RISK AS A METRIC IN THE NUCLEAR MATERIALS INTEGRATION PROJECT

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ABSTRACT

This paper describes work sponsored by the Center for Risk Excellence (CRE). The Nuclear Materials Integration Project (NMI) was chartered to identify the Department of Energy's (DOE) nuclear material inventories; to determine disposition paths for excess nuclear materials that are under the control of or of interest to the Office of Environmental Management (DOE-EM); to evaluate the programmatic risks associated with these plans; and to identify opportunities for program improvement and cost savings.

In order to achieve these objectives, an NMI assessment and evaluation process was established. Baseline and alternative materials disposition pathways were developed by evaluating parameters associated with the technical maturity of the proposed stabilization and disposition processes, the programmatic risks associated with moving from current state conditions to ultimate disposition along a pathway, and the environmental, safety, and health (ES&H) risks associated with the current state conditions and the pathway processes. Over 1,100 disposition pathways were defined and mapped for nuclear materials in three general categories: transuranic materials; uranium/thorium materials; and non-actinide sealed source and special isotope materials.

CRE supported the development of the ES&H risk metrics used in the evaluation process. The NMI Integration Team identified two objectives for the ES&H risk metrics: (1) help identify, through a triage process, the highest current state risk materials that need priority attention for stabilization activities; and (2) help discriminate among baseline versus alternative disposition pathways based on potential worker and public risks.

The screening level approach used to address potential ES&H risks was based on the "Target-Barrier-Hazard Analysis" methodology used by DOE's Office of Environment, Safety and Health (DOE-EH) in the vulnerability studies conducted for spent fuel in 1993, for plutonium in 1994, and for highly-enriched uranium (HEU) in 1996. Worksheets were developed to document expert opinion on factors related to: (1) Material Current State Vulnerability; (2) Material Handling Vulnerability; and (3) Transportation Vulnerability. Material Current State Vulnerability addressed the triage (i.e., categorization into high, medium, and low priority attention needs) of materials under current conditions, whereas, Material Handling and Transportation Vulnerabilities addressed potential differences in worker and public risks, respectively, among baseline versus alternative disposition pathways.

Analysis of the results of the screening process indicated that the Material Current State Vulnerability scores provided some discrimination of materials into high, medium, and low categories. Follow-up activities to improve the effectiveness of this screen included revising the worksheet to incorporate parameters addressing facility vulnerabilities to supplement the material form and packaging vulnerability parameters contained in the original worksheet. The results of the Material Handling and Transportation Vulnerability scoring indicated that these metrics provided little discrimination among baseline versus alternative disposition pathways. The Material Handling Vulnerability parameters were too generic to provide useful information. Insufficient information was available regarding packaging containers and numbers of intersite shipments of materials to enable effective use of the Transportation Vulnerability screen.

INTRODUCTION

The Nuclear Materials Integration Project (NMI) was chartered to identify DOE's nuclear material inventories; to determine disposition pathways for excess nuclear materials that are under the control of or of interest to DOE-EM; to evaluate the programmatic risks associated with these plans; and to identify opportunities for program improvement and cost savings.

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METHODOLOGY

The methodology developed to assess ES&H risk needed to be consistent in format with the Disposition Path Maturity, Programmatic Risk, and Life-Cycle Cost assessments that were concurrently conducted on the NMI material disposition pathways. Given the large number of pathways to consider for each category of materials, and the need to address multiple functions per pathway, an attempt was made to use simple factors, for which information was likely to be readily available, as surrogate indicators of potential risk. Finally, the approach was based on the large amount of work on nuclear materials already conducted by DOE-EH in the preparation of ES&H vulnerability studies for spent fuel (DOE 1993), plutonium (DOE 1994), and HEU (DOE 1996).

The DOE-EH studies used the "Target-Barrier-Hazard Analysis" approach, which evaluated the likelihood of breakdown of the barriers that protect workers, the public, and the environment from exposure to nuclear materials during routine operations and accidents. Barriers include packaging and containers of materials, facilities and all engineering safety features, and facility management and administrative controls. These studies evaluated three receptor groups (EH called them targets): facility workers, the public, and the environment. ES&H vulnerabilities were categorized as material/packaging, facility condition, and institutional/administrative.

The findings of the spent fuel study were (1) that the vulnerabilities identified predominantly affect workers and the environment; the potential for significant negative impacts to the public was much less likely and (2) the predominant adverse condition for spent fuel is the actual or potential loss of barriers leading to the release of radiological materials.

The findings of the plutonium study were: (1) that the vulnerabilities identified were of highest significance to workers; and (2) that material/packaging vulnerabilities were the most important type for plutonium.

The findings of the HEU study were: (1) that the vulnerabilities identified pose the most significant hazards to workers; the potentials for impacts on the public and the environment were much less serious due to effective safety barriers and distance between the public and the facilities; and (2) facility condition vulnerabilities were the most important type for HEU.

Vulnerability Categories and Criteria Factors

Of the three categories of vulnerabilities identified in the DOE-EH nuclear material studies (material/packaging, facility condition, and institutional/administrative), material/packaging vulnerability factors were used as ES&H risk screening criteria for the NMI project. The facility condition vulnerability factors (e.g., facility structural integrity, safety systems status) and institutional vulnerability factors (e.g., authorization basis status, personnel training and qualification status) were addressed in the NMI Disposition Path Maturity assessment screening process.

The Material Vulnerability Category included five factors: material characterization; package integrity/condition; material form; mass of material; and material toxicity. For each factor, a description was provided of relatively lower vulnerability and relatively higher vulnerability conditions.

Worker ES&H vulnerability was expected to be influenced by the three factors described in the Handling Vulnerability Category. These include factors for: radiological hazard potential; non-radiological hazard potential; and material handling frequency.

In addition, public ES&H vulnerability from the routine stabilization and disposition of nuclear materials was expected to be driven by transportation vulnerabilities. The Transportation Vulnerability Category contained a single factor that considered whether offsite shipment of nuclear materials will occur. This factor is based on the potential physical trauma related to truck accidents, rather than on radiological exposure. On a national average basis, a physical trauma fatality resulting from a transportation accident is expected to occur every 2.5 million miles of truck travel, irrespective of the cargo shipped. This figure is very conservative, given the expected much lower incidence of shipping accidents for shipments of nuclear materials.

Material Current State ES&H Vulnerability Screen

Material Current State Vulnerability (MCSV) is *qualitatively* characterized as High, Medium, or Low based on the scores for Factors 1 through 5 on the MCSV Worksheet, as follows:

Factors 1-5 — Material Current State Vulnerability is Low if:
- Scores for Factors 1-3 are 1 (irrespective of scores for Factors 4 & 5)

Factors 1-5 — Material Current State Vulnerability is High if:
- Scores for Factors 1 and 2 are 2 and Factor 3 are 2 or 3 ***AND***
- Scores for Factor 4 are 2 or 3 *OR* Score for Factor 5 is 3

Factors 1-5 — Material Current State Vulnerability is Medium:
- for all other combinations of Factor scores

Disposition Pathway ES&H Vulnerability Screens

For comparison of baseline and alternative disposition pathways, ES&H vulnerability metrics are:

Handling Vulnerability = sum of scores of Factors 6, 7 & 8 on the Disposition Pathway Vulnerability Worksheet

Transportation Vulnerability = score of Factor 9 on the Disposition Pathway Vulnerability Worksheet

ES&H vulnerability scores were estimated for each disposition pathway. Guidance provided to the NMI Material Evaluation Teams suggested consideration of the entire disposition pathway in developing scores for Material Handling Vulnerability Factors 6 through 8 and Transportation Vulnerability Factor 9. The overall pathway Material Handling Vulnerability score is the sum of the scores for Factors 6 through 9. The pathway Transportation Vulnerability score is the score for Factor 9. These scores were used to compare baseline disposition pathways with alternative pathways.

Samples of the ES&H Material Current State Vulnerability Screening Worksheet and the ES&H Disposition Pathway Vulnerability Screening Worksheet are as follows:

ES&H MATERIAL CURRENT STATE VULNERABILITY SCREENING WORKSHEET

Material Stream ID: **Material Stream Name:**	**Factor Score**	**Material Current State Vulner-ability**
1. Material Characterization Factor • material well characterized; packages accurately labeled, including material limits and spacing requirements – 1 • Material not well characterized; missing or inaccurate labels, unknown or uncharacterized material or packaging – 2	1 or 2	
2. Package Integrity/Condition Factor • Packages intact and unlikely to be breached during handling accidents - 1 • Deficiency or degradation of package or container due to aging, corrosion, radiolytic damage, pressurization; package breach during handling accidents likely – 2	1 or 2	
3. Material Form Factor • Material is a metal or solid with low leak, spill, dispersion potential - 1 • Material is in a powder, oxide, or particulate form (e.g., ash) with intermediate leak, spill, dispersion potential – 2 • material is a liquid or gas with high leak, spill, dispersion potential – 3	1, 2 or 3	
4. Mass of Material Factor • Amount of material $\leq$1 g – 1 • Amount of material >1 g < 1 metric ton - 2 • Amount of material >1 metric ton - 3	1, 2, or 3	
5. Material Toxicity Factor • Radioisotope-specific DAC exponent range 10^{-1} to 10^{-4} - 1 • Radioisotope-specific DAC exponent range 10^{-5} to 10^{-9} - 2 • Radioisotope-specific DAC exponent range 10^{-10} to 10^{-13} – 3	1, 2 or 3	H, M, or L

Material Current State Vulnerability:

LOW — if scores for Factors 1-3 are 1 (irrespective of scores for Factors 4 and 5), Material Current State Vulnerability is Low

HIGH — if: (a) scores for Factor 1 & 2 are 2 and scores for Factor 3 are 2 or 3;

AND

(b) scores for Factor 4 are 2 or 3 ***OR*** score for Factor 5 is 3, Material Current State Vulnerability is High

MEDIUM — Material Current State Vulnerability for all other combinations of scores is Medium

ES&H DISPOSITION PATHWAY VULNERABILITY SCREENING WORKSHEET

Material Stream ID: **Material Stream Name:**	**Factor Score**	**Category Score**
Material Handling Vulnerability Category		
6. Radiological Hazard Potential Factor • contact-handled processing - 1 • remote-handled processing – 2	1 or 2	
7. Non-radiological Hazard Potential Factor • non-energetic process; no hazardous chemicals – 1 • energetic process; hazardous chemicals – 2	1 or 2	
8. Material Handling Frequency Factor • handling related to storage functions only – 1 • handling related to storage and processing functions, ***OR*** storage and intersite transfer functions, ***OR*** processing and intersite transfer functions - 2 • handling related to storage, processing, ***AND*** intersite transfer functions - 3	1, 2 or 3	Sum
Transportation Vulnerability Category		
9. Material Shipment Factor **Option A - if information is *insufficient* to estimate number of truck shipments, use following:** • intrasite transfer of material for storage or processing - 1 • intersite transfer of material for storage or processing - 2 **Option B - if information is *sufficient* to estimate number of truck shipments, use following:** • no intersite transfer of material for storage or processing - 1 • intersite transfer of material - total number of truck shipments **x** number of round-trip miles per shipment = <2.5 million miles - 2 • intersite transfer of material - total number of truck shipments **x** number of round-trip miles per shipment = ≥2.5 million miles – 3		1, 2, or 3

RESULTS

In November 1998, CRE was invited to participate in a review of the results of NMI Phase I activities. At the NMI Lessons Learned Meeting held in Las Vegas, NV, CRE presented the results of the ES&H vulnerability screening conducted by each of NMI's Material Evaluation Teams (MET). Analysis of the results of the screening process indicated that the Material Current State Vulnerability (MCSV) scores provided some discrimination of materials into high, medium, and low categories. The distribution of MCSV scores among the categories is summarized below for each MET:

	MCSV Score		
Material Evaluation Team	**Low**	**Medium**	**High**
Transuranic Team (based on 95 material pathways)	35%	58%	4%
Uranium/Thorium Team (based on 226 material pathways)	55%	43%	2%
NISS Team (based on 40 generic material pathways)	98%	2%	--

A large number of material pathways were not scored for ES&H Vulnerability because insufficient information was available to apply the screens. Other findings of the results of Phase I activities for MCSV included problems with the use of the material toxicity factor for materials containing fission products, and problems with the decision criteria used to roll-up the individual parameter scores to develop the category (High, Medium, Low) scores. In addition, users of the MCSV worksheet suggested that the use of a larger range of pick list choices for each parameter might provide more resolution among the scores. Also, several comments were received about the need to consider adding other factors (e.g., criticality concerns) to the worksheet.

In general, the MCSV scores were seen to underestimate material vulnerability in comparison to other studies (e.g., DOE-EH vulnerability reports). CRE polled the participants at the Lessons Learned Meeting to obtain the team's opinions about the highest hazard materials.

The results of the Material Handling and Transportation Vulnerability scoring indicated that these metrics provided little discrimination among baseline versus alternative disposition pathways. The Material Handling Vulnerability parameters were not well defined; they were too generic to provide much useful information. Insufficient information was available regarding packaging containers and numbers of intersite shipments of materials to enable effective use of the Transportation Vulnerability screen.

NMI Phase II Activities

One of the action items from the NMI Lessons Learned Meeting was for CRE to form a team to investigate options for improving the ES&H vulnerability screening used in Phase I of NMI. This NMI ES&H Team was chaired by CRE and included representatives from each MET. The NMI ES&H Team met in Albuquerque, NM on February 1-2, 1999. The Team's charter from the NMI Integration Team was as follows:

The ES&H Team will recommend revisions to the Nuclear Materials Integration (NMI) Project ES&H Vulnerability Method to:

(1) enhance the ability of the Material Current State Vulnerability Factor to qualitatively screen all types of nuclear materials of interest to NMI and differentiate high, medium, and low risk materials;
(2) develop a Material Handling Vulnerability Factor that will provide useful qualitative screening level information about potential worker risk for baseline versus alternative disposition pathways; and
(3) develop a strategy for addressing potential transportation risk for baseline versus alternative disposition pathways.

In addition, the ES&H Team will identify a path forward for implementation of the recommendations.

The ES&H Team considered the results of the expert opinion poll conducted during the NMI Lessons Learned Meeting during their discussions on the MCSV Factor. At the conclusion of the meeting, the ES&H Team recommended the following revisions to NMI ES&H Vulnerability Method:

1. Revise the Material Current State Vulnerability Factor to incorporate parameters addressing facility vulnerabilities to supplement the material form and packaging vulnerability parameters contained in the original worksheet. The revisions should provide better estimates of current state risk, and, therefore, be more useful in efforts to triage nuclear materials based on their need for priority management.
2. Drop the Material Handling Vulnerability Factor screen. The Team felt that it may be better to develop quantitative estimates of risk for specific scenarios (e.g., Trade Studies), rather than attempting to develop qualitative estimates for all materials and pathways, particularly when some disposition pathways are undefined.
3. Drop the Transportation Vulnerability Factor screen. The Team felt that attempts to qualitatively screen transportation risks are not appropriate at this time, given the uncertainty in disposition pathways and in a number of important transportation parameters (e.g., shipping containers).

Revised Material Current State Vulnerability Screen

The revised Material Current State Vulnerability worksheet is shown on the next page. Revisions include providing a greater range of options for each factor; the addition of several factors to address potential facility vulnerabilities; and the lack of an a priori decision metric for rolling up factor scores into overall High, Medium, and Low MCSV scores. Instead of a decision metric, CRE recommends that a factor analysis approach be used to identify High, Medium, and Low MCSV scores from the individual factor scores. For example, the worksheet includes material-related factors (Factors 1-4); container-related factors (Factors 5-6); and facility-related factors (Factors 7-10). The individual factor scores can be composited into a materials score, a container score, and a facility score. These scores can then be graphed in a three-dimensional space, and the breaks in the graph will indicate clusters of High, Medium, or Low MCSV scores.

REVISED NMI MATERIAL CURRENT STATE VULNERABILITY WORKSHEET

Material Stream ID: **Material Stream Name:**	**Factor Score**
Material Characterization Factor • Material well characterized; packages accurately labeled, including material limits and spacing requirements = **1** • Material not well characterized (missing or inaccurate labels, unknown or uncharacterized material or packaging), but process knowledge available; **Material Internal Energy Factor** <2 = **2** • Material not well characterized; missing or inaccurate labels, unknown or uncharacterized material or packaging; **Material Internal Energy Factor** $\geq$2 = **3**	1, 2 or 3
Material Internal Energy Factor • Material is not reactive = **1** • Material has chemical/corrosion/pressurization potential = **2** • Material has criticality or hydrogen generation potential = **3**	1, 2, or 3
Material Dispersion Factor • Material is in ceramic form = **1** • Material is a metal or solid with low leak, spill, dispersion potential = **2** • Material is a powder, oxide, or particulate (e.g., ash) with intermediate leak, spill, dispersion potential = **3** • Material is a liquid or gas with high leak, spill, dispersion potential = **4**	1, 2, 3 or 4
Source Term Factor • Number of items = • Curies per item = • Total curies = • Inhalation dose equivalents =	Dose Equivalents
Container Design Factor • Containers comply with approved national standards = **1** • Containers <20 years old = **2** • Containers >20 years old = **3** • Confinement only by facility systems or structures = **4**	1, 2, 3, or 4
Container Condition Factor • Containers in good condition = **1** • Containers degraded/deformed = **2** • Containers breached/material unconfined = **3**	1, 2 or 3
Facility Integrity Factor (Structure, HVAC, Safety & Support Systems) • Post-Cold War, DBE design w/paperwork (1970s-1990s) = **1** • Mid-Cold War, or upgraded 1950s design, UBC w/records = **2** • Initial Cold War design (1940s-1970s) = **3**	1, 2, or 3
Number of Facility Barriers • 3 barriers = **1** • 2 barriers = **2** • 1 barrier = **3**	1, 2 or 3
Facility Operational Status • Minimal exposure (<1R total annual facility exposure) = **1** • Moderate exposure (1-5 R total annual facility exposure) = **2** • High exposure (>5 R total annual facility exposure) = **3**	1, 2, or 3
Facility Location Factor • Distance to fenceline (km) =	kms

CRE recommends that the revised MCSV Worksheet be used by the METs to complete screening of the NMI material pathways that were labeled TBD (To Be Determined) at the end of Phase I activities. Additional information may need to be obtained through site visits/contacts to enable the new factors to be addressed.

Members of the CRE Support Team provided an independent review of these recommendations. One of the peer reviewers suggested rescoring 10-20% of NMI materials using the revised MCSV worksheet to determine if significant differences in rankings are obtained. The results of this analysis could then be used to determine the need to rescreen all materials.

CONCLUSION AND RECOMMENDATIONS

The Nuclear Materials Integration Project (NMI) is developing disposition pathways for excess nuclear materials that are under the control of or of interest to DOE-EM. ES&H risk screening, along with process technical maturity, cost, and programmatic risk considerations, can help identify materials in need of priority attention for stabilization activities, as well as help identify preferences among baseline and alternative material disposition pathways.

This study demonstrated that the use of worksheets is an effective and transparent way to document expert opinion. Ideally, the worksheets should be simple enough to be applied to a wide variety and large number of materials, address information at a level of detail that is likely to be readily available, and seamlessly integrate with the other types of screening (e.g., technical maturity, programmatic risk) being concurrently conducted.

The ES&H risk screening conducted for NMI was somewhat successful. The Material Current State Vulnerability (MCSV) Screen, which attempted to address the triage of materials in their current condition into high, medium, and low categories for priority attention for stabilization actions, provided some discrimination. The Material Handling and Transportation Vulnerability Screens addressed potential differences in worker and public risks, respectively, among baseline versus alternative disposition pathways. The results of the Material Handling and Transportation Vulnerability scoring indicated that these metrics provided little discrimination among baseline versus alternative disposition pathways.

CRE recommends that the updated MCSV screening be implemented to provide improved estimates of potential current state vulnerability. Since nuclear materials management currently has more programmatic uncertainty than, for example, its waste management counterpart, risk indicators, like hazard, are appropriate criteria for planning and preliminary decision making. As the nuclear materials stewardship program commences preparation of specific trade studies to choose among multiple candidate disposition pathways, more traditional risk assessment methods can be applied. The CRE has developed a guidance document and a case study that describe and demonstrate a process. Both are available from the Center.

REFERENCES

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