Probabilistic performance calculations for these activity sets resulted in over 1.3 million complementary cumulative distribution functions (CCDFs).

As applied to the WIPP, SPM can be described in terms of eleven key steps (see Figure 1):

1) Define the performance objective (i.e., long-term performance requirements in 40 CFR 191.13(a) and 40 CFR 268.6);
2) Develop a technical baseline for SPM calculations;
3) Perform modeling of the baseline;
4) Determine whether the baseline is predicted to succeed or fail in meeting the performance objectives using a binary compliance indicator (CI);
5) (If the baseline fails to meet performance objectives), identify activities that, if implemented, could improve a predicted ability to meet the performance objectives, and elicit potential outcomes for those activities (if the baseline passes, proceed to Step 11);
6) Evaluate the baseline combined with potential outcomes of activities (i.e., calculate the PDC);
7) Create a decision matrix containing the PDC, cost, and duration for all activities and perform decision analysis to develop final recommendations;
8) Make programmatic decisions about which activities to implement, if any (DOE/CAO);
9) Implement the activities;
10) Update the technical baseline with actual results after implementing the activities; and iterate the process from step 3 as necessary until the baseline is predicted to meet the performance objectives; and,
11) Perform final compliance calculations with approved data and models when the baseline is predicted to comply.

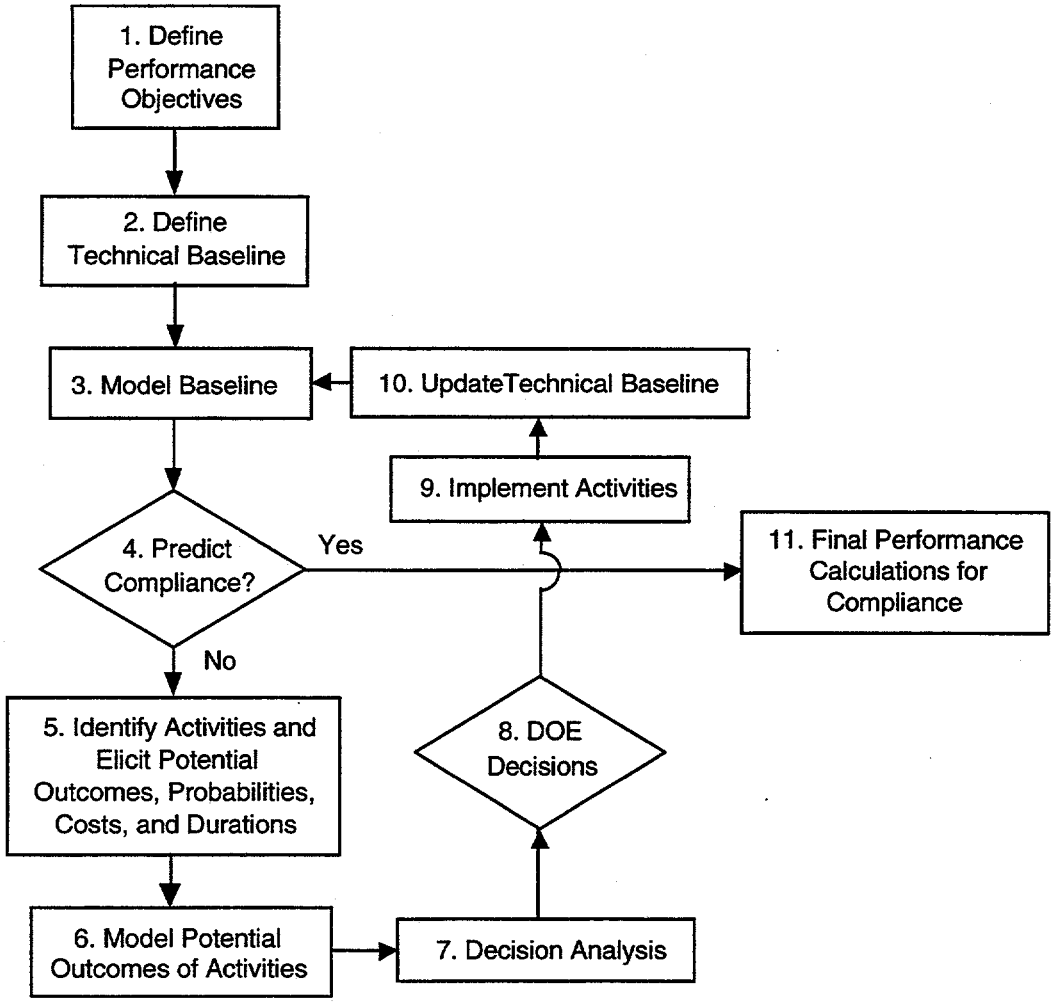

Figure 1. Key steps of SPM as applied to WIPP.

A key to understanding how SPM works is in the relationship between the output of the performance assessment models, the regulatory performance requirements, and the analysis of the results (see Keeney and Raiffa, 1993). It is also important to understand the role of expert judgment in the elicitation process and performance assessment calculations.

Performance assessment models are used by the WIPP Project to produce information about the predicted performance of the disposal system that can be compared to the regulatory requirements (see WIPP PA, 1993). For WIPP, this means calculating a CCDF for radionuclide releases, which represents the probability distribution of summed normalized releases from the disposal system to the accessible environment, and estimating potential releases of regulated volatile organic compounds and heavy metals. The WIPP disposal system is predicted to be in compliance with the containment requirements in 40 CFR 191.13(a) if no point on the CCDF exceeds the summed normalized release limits. The disposal system is predicted to be in compliance with the requirements in 40 CFR 268.6 if the hazardous waste soil concentration limits are not exceeded.

While the regulatory release limits are fixed, estimates of the predicted performance of the WIPP disposal system are not; they are determined by a state of knowledge that changes over time as a result of performing scientific investigations, implementing EAs, or modifying WACs. The changed state of knowledge, for example, can alter the position of the CCDF with respect to the release limits. The state of knowledge can be expressed, in part, through probability distributions. For example, although it is not possible to predict the solubility of plutonium in WIPP brines with absolute certainty, a range of solubilities under various chemical conditions and based on many types of existing information can be postulated, thus defining a portion of the SPM-2 calculational baseline.

Consider a scientific experiment designed to more accurately determine the solubility of plutonium in brine. The experimental design anticipates a range of possible outcomes based on both published information and expert judgment. For simplicity, suppose that the set of experimental outcomes can be classified into five ranges (actually probability distributions), from lowest to highest solubility. Denote the event that the experimental outcomes are in the first range by x_1; in the second range, by x_2; etc. Denote the five probability distributions corresponding to the five experimental outcomes by f_1, f_2, etc. After the experiment has been completed, the state of knowledge about plutonium solubility changes to reflect the new information produced by the experiment. All uncertainty, however, will not be resolved by the experiments. Uncertain repository conditions make it impossible to know with certainty what the solubility will actually be. Therefore, after the experiments are completed, residual uncertainty about the solubility can, again, be expressed through a probability distribution that reflects the new information and incorporates the new expert judgments.

Now, suppose that we use expert judgment to specify potential experimental outcomes O_i and associated probability distributions f_i *before* conducting the experiment, and use these distributions in performance assessment models to estimate the corresponding CCDFs: $CCDF_1$, $CCDF_2$, etc. In addition to providing the O_i and f_i, we also use expert judgment to specify the relative likelihood or probabilities of the various events (x_i), denoted by p_i. Suppose that performance calculations predict that events x_1, x_2, x_3, and x_4 will indicate compliance with long-term performance requirements, but that the event x_5 will indicate noncompliance. The predicted probability of successfully demonstrating compliance for the five events x_1, x_2, x_3, x_4, and x_5—viewed prior to conducting the experiment—is then $p_1 + p_2 + p_3 + p_4$. This process is the fundamental basis for calculating the PDC of an activity set, the key measure of programmatic value in the SPM method. For the WIPP, this technique applies to any activity or combination of activities that can be expressed in terms of effects on WIPP performance assessment components.

Although the above discussion pertains to compliance with 40 CFR Part 191.13(a), WIPP must also comply with the RCRA requirements in 40 CFR 268.6. The SPM criterion for successfully demonstrating compliance with the specified performance objectives was that the CCDF is at all points less than the release limits and that the RCRA soil concentration limits are not exceeded. The CI for each activity set outcome indicates whether the 40 CFR Part 191.13(a) regulatory release limits and the 40 CFR 268.6 soil concentration requirements are met by the activity set. If both requirements are met, the CI is equal to one; otherwise it is 0.

For example, suppose an activity set composed of activities A and B, each with two possible outcomes, and suppose that performance results show that quantitative performance requirements are satisfied *only* if activity A has outcome O_{A2} and activity B has outcome O_{B2}. The compliance indices for each of the four possible activity set outcomes would then be equal to 0 for all but the outcome consisting of both O_{A2} and O_{B2}, which would have a compliance indicator equal to one. Once the CI values have been determined for each activity set outcome, the PDC is calculated by summing the probabilities for all activity set outcomes where the CI is equal to 1. The PDC for the activity set consisting of A and B would then be calculated as follows:

$$PDC = 0 \times ((P_{A1} \times P_{B1}) + (P_{A1} \times P_{B2}) + (P_{A2} \times P_{B1})) + 1 \times (P_{A2} \times P_{B2})$$

Thus, because all terms (outcomes) with a CI not equal to one would drop out of the PDC calculation, the PDC would equal $P_{A2} \times P_{B2}$.

Because of the multiple possible outcomes of SPM activities, each activity set can have anywhere between two and nearly 60,000 possible outcome combinations, each of which corresponds to a CCDF and a compliance indicator. Thus, the PDC for an activity set represents a logically straightforward but very computationally intense set of calculations.

SPM-2 RESULTS

The first iteration of SPM (SPM-1), the prototype of SPM, was completed September 1994. It served to develop the tools needed for the second iteration (SPM-2), which was completed in March 1995 for programmatic decision making. SPM-2 used technical positions derived from WIPP project technical staff, stakeholders, and oversight groups as a starting point for establishing a baseline. Technical teams also defined proposed activities and were elicited on the predicted outcomes of those activities. Trained elicitors external to the WIPP project worked with the technical teams in a formal, structured process to elicit the parameters and models, and to describe the activity outcomes and the probabilities of those outcomes. Activity cost and duration estimates completed the activity descriptions. DOE/CAO and the Westinghouse Waste Isolation Division provided information regarding EAs, potential changes to WACs, and other programmatic guidance.

Potential outcomes were initially elicited for 37 scientific investigations, 18 EAs, and three WACs. These were screened to 26 discrete activities, 21 scientific investigations, three EAs, and two WACs.[2] SPM-2 used existing WIPP performance assessment computer codes, with modifications required to model the baseline and activity sets, to calculate CCDFs of potential radionuclide releases. SPM-2 evaluated more than 600,000 possible activity sets. Activities that had no performance impact were removed from the decision matrix, reducing the number of activity sets in the decision matrix to roughly 46,700. Because each activity set had multiple outcomes, approximately 1.3 million CCDFs were needed to complete the SPM-2 analysis.

For activities in the decision matrix, SPM-2 showed that the PDC generally increased, as expected, with increasing activity set cost and duration. Figure 2 shows the overall structure of the results in terms of the PDC versus activity set cost. The large cluster of diamond-shaped points (each one corresponding to an activity set) on the far left includes only scientific investigation activities. Activity sets aligned near the top of the figure all include one or more EAs. Activity sets with a PDC of 0 are not shown in Figure 2 for reasons of clarity, but can be viewed on the SPM-2 CD-ROM, an information management tool produced as part of SPM-2 (see Harris et al., 1996). Programmatic dependencies were also apparent from general trends in the data and are discussed in the next section, which summarizes the statistical regression analysis of the SPM-2 results.

The SPM-2 baseline calculation predicted release of radionuclides in violation of 40 CFR 191.13(a) but compliance with respect to 40 CFR 268.6. About 40% of the SPM-2 activity sets also had a PDC of 0 (i.e., with no predicted value in supporting a demonstration of compliance). Of the remaining 60% of the SPM-2 activity sets, one half had a PDC equal to one. When

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[2] Each activity was assigned an identifying indicator. See the Appendix for a list of the activities analyzed and their indicators. For summary information on the SPM-2 activities and their elicited outcomes and outcome probabilities, see Prindle et al. (1996b).

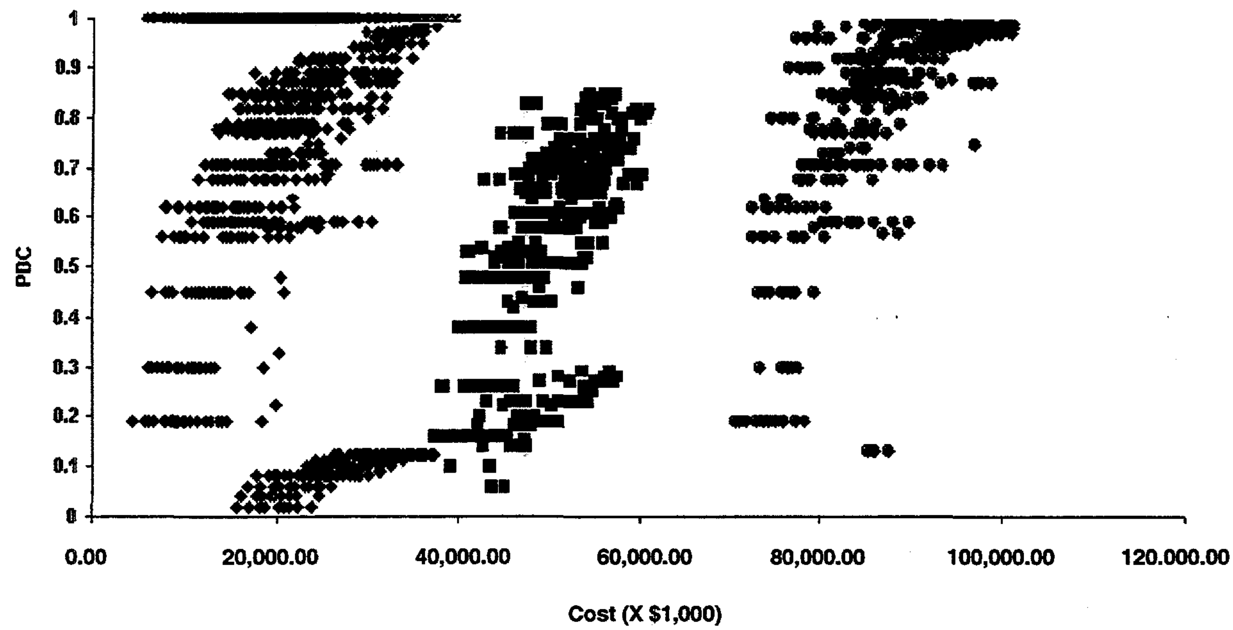

Figure 2. SPM-2 scatter plot showing PDC versus activity set cost for activity sets with a PDC greater than 0.

conducted alone, no single activity—whether a scientific investigation, an EA, or a WAC—had a nonzero PDC.

Activity sets with a PDC of 1.0 included one of two scientific investigations for colloids (either NS 8.1 (concentrations and transport of high-molecular weight organic compounds and microbes) or NS 8.2 (enhanced colloid experimental program)) and one of two EAs (either EA 1 (backfill and a pH buffer to control actinide solubility) or EA 2 (an engineered backfill (such as clay) in combination with waste form modification)). (Note that EAs and WACs were assumed to be optimally effective and were assigned a 100% probability of yielding the predicted performance. Subsequent sensitivity studies investigated the impact of this assumption on the final decision.) Two WACs were analyzed by SPM-2. In the WAC-1 activity, steel drums used to store the waste were replaced with noncorrodible materials. WAC-1 added costs to the program and slightly reduced the PDC. WAC-2, the elimination of all high-molecular weight organic compounds (such as soils) from the waste, had no discernible impact on the PDC.

The evaluation of the sensitivity of SPM-2 results to the outcome probabilities for the EAs was straightforward (see Prindle et. al, 1996c, for details). DOE/CAO had a preliminary decision to make, which was to either:

1) depend on a program consisting of EAs and minimal scientific investigations to provide a basis for the final compliance calculations; or

2) reserve EAs for possible use in providing assurance and depend on the scientific investigations to demonstrate compliance with 40 CFR 191.13(a) and 40 CFR 268.6.

In May 1995, DOE/CAO chose the second option. Additional work has been conducted on EAs since the completion of SPM, and the final balance between predicted performance of the geologic system, EAs, and WACs will be described in the compliance certification application to the EPA.

The final programmatic recommendations made to DOE/CAO in May 1995 considered the SPM-2 results along with existing information such as the 1992 WIPP PA Sensitivity Analysis (WIPP PA, 1993) and some sensitivity and uncertainty analyses. The sensitivity and uncertainty analyses did not alter the recommended series of activities. Other issues that were considered in using the SPM-2 results for decision making were:

1) The technical baseline was for SPM use only. The final project technical baseline that will be used for preparing the WIPP compliance certification application will incorporate information from the activities completed subsequent to the SPM-2 effort.

2) The results were based on calculations using mean values, and were therefore valid for discriminating between activities intended to shift a mean value for a parameter but not for discriminating between activities intended to reduce uncertainty about a mean.

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ANALYSIS OF SPM-2 RESULTS

SPM-2 generated roughly 46,700 unique activity sets. In order to determine the most favorable activity set(s) for meeting the DOE/CAO objectives, a statistical regression analysis was conducted. This analysis employed a logit regression methodology. A logit regression assumes that a probability, p (or other number bounded by 0 and 1), is related to several independent variables through the following equation:

$$\log [p/(1-p)] = \Sigma\, b_i\, x_i.$$

where x_i is the indicator variable (equal to 0 or 1) and b_i is a regression coefficient to be estimated. Here, p is the PDC. Because the left side of the equation is unbounded at $p = 0$ and $p = 1$, the PDC values were decreased slightly towards 0.5 as shown in the following equation:

$$p = (p - 0.5)(1 - \varepsilon) + 0.5,$$

where ε is a small number such as 0.01.

An initial inspection of activity sets in the decision matrix revealed two very strong relationships. First, if neither colloid activity (NS 8.1 nor NS 8.2) was included in an activity set, the PDC was 0. Second, if either NS 8.1 or NS 8.2 was in an activity set, the PDC was equal to 1 *as long as* an EA (EA 1 or EA 2) was also in that activity set, and less than 1 otherwise. Both of these relations were always true, and thus the first relation provided a sufficient condition for creating a PDC equal to 0. The second relation provided a condition that was both necessary and sufficient for PDC to equal 1. These two relations logically limited the PDC of activity sets without EA 1 or EA 2 to $0 \le \text{PDC} < 1$.

In the absence of EA 1 and EA 2, what scientific programs should be undertaken to achieve a high PDC? This question was important because the predicted performance of EA 1 and EA 2 did not account for the possibility that an EA might prove less effective than assumed. Moreover, there were reasons to believe that the system-wide costs of EA 1 and EA 2 might ultimately be larger than initially estimated. For these reasons and to better understand the cost/benefit tradeoffs for the scientific program, a statistical analysis was limited to those activity sets where both of the following occurred: 1) NS 8.1 or NS 8.2 was present, and 2) neither EA 1 nor EA 2 was present.

Using the logit model and excluding from the data set those activity sets without either NS 8.1 or NS 8.2 and excluding those having some combination of colloid activity with EA 1 or EA 2, regression coefficients were obtained. Based on regression results, activities are ordered from those with the greatest impact to those with the least impact, creating a series of activities such that as activities are added to the series, the PDC continues to increase, but at a decreasing rate (see Figure 3). If the costs of the activities are similar, it is, in principle, possible to build a concave, monotonically increasing function that maximizes incremental PDC gained while

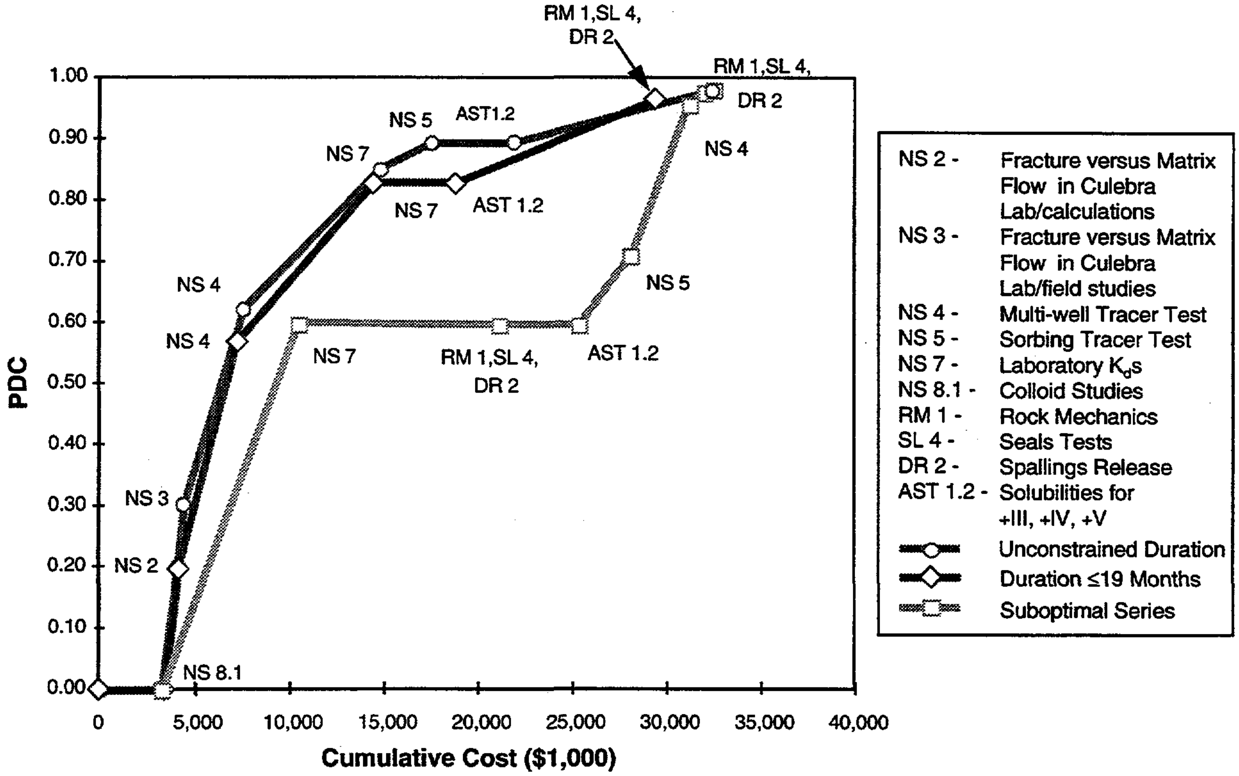

Figure 3. PDC versus activity set cost for duration-constrained and unconstrained activity series. (A suboptimal series, which does not maximize incremental PDC gained per dollar invested, is also shown.)

minimizing incremental costs as more activities are added to the series. Two such activity series are shown in Figure 3 (the two curves on the left-most side of the graph), but they are not fully concave. The far-left curve is unconstrained by duration while the middle curve is constrained by a 19-month duration. The reason that these curves are not fully concave is that there are both thresholds and interactions (synergies) among some activities. The right-most curve in Figure 3 is a suboptimal activity series that ultimately reaches nearly the same PDC as the pareto-optimal series but without the same ability to maximize incremental PDC per dollar at every point in the series.

For both the duration-constrained and unconstrained activity series in Figure 3, no improvement in the PDC was obtained by performing NS 8.1 by itself. (Here NS 8.1 was chosen over NS 8.2 because of equal impact on the PDC and lower cost for NS 8.1.) However, for the duration-constrained series, the addition of the two scientific investigations NS 2 (Culebra fracture/matrix/flow – laboratory) and NS 4 (multi-well tracer test) increased the PDC to 0.56. The addition of NS 7 (chemical retardation for Th, Np, Pu, U, and Am) further increased the PDC to 0.82. As Figure 3 shows, the addition of AST 1.2 (dissolved actinide solubilities for oxidation states +III – +VI) did not increase the PDC. However, AST 1.2 was necessary to gain the PDC improvement provided by the combination of RM 1 (rock mechanics), SL 4 (studies of short- and long-term seal components), and DR 2 (blowout releases). In fact, without first performing AST 1.2, the addition of RM 1, SL 4, and DR 2 produced a decrement in PDC. The same unexpected behavior occurred when the order of the activities was switched. It can therefore be concluded that some interaction is taking place between AST 1.2 and the collection of three activities. Addition of any other activity to the series only brings minuscule improvements. A PDC of 0.96 is achieved from the duration-constrained pareto-optimal series.

The two series on the left are both considered pareto-optimal, that is, each series cannot be bettered simultaneously in both cost and PDC for its respective duration. Faced with programmatic options limited to scientific investigations—without EAs or WAC modifications—both the duration-constrained and unconstrained activity series appear to be logical programmatic choices. However, the duration-constrained series, which eliminated two scientific activities (NS 3 (Culebra fracture/matrix/flow – field) and NS 5 (sorbing tracer test)) resulted in virtually the same PDC as the unconstrained set and with lesser cost. SPM-2 results were the basis for recommendations to DOE/CAO in May 1995 for programmatic prioritization for the WIPP Project. The duration-constrained series was selected for implementation by the DOE/CAO.

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COMMENTARY AND LESSONS LEARNED

The SPM-2 decision matrix yielded valuable information for identifying: 1) activity sets necessary to achieve a given PDC; 2) activity sets that provide the maximum PDC; and 3) activities that have minimal impact on the PDC. Moreover, the use of quantitative analyses balanced with expert judgment was essential in developing insights about decision options in a highly nonlinear system. SPM required a significant commitment of human and computational resources, but numerous improvements could be made to increase efficiency.

Information needed for SPM was elicited from individuals directing the various activities and those proposing new activities. Adequate time for training participants in an expert elicitation process is essential.

Concerns were raised that the SPM baseline was excessively conservative and would not produce a useful basis for evaluating activities. A management review was held to assure that the baseline was, in fact, appropriately balanced and integrated and that it was acceptable as the basis for performance calculations. Such a review is recommended for both the baseline and activities prior to performing calculations to assure consistency and appropriate integration of the elicited information.

Side investigations (also known as side bar calculations, or side calculations) were also important in being able to keep the probabilistic calculations tractable and in preventing unnecessary conservatism in the baseline. Side investigations are supplementary and confirmatory evaluations required to 1) fully address certain technical positions[3] taken in the SPM-2 baseline; 2) investigate the impact of potential activities where the cost and expense of carrying an activity outcome all the way through the formal SPM decision process was not warranted; and 3) investigate the impact of calculational models chosen for SPM-2, such as two-dimensional versus three-dimensional models for both baseline and activity outcomes. The expected outcomes of the side investigations were included in SPM-2 calculations because the probability of their successful completion was considered very likely. These confirmatory evaluations included scenario screening work, literature searches, bounding calculations, and some computer modeling.

There are computational limitations to probabilistic calculations underlying SPM. Suppose, for example, that m activities are to be considered and each activity has k potential outcomes. The number of endpoints to be evaluated is calculated as $\Sigma_{i=1,m}\ k^i m!/[(m-i)!i!]$, a value that becomes very large, very quickly. Clearly, not all combinations of activities can be evaluated. But this is where judgment and an understanding of disposal system performance can be used to create reasonable sets of activities for evaluation. Other computational schemes, such as sampling certain computationally intensive parts of the performance assessment model, should

[3] Technical positions refer to the conceptual models, scenarios, data, and parameter distributions defined for WIPP by the scientific investigators to use in assessing the performance of the repository.

be explored. In addition, multiattribute utility analysis techniques could be useful for up-front screening and focusing an initial large set of potential activities into a smaller set that requires quantitative evaluation.

The usefulness of an SPM-like method depends upon the quality of the elicited information about activity outcomes, their probabilities, and the state of knowledge about system parameters and conceptual models. Retrospective analyses of SPM results can assess the degree to which actual outcomes were consistent with elicited predictions. Bayesian updating methods could also be used if SPM were applied on an iterative basis.

CONCLUSIONS

SPM identified viable combinations of programmatic options (activities) for WIPP that, if implemented, were predicted to lead to a demonstration of compliance with U.S. EPA long-term performance requirements. Moreover, analysis of the results also indicated that optimal programmatic pathways existed and that these activity series could provide useful insights into which activities to cut or add if budgets changed. The analysis, in fact, indicated that a demonstration of compliance with the long-term performance requirements could be anticipated within the DOE/CAO WIPP Disposal Decision Plan schedule.

SPM focused on work to achieve compliance with long-term disposal system performance requirements and helped eliminate concerns that activities would merely contribute to scientific knowledge. SPM utilized the existing performance assessment codes to calculate the expected results of various programmatic options. Use of quantitative performance assessment tools for prioritization was essential in gaining insights into the behavior of a highly coupled, nonlinear disposal system. SPM built upon the power of both performance assessment and decision analysis techniques, providing insights for decision making.

The general method of SPM can be applied to other complex issues in the environmental and waste management arena that need to clearly focus scientific and engineering activities on specific (and measurable) objectives within cost and schedule constraints. Because SPM combines decision analysis methods with quantitative analyses, it is conceptually applicable to any complex problem for which performance objectives, performance measures, and options for achieving the performance objectives can be defined. Projects that are likely to benefit the most are those with a complex set of technical issues and decision options that would benefit from planning based on *calculated* performance, rather than expert prediction alone. Projects with significant stakeholder involvement or with multiple participants might also benefit. Finally, probabilistic techniques used to treat uncertainties in the performance of a system could also be used to treat uncertainties in the cost or duration of programmatic alternatives (see Boak and Painton, 1996).

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APPENDIX: TABLE OF SPM-2 ACTIVITIES

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Table A-1. SPM-2 Activities

Activity	Indicator
Actinide Source Term (AST)	
Dissolved Actinide Solubilities for Oxidation States +III – +VI	AST 1.1
Dissolved Actinide Solubilities for Oxidation States +III – +V	AST 1.2
Gas Generation (GG)[a]	
Reaction-Path Gas Generation Model (RPM) and Supporting Data	GG 1
Disposal Room (DR)	
Decomposed Waste Properties	DR 1
Blowout Releases	DR 2
Non-Blowout Releases	DR 3
Seals and Rock Mechanics (SL and RM)	
Rock Mechanics	RM 1
Studies of Short- and Long-Term Components	SL 4
Salado (SAL)	
Lab/Field Properties of Anhydrite	SAL 1
Halite Far-Field Pore Pressure	SAL 2
Halite Lab/Field Properties	SAL 3
Fingering/Channeling Studies – Existing Data	SAL 4.1
Fingering/Channeling Studies – New Data	SAL 4.2
Anhydrite Fracture Studies	SAL 4.3
Non-Salado (NS)	
Dewey Lake - Paper and Low-Effort Field Studies	NS 1
Culebra Fracture/Matrix/Flow – Lab	NS 2
Culebra Fracture/Matrix/Flow – Field	NS 3
Multi-Well Tracer Test	NS 4
Sorbing Tracer Test	NS 5
Chemical Retardation for Th, Np, Pu, U, and Am	NS 7
Concentrations and Transport of Colloid Carriers: High-Molecular Weight Organic Compounds (HWMOC) and Microbes	NS 8.1
Enhanced Colloid Experimental Program	NS 8.2
Engineered Alternatives (EAs)	
Passive Markers	EA 3
Backfill with pH Buffer	EA 1
Backfill with pH Buffer and Waste Form Modification	EA 2
Waste Acceptance Criteria (WAC)	
Non-Corroding Waste Containers	WAC 1
Elimination of Humic-Containing Waste Drums	WAC 2

[a] This activity was elicited, but not modeled for the SPM-2 analysis.

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