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The Development and Application of a Risk-based Prioritization Model for the Oak Ridge Environmental Restoration Program

Joyce L. Dail

University of Tennessee, Knoxville, Tennessee for Center for Risk Management, Health Sciences Research Division, Oak Ridge National Laboratory, managed by Lockheed Martin Energy Systems, Inc.[1]
1060 Commerce Park Drive, Oak Ridge, TN 37830-6480
(615) 576-5998

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Robin K. White

Technical Integration Program Manager, Environmental Restoration Division
Lockheed Martin Energy Systems, Inc.[1]
P. O. Box 2003, Oak Ridge, TN 37831-7298
(615) 574-0326

The Oak Ridge Environmental Restoration (ER) Program developed and implemented the Environmental Restoration Benefit Assessment Matrix (ERBAM) early in 1994 to provide a simple, efficient process for prioritizing and justifying fiscal budget decisions for a diverse set of activities. The decision to develop a methodology for prioritizing sites was necessitated by the large number of buildings and areas managed by the DOE Oak Ridge Field Office and the finite resources available to address these areas. The ERBAM was based on the Integrated Resource Management System prioritization methodology historically used by the United States Department of Energy (DOE) and Lockheed Martin Energy Systems, Inc., to rank compliance and operational activities. To develop the matrix, ER Program management, working with federal and state regulators, agreed on impact criteria that balance the major objectives within the ER Program: protection of public health, protection of the environment, protection of on-site workers, consideration of stakeholder/community preference, achievement of ER mission, and optimization of cost efficiency.

Lessons learned from the initial application of the matrix were used to make refinements and improvements in the methodology. A standard set of assumptions (both overall and categoric) and a prioritization board, consisting of top level DOE and Lockheed Martin Energy Systems, Inc., managers along with federal and state regulatory representatives, were established to facilitate consistent application. Current and future improvements include a method to incorporate existing quantitative risk data and facilitate increased efficiency in applying baseline cost data and approved funding levels to the prioritized output.

Application of the prioritization methodology yields a prioritized list of all work activities within the programs' work breakdown structure. This list is tied to both performance and projection baselines for cost and schedules as well as to fiscal year funding targets. Combination of these parameters produces a prioritized fiscal year funding profile and prioritized baseline profile. This integration allows an understanding of budget impacts on current priorities and helps to forecast perturbations of projected future work, based on risk-benefit priorities.

The ERBAM is being used to evaluate and rank ER work packages at the five DOE Oak Ridge Operations sites and the ER Off-site Program to ensure resources are allocated based on the overall risk-benefit value provided by the chosen response actions. The methodology has been applied to approximately 260 individual work packages to allocate funds for FY 1996 and FY 1997. In addition, it has also been used to prioritize the Weldon Spring Site Remedial Action Program, the Formerly Utilized Sites Remedial Action Program, and the EM-60 Nuclear Materials & Facilities Stabilization activities for FY 1997.

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The Development and Application of a Risk-based Prioritization Model for the Oak Ridge Environmental Restoration Program

Joyce L. Dail[a], Kenton T. O'Kane [a], Curtis C. Travis [b], Robin K. White [c]

[a] University of Tennessee, Knoxville, Tennessee for Center for Risk Management, Health Sciences Research Division, Oak Ridge National Laboratory, managed by Lockheed Martin Energy Systems, Inc.[1], 1060 Commerce Park Drive, Oak Ridge, Tennessee, 37831-6492
(615) 576-5998

[b] Center for Risk Management, Health Sciences Research Division, Oak Ridge National Laboratory Ridge, managed by Lockheed Martin Energy Systems, Inc.[1], 1060 Commerce Park Drive, Oak Ridge, Tennessee, 37831-6492
(615) 576-2109

[c] Environmental Restoration Division, Lockheed Martin Energy Systems, Inc.[1], P. O. Box 2003, Oak Ridge, Tennessee, 37831-7298
(615) 574-0326

1. INTRODUCTION

The U. S. Department of Energy's (DOE) Office of Environmental Management analyzed current and proposed risk management activities and supports the use of risk to determine which environmental problems should be given priority and appropriate funding (DOE 1995). DOE Assistant Secretary for Environmental Restoration and Waste Management Thomas P. Grumbly has stated his commitment to reducing both environmental risks and the cost involved. He suggests focusing on major DOE cleanup problems as one way to reach these goals (DOE 1993). This paper describes the application of the risk-based prioritization methodology used by the U. S. Department of Energy, Oak Ridge Field Office (DOE-ORO) to rank environmental restoration options. This was successfully applied to approximately 260 DOE-ORO Environmental Restoration (ER) Program work packages for allocation of funds for fiscal years 1995, 1996 and 1997, DOE'S Weldon Spring Site Remedial Action Program, and the DOE Office of Environmental Restoration and Waste Management's nuclear materials and facilities stabilization activities for fiscal year 1997.

2. THE RISK-BASED PRIORITY MODEL

DOE-ORO developed the Environmental Restoration Risk-based Prioritization Work Package Planning and Risk Ranking Methodology (Dail 1995). The methodology is based on the Integrated Resource Management System prioritization methodology historically used by DOE and Lockheed Martin Energy Systems to rank compliance and operational activities and uses multi-attribute utility analysis principles. Multi-attribute utility analysis is a form of decision analysis that enables its users to evaluate how available options meet multiple criteria for resolving a problem. This technique is very useful to force a systematic evaluation for those aspects of a problem that must be resolved. This process identifies options that provide the best overall performance to meet the set of important objectives that decision makers are likely to use (EPA 1994). Multi-attribute utility analysis has long been used by decision makers to evaluate decisions regarding costs, health efforts, and environmental degradation (Merkhofer 1987).

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This methodology provides a framework for 1) organizing information about identified DOE-ORO environmental problems, 2) generating qualitative assessments of the long- and short-term risks posed by those problems, and 3) evaluating the benefits associated with candidate work packages (i.e., ER projects) designed to reduce those risks and a simple cost-effective approach to risk-based development of resource requests.

2.1 THE DECISION MODEL

Any resource allocation can be viewed as an attempt to reduce a negative impact in terms of either its severity or the probability of its occurrence. Therefore, a risk-based decision model must address three issues: 1) the type of impact to be considered in the prioritization, 2) the severity of potential impacts, and 3) the probability of those impacts occurring. The prioritization model developed as a decision support tool for the Oak Ridge ER Program uses the Environmental Restoration Benefit Assessment Matrix (ERBAM) (Figure 1) to deal with these issues. The four elements of project prioritization using the ERBAM are: 1) criteria identifying the possible types of impacts, 2) application of values for assessing impact severity and probability, 3) a procedure for generating scores, and 4) the rule, or output (Figure 2). Each of the four elements is addressed in turn.

2.1.1 Impact Criteria

The first element of the ER prioritization methodology to be developed was identification of the criteria used to define the risks and benefits associated with funding decisions. The impact criteria, also the first dimension of the ERBAM, were selected based on the primary objectives of the ER mission:

- **Public health** addresses potential adverse impacts on the health and safety of the surrounding or affected human population (off-site) from accidents involving the release of radioactive or hazardous materials.

- **Environmental protection** addresses potential adverse impacts on the environment, including physical degradation of surrounding or affected ecological systems and harmful effects on plants and animals, as well as loss of use of natural resources, from accidents involving the release of radioactive or hazardous materials.

- **Site personnel safety** addresses potential adverse impacts on the health and safety of site personnel working inside the site boundary, including physical injury and exposure to radioactive or chemical pollutants.

- **Stakeholder preference** addresses potential adverse impacts on the level of confidence that the public maintains in the DOE-ER Program.

- **Mission** addresses potential adverse impacts on ER's ability to accomplish the DOE-ORO mission.

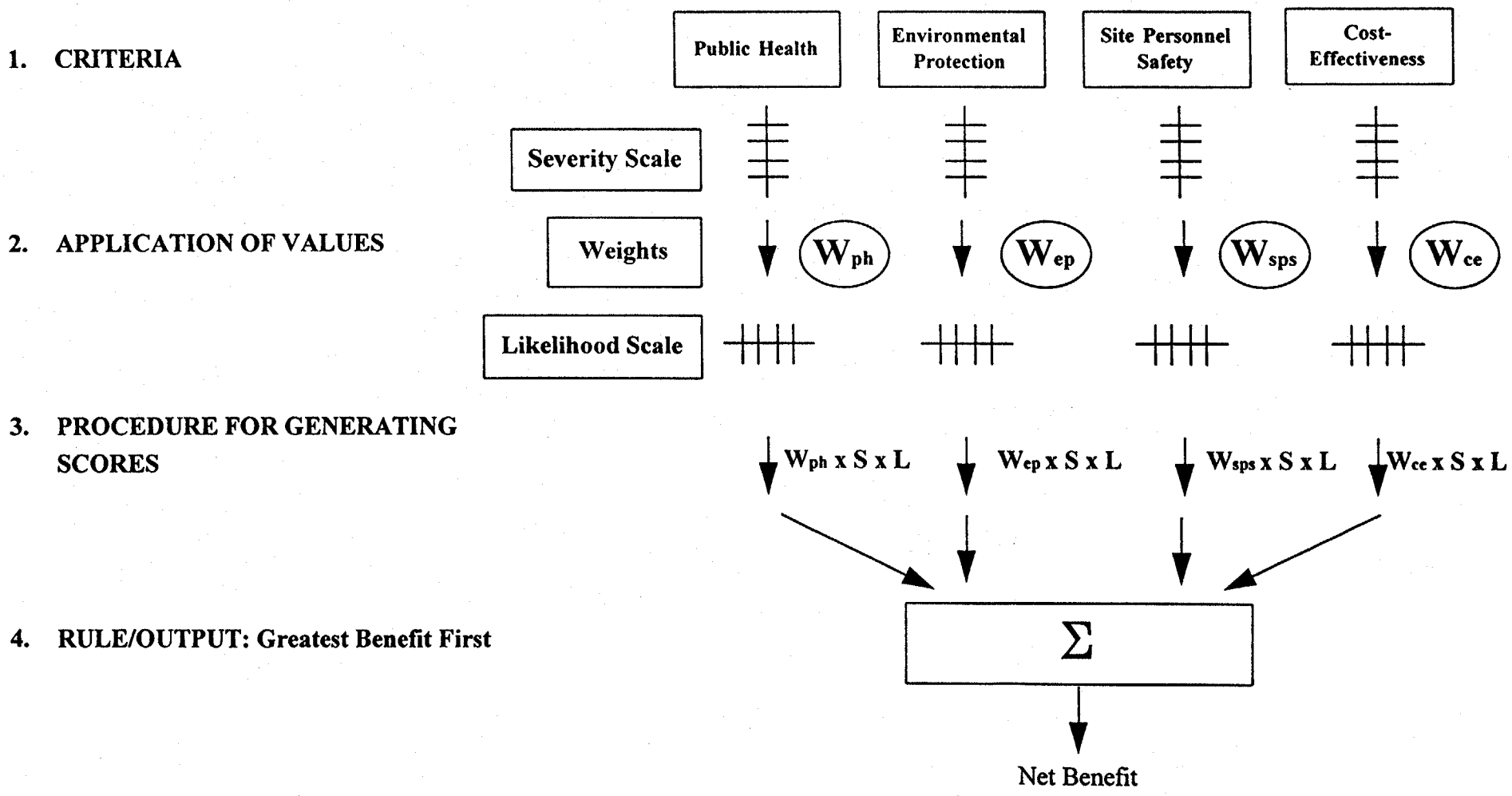
- **Cost-effectiveness** addresses potential adverse impacts on ER's ability to avoid future costs.

Regulatory compliance is not a separate category in the ERBAM because it is not a discriminating factor. Since all of the ER Program's work supports regulatory compliance in some measure, state and federal regulators agreed that this category is not functional.

Figure 1. Environmental Restoration Benefit Assessment Matrix (ERBAM)

ERBAM	EVENT LIKELIHOOD			
	A	B	C	D
IMPACTS	Very High	High	Medium	Low
Public Health				
1. Significant/high risk of exposure to off-site public	3000	1500	750	0
2. Moderate risk of exposure to off-site public	1500	750	375	0
3. Low risk of exposure to off-site public	750	375	187.5	0
Environmental Protection				
4. Widespread and/or long-term damage to surrounding or affected ecological systems	2000	1000	500	0
5. Widespread and/or short-term damage to surrounding or affected ecological systems	1000	500	250	0
6. Localized and or/short-term damage to surrounding or affected ecological systems	500	250	125	0
Site Personnel Safety				
7. Significant/high risk of exposure or physical injury to on-site personnel	2000	1000	500	0
8. Moderate risk of exposure or physical injury to on-site personnel	1000	500	250	0
9. Low risk of exposure or physical injury to on-site personnel	500	250	125	0
Stakeholder Preference				
10. Significant stakeholder interest	1000	500	250	0
11. Moderate stakeholder interest	500	250	125	0
12. Minor stakeholder interest	250	125	62.5	0
Mission				
13. Significant impact on cost, schedule or environmental impact of multiple activities resulting in shutdown of key program components	1000	500	250	0
14. Moderate impact on cost, schedule or environmental impact of more than two activities	500	250	125	0
15. Minor impact on cost, schedule or environmental impact of one other activity	250	125	62.5	0
Cost-Effectiveness				
16. Loss of opportunity to avoid total future costs $5-25M, or annual costs $1-5M	1000	500	250	0
17. Loss of opportunity to avoid total future costs $1-5M, or annual cost $0.2-1M	500	250	125	0
18. Loss of opportunity to avoid total future costs < $1M, or annual cost < $0.2M	250	125	62.5	0

Figure 2: Schematic of Selected ERBAM Elements



2.1.2 Application of Values

The second element in application of the three-dimensional ERBAM is the procedure for applying values to the chosen decision parameters in order to generate a score. Values were assigned to the matrix criteria, the first dimension of the ERBAM, and scales were developed to quantify the severity and the probability of anticipated impacts, the second and third dimensions of the matrix.

2.1.2.1 Risk Impact Criteria Weights

The six risk impact criteria were assigned values based on the perceived relative weights of each objective (Table 1).

Table 1. Risk Impact Criteria Weights

Risk Impact Criteria	Weight	Relative Importance
Public Health	3000	30% contribution overall
Environmental Protection	2000	20% contribution overall
Site Personnel Safety	2000	20% contribution overall
Stakeholder Preference	1000	10% contribution overall
Mission	1000	10% contribution overall
Cost-Effectiveness	1000	10% contribution overall

2.1.2.2 Impact Severity

The severity scale, the second dimension of the ERBAM, measures the magnitude of the impact. Generally graded significant, moderate, and low, severity levels quantify the magnitude of a potential impact (e.g., the degree of public exposure or the extent of ecological damage). The impact severity scale was developed on the premise that reduction of an impact from high to moderate is of greater overall significance than reduction of an impact from moderate to low (i.e., high = 100%, moderate = 50% of high, and low = 50% of moderate). For example, for the public health criterion, high severity is 3,000, moderate severity is 1,500, and low severity is 750 (see Figure 1). The highest severity levels are shown in Table 2.

2.1.2.3 Probability of Occurrence

The third ERBAM dimension measures the probability of impact occurrence. A probability value is assigned to predict the likelihood of a certain impact severity occurring within a specified time frame. A time frame of 1, 10, 100 or greater than 100 years (Table 2) is used for the human health and environmental risk impacts. A time frame of 1, 3, 5 or greater than 5 years (Table 3) is used for the socio-economic and programmatic impacts.

Table 2. Probability of Occurrence Values for Human Health and Environmental Impacts

Likelihood	Very High	High	Medium	Low
Numeric Value	1.00	0.50	0.25	0.00
Probability	1 in 1 yr.	1 in 10 yrs.	1 in 100 yrs.	1 in >100 yrs.

Table 3. Probability of Occurrence Values for Programmatic Impacts

Likelihood	Very High	High	Medium	Low
Numeric Value	1.00	0.50	0.25	0.00
Probability	1 in 1 yr.	1 in 3 yrs.	1 in 5 yrs.	1 in >5 yrs.

Each cell in the matrix has a value equal to the product of its respective risk impact severity value multiplied by its probability of occurrence value:

$$Risk = S_i \times P_i$$

where

S_i = severity of impact, and

P_i = probability of impact occurrence.

For example, if the impact predicted for public health is low, (e.g., a numerical value of 750) and is likely to occur within 1 year, the cell value is 750. If the same low impact is not likely to occur within 1 year, but may occur within 2-10 years, the cell value is 375.

2.1.3 Procedure for Generating a Score

For the third element of the prioritization methodology, a project is evaluated for each of the six impact criteria and a score is generated. First, the severity of the existing situation (i.e., if the project were not implemented) is assessed for each risk impact criterion, and a severity level chosen. Second, the probability of the chosen impact severity is determined. This assessment produced a *before* score that represents the situation if the project does not receive funding and cannot be implemented. Next, the situation expected to exist following project implementation is assessed. A severity level and a probability value are chosen to represent the project *after* score, or the risks that remain after a project has been implemented. The delta of these scores are calculated and summed for each category to yield the net benefit score of the project.

2.1.4 Decision Model Rule/Output

For a decision output, the fourth element of project prioritization, the ERBAM yields a numerical value that reflects the level of risk reduction and other benefits achieved by implementing the work package. The projects are ranked from highest to lowest ERBAM score, generating a priority list of funding decisions that provide the greatest benefit to the organization.

3. APPLICATION OF ERBAM TO PRIORITIZE ENVIRONMENTAL RESTORATION FUNDING DECISIONS

The ERBAM is used within a qualitative risk management process that relies on technical expertise and sound management judgement. Application of the ERBAM is conducted by a panel consisting of project managers, technical experts, risk management experts, senior managers and state and federal regulatory representatives. Environmental Restoration projects are qualitatively evaluated, compared and ranked using the ERBAM, producing a prioritized list of funding decisions. Over 260 environmental restoration projects were prioritized using the ERBAM. After briefly discussing the background that lead to the methodology's development, the prioritization process and results are described.

The DOE-ORO is comprised of seven components including three sites in Oak Ridge, Tennessee (Oak Ridge K-25 Site, Oak Ridge National Laboratory, and the Oak Ridge Y-12 Plant), Portsmouth Gaseous Diffusion Plant, Paducah Gaseous Diffusion Plant, the ER Off-site Program and Central ER. In the past, the seven separate groups submitted uncorrelated resource requests individually to DOE, basing their individual requests on disparate criteria and site-specific needs. DOE-ORO conducted a formalized risk-based budget prioritization for several reasons. Merkhofer (1994) recently described how organizations use priority systems to achieve their objectives, by 1) using limited resources more effectively, 2) improving decision-making efficiency, and 3) improving decision-making defensibility (Table 4).

Table 4. Objectives for Using Priority Systems

Organization's Objectives	How Priority Systems Help Achieve Objectives
Use limited resources more effectively	• Helps eliminate decision errors and biases • Promotes consistency and "level playing field" • Reduces duplicity of effort • Controls the role of politics in decision making
Improve decision-making efficiency	• Provides framework for organizing information and exploring issues • Facilitates communication among parties • Serves as a catalyst for action
Improve decision-making defensibility	• Documents underlying assumptions and logic • Promotes consensus

3.1 PRIORITIZATION IMPLEMENTATION AND RESULTS

DOE-ORO's implementation of the ERBAM involved a four steps process: 1) project data gathering and database development, 2) evaluation and scoring of candidate work packages, 3) development of resource requests, and 4) management adjustment and approval. The result is the funding profile for a specific fiscal year.

3.1.1 Project Data Gathering and Database Development

During the first step of the prioritization process, relevant project data (e.g., responsible manager, project scope, significant milestones or scheduled accomplishments, preliminary discussion of before and after impact, site suggested scores) were collected for each project. A database was developed to facilitate efficient storage and retrieval of these data. These data were utilized during the application of the ERBAM as background project information. The database also provided storage for documented project evaluation information and justifications for relative project rankings. These data were utilized as documented justification to defend resource requests.

3.1.2 Application of the ERBAM

The second step of prioritization is to apply the ERBAM to candidate work packages. A Prioritization Board, consisting of seven senior DOE and Lockheed Martin Energy Systems, Inc. ER managers, representatives from the U.S. Environmental Protection Agency (Region IV and Region V), and Tennessee, Ohio, and Kentucky state regulatory agencies was assembled. The Prioritization Board met, evaluated, and scored candidate projects using the ERBAM.

3.1.2.1 Prioritization Board Project Evaluation Sessions

To facilitate the process conducted in formal scoring sessions, the board established benchmark work packages for each group of cleanup activities (i.e., burial grounds, groundwater, monitoring, decontamination and decommissioning, waste management). Once these benchmark work packages were evaluated and scored, the remaining work packages were scored relative to the benchmarks.

Each work package was discussed and evaluated in turn. Each ERBAM criteria was considered during review and either given a score by the board or deemed "not applicable" and not scored. Before and after implementation scores were assigned by the board using the process discussed in Sect. 2.1.3 and a net benefit score was calculated for each project.

The database was updated and scores were calculated during the scoring session and the initial ranking was prepared for review. The board reviewed the initial ranking for consistent application of assumptions, compatibility with on-going activities or newly-identified priorities and objectives. The ranking adjustments were included and the risk-based priority list was generated.

3.1.2.2 Prioritization Process Assumptions

Process assumptions were developed to increase consistency in the comparative analysis of diverse environmental restoration funding decisions within the ERBAM framework. These process assumptions were employed during the prioritization process:

- Allocation of funding will not be considered during the ERBAM analyses.
- When determining work package *after* scores, assume the "life of the work package" rather than one-year risk reduction or incremental risk reduction.
- When determining work package *after* scores, assume work package effectiveness/success in terms of scope and objective.
- To justify a "Very High" probability of occurrence, the impact must be either an existing condition or must be anticipated to occur within 1 year/12 months from the fiscal year under evaluation.
- The prioritization of ER work packages using the ERBAM is a comparative analysis. Therefore, during each application of the ERBAM, for each impact criterion, the board will establish benchmark work packages that define the highest achievable severity level in a given application.

Specific assumptions have been developed to facilitate common interpretation of the ERBAM impact criteria (Table 5).

Table 5. ERBAM Impact Criteria Assumptions

ERBAM IMPACT CRITERIA ASSUMPTIONS	
Public Health	• For remedial actions, assume that applicable administrative controls/boundary controls are in place for exposure scenarios. • For decommissioning and decontamination projects, assume realistic and consistent probability of failure for release scenarios (e.g., do not assume that surveillance and maintenance completely reduces the risk of release and subsequent exposure).
Environmental Protection	N/A
Site Personnel Safety	• This category covers on-site risks of exposure and physical injury to all Lockheed Martin Energy Systems, Inc. and DOE staff, subcontractors, and on-site visitors. • For remedial actions, assume that applicable administrative controls or boundary controls are in place when developing exposure scenarios. • For decommissioning and decontamination, assume realistic and consistent probability of failure when developing release scenarios (e.g., do not assume that surveillance and maintenance completely reduces the risk of release and subsequent exposure). • Assume reasonable work-arounds for workers who receive their annual exposure limits (e.g., workers will be assigned to different work areas).
Stakeholder Preference	• Stakeholders includes the surrounding, affected or interested/concerned public, interest groups and site-specific advisory boards.
Mission	• Consider dependency among work packages when determining impact on mission.
Cost-effectiveness	• Address cost avoidance estimates associated with implementing work packages. • Consider dependency among work packages when determining impacts on productivity and cost avoidance.

3.3.1 Project Cost Data Integration and Development of Resource Requests

The third step in application of the prioritization methodology was to produce the funding profile for the specific fiscal year using the prioritization net benefit scores, the associated project cost estimates, and fiscal year specific DOE budget guidance. ER business operations used the risk-based priority list to develop two additional lists: 1) the baseline activity list, and 2) the funding profile. The baseline activity list was developed by applying current ER baseline cost information to the risk based priority list. Using the baseline activity list as a basis, activity data sheets and other budget request documents were developed. The funding profile for the specific fiscal year was produced by applying fiscal-year specific budget information to the baseline activity list. The funding profile allocated dollars to activities based on the rankings in the risk-based priority list (from highest to lowest priority) and the funding constraints received in the DOE ER budget guidance. This exercise produced the "funding line" for the specific fiscal year.

3.3.2 Upper Management Ranking Adjustment and Approval

After business operations established a preliminary funding profile, upper management examined the list carefully with consideration given to factors previously not considered. In some cases, small risks that could be readily eliminated merited higher priority than larger risks that could be reduced by, at most, ten to twenty percent. Some factors that were considered in applying ranking adjustments included 1) organizational or mission changes, 2) relationships among projects, 3) continuity of operations, and 4) the current political climate.

4. CONCLUSIONS

The ERBAM offers a multi-parameter model for determining project benefits within a qualitative process that requires important value judgements as well as scientific evidence. The quantified risk decision matrix described provides management with a reasonably accurate decision model that is easy to use.

The merging of the prioritization and costing databases has greatly enhanced our preparation and submission of resource requests. Another benefit is the ability to accommodate various funding scenarios and provide management with valuable information regarding impacts of different funding levels.

The inclusion of regulatory representatives has proven to be very valuable to the process as it has become another forum for working together to realize our cleanup goals.

5. FUTURE DEVELOPMENTS

The Oak Ridge National Laboratory Risk Assessment Council is developing an approach for consistent and comprehensive incorporation of existing quantitative ecological and human health risk information into the scoring process. While quantitative data were available and were considered in many cases when evaluating each project, use of such data have not previously been formally incorporated into the prioritization methodology. This approach will help to reduce subjectivity in scoring and render the scores more technically defensible.

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