BNL-63759

CONF-970437--1

A PERFORMANCE INDICATOR FOR REDUCTION IN VULNERABILITY THROUGH STABILIZATION OF PLUTONIUM*

A.R. Marchese
United States Department of Energy
19901 Germantown Road
Germantown, MD 20874-1290
Fax: 1-301-903-2329

P. Neogy and M.A. Azarm
Department of Advanced Technology
Brookhaven National Laboratory
P.O. Box 5000
Upton, N.Y. 11973-5000
Fax: 1-516-344-5730

ABSTRACT

An approach to measuring and tracking the reduction in vulnerabilities resulting from stabilizing and repackaging plutonium is developed and presented. The approach utilizes results obtained by the DOE Working Group on the vulnerabilities associated with plutonium storage.

INTRODUCTION

The U.S. Department of Energy (DOE) is currently storing several metric tons of plutonium in various forms in a variety of facilities throughout the DOE complex. Since the cessation of weapons production in 1990, many of these facilities with plutonium in storage have not operated. Since the shutdown was regarded as temporary, little attempt was made at that time to empty the process lines of plutonium, or to place the plutonium in containers or packages that would provide safe storage for extended periods of time. As a result, the packages and containers providing interim storage are vulnerable to failure through leakage, rupture and other modes, and pose potential hazards to facility workers, the public and the environment. In November 1994, the DOE Office of Environment, Safety and Health published a Working Group Report[1] on the vulnerabilities associated with plutonium storage. The DOE Office of Environmental Management published a Plutonium Vulnerability Management Plan[2] in March 1995 to respond to the vulnerabilities identified in the Working Group Report. The purpose of this paper is to present an approach by which the reduction in vulnerabilities brought about by stabilization and repackaging of plutonium can be measured and tracked.

PLUTONIUM WORKING GROUP REPORT

The Plutonium Working Group comprised over 150 staff and managers from DOE headquarters, site and operations offices, and operations contractors including experts in plutonium chemistry, metallurgy, nuclear criticality, health physics and safety analysis. The Working Group assessed 166 facilities at 35 sites utilizing a "target-barrier-hazard analysis" methodology. This methodology identified accident scenarios associated with the stored plutonium, and classified the vulnerabilities based on the estimated likelihoods and consequences of the accident scenarios. The consequences were estimated for the worker population, the public and the environment. The consequences to the workers and the public were estimated in terms of the potential radiological doses, while the consequences to the environment were estimated in terms of the radiological contamination. The "target-barrier-hazard analysis" methodology, therefore, provided point estimates of risk arrived at mainly through expert judgment. In this paper, for consistency, we refer to this point estimate of risk as the "vulnerability" associated with a given accident scenario.

*This work was supported by the U.S. Department of Energy under Contract DE-AC02-76CH00016.

PERFORMANCE INDICATORS FOR REDUCTION IN VULNERABILITY

Measures of the reduction in vulnerability due to stabilization of plutonium can be developed and tracked by (1) utilizing the site and facility specific vulnerabilities identified and evaluated in the Working Group Report, (2) utilizing information on inventories of Pu being stabilized as reflected in databases such as the "Critical Few" database, the NIMIS database, etc., and (3) formulating a process and a set of rules that relate the inventory of plutonium stabilized to corresponding reductions in vulnerability. The model for estimating reductions in vulnerability is described below.

The following set of indices will be utilized to denote a site, a facility, form of Pu being stabilized, and vulnerability scenario being assessed:

Site Index: "s"
Facility Index: "i"
Pu Form Index: "j" (liquid, metal, oxide, residue, etc.)
Scenario Index: "k" (as defined in the Working Group Report).

Let m_{ij} be the total amount of Pu of form "j" to be stabilized at the facility "i", let m'_{ij} be the amount of Pu of form "j" at the facility "i" stabilized at any point in time, and let f_{ij} be the fraction of the total inventory stabilized at the same point in time, then

$$m_{ij}' = f_{ij} \times m_{ij} \quad (2)$$

Let Δv_{ijk} be the change in vulnerability for scenario "k", Pu form "j", at facility "i" after complete stabilization. Then

$$\Delta v_{ijk} = v_{ijk}^{\text{final}} - v_{ijk}^{\text{initial}} \quad (2)$$

where v_{ijk}^{initial} is the vulnerability evaluated in the Working Group Report, and v_{ijk}^{final} is the vulnerability corresponding to the same material after stabilization.

At any point in time, the change in vulnerability is given by

$$\Delta v_{ijk}' = v_{ijk}^{\text{intermediate}} - v_{ijk}^{\text{initial}}, \quad (3)$$

$$= f_{ij} \times \Delta v_{ijk}, \quad (4)$$

where $v_{ijk}^{\text{intermediate}}$ is the vulnerability associated with the material at the given point in time.

Equation (4) constitutes the first of the set of rules necessary to evaluate a Performance Indicator (PI), namely, *the change in vulnerability at any point in time can be scaled to the total change in vulnerability after stabilization by the fraction of the total inventory stabilized.*

The change in vulnerability at a facility "i" at any point in time is determined by summing over the scenarios "k" and the Pu forms "j",

$$\Delta V_i' = \Sigma_j \Sigma_k f_{ij} \times \Delta v_{ijk} \quad (5)$$

The change in vulnerability at a facility "i" after stabilization is complete is given by:

$$\Delta V_i = \Sigma_j \Sigma_k \Delta v_{ijk} \quad (6)$$

A Performance Indicator for the facility "i" can now be defined as:

$$(PI)_i = (\Delta V_i' / \Delta V_i) \quad (7)$$

Note that the PI defined in Equation (9) will generally assume values ≤ 1.0, and will have a value 1.0 when stabilization is complete.

Similarly, PIs for a site and for the complex can be defined as:

$$(PI)_s = \Sigma_i \Sigma_j \Sigma_k f_{ij} \times \Delta v_{ijk} / \Sigma_i \Sigma_j \Sigma_k \Delta v_{ijk} \quad (8)$$

and,

$$(PI)_c = \Sigma_s \Sigma_i \Sigma_j \Sigma_k f_{ij} \times \Delta v_{ijk} / \Sigma_s \Sigma_i \Sigma_j \Sigma_k \Delta v_{ijk} \quad (9)$$

As with $(PI)_i$, $(PI)_s$ and $(PI)_c$ will generally have values ≤ 1.0 until all material is stabilized, when they will assume a value of 1.0.

EVALUATION OF PERFORMANCE INDICATORS

In order to evaluate the Performance Indicators, it is necessary to consider the process by which plutonium is stabilized. Pu exists at the facilities either as Pu solution or as Pu metal or oxide. Low assay Pu metal or oxide (typically less than 50%) is often referred to as "residue". Pu solution will be processed

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(purified, precipitated, calcined, repackaged, etc.) to yield metal and oxide in safe interim storage. The purified Pu solution may also be stored in double shell waste tanks. Pu metal and oxide will undergo processing (calcination, thermal stabilization, repackaging, etc.) to yield metal and oxide in safe interim storage. A schematic of the processing of Pu solution and metal and oxides is presented in Figure 1. The vulnerabilities associated with Pu in the initial form are defined in the Working Group Report (indicated by v(a,b) in the schematic, the quantities "a" and "b" indicating the levels of likelihood and consequence, respectively). Likelihoods and consequences are characterized as "high," "medium," and "low" in the Working Group Report as indicated in Table 1, and adopted in this paper.

The vulnerabilities associated with material being processed, and those associated with stabilized material have not been defined yet. The second of the set of rules is now proposed as follows: *The vulnerability associated with stabilized material is characterized as v(low, low).* Assigning a v(low,low) characterization to stabilized material is generally consistent with the objectives and criteria of safe interim storage. However, the characterization of the consequence associated with stabilized material as "low" is still provisional, and subject to future revision. An alternate assignment for the stabilized material could be a consequence category one lower than that for the original material. Assigning vulnerability characteristics to material undergoing processing is more difficult since these vulnerabilities were not studied by the Working Group. It may be more appropriate to characterize the short term fluctuations in vulnerability due to stabilization in a separate and specific hazard and risk analysis of the stabilization process. In which case it would be possible to disregard the short term fluctuations in vulnerability due to material undergoing processing for the purposes of this study. The v(low,low) characterization can then be assigned to material as soon as it enters processing for safe interim storage. If material moves from one facility to another for safe interim storage, then the corresponding vulnerabilities also move from the first facility to the second and are appropriately accounted for. This is fairly straightforward if we restrict ourselves to material and packaging vulnerabilities (which dominate) and disregard facility condition and institutional vulnerabilities for purposes of this study.

Table 1 Likelihood and Consequence Characterizations

Characterization	Low	Medium	High
Likelihood	Once in 5-50 yrs	Once in 2-5 yrs	Once in 0-2 yrs
Consequence (Worker)	Dose between 0.005 and 5 rem CEDE	Dose between 5 and 50 rem CEDE	Dose greater than 50 rem CEDE
Consequence (Public)	Dose between 0.001 and 0.1 rem CEDE	Dose between 0.1 and 1 rem CEDE	Dose greater than 1 rem CEDE
Consequence (Environment)	On-site contamination between 10 and 33 dps/m^2	On-site contamination greater than 33 dps/m^2 and off-site contamination between 10 and 33 dps/m^2	Off-site contamination greater than 33 dps/m^2

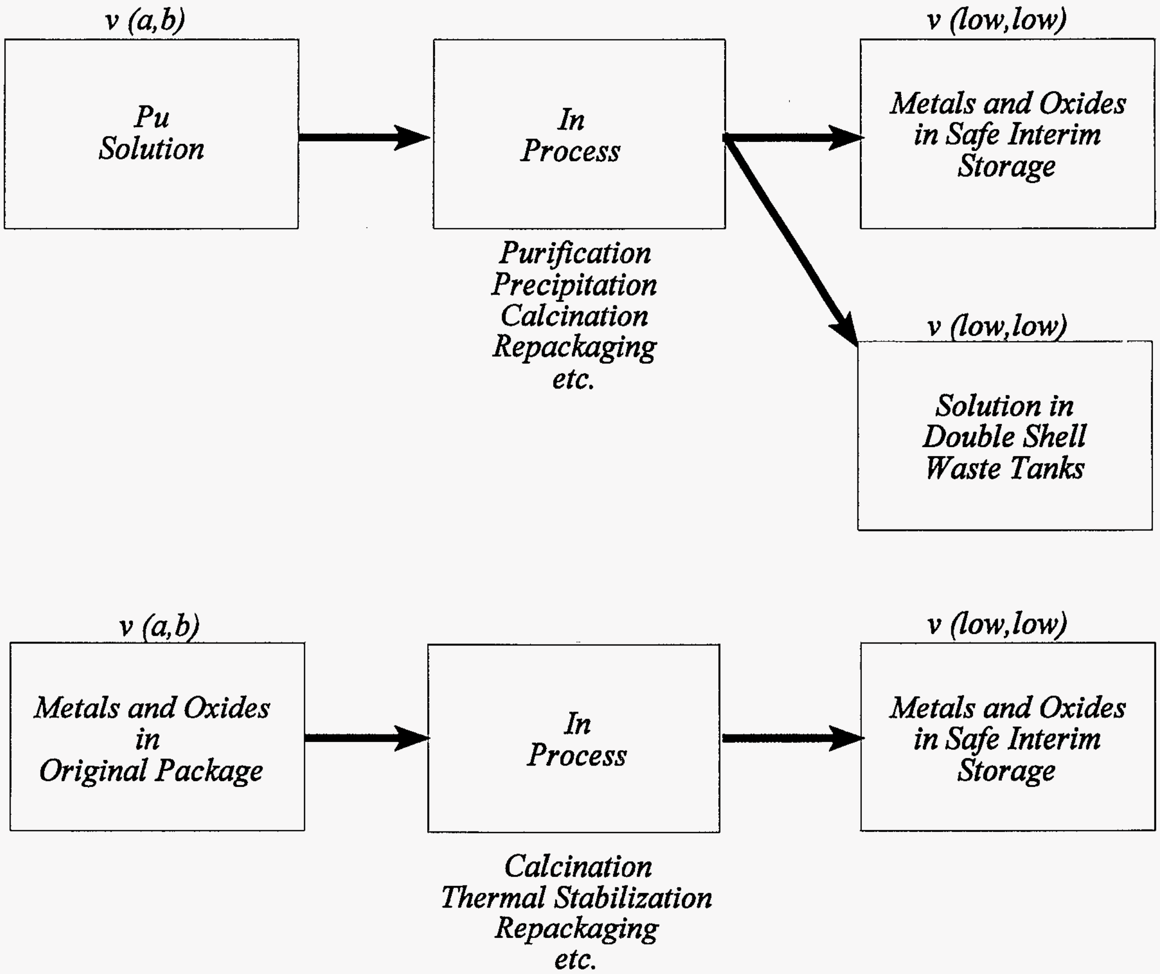

Figure 1. Schematic of processing of Pu materials (see text for explanation)

ILLUSTRATION OF METHODOLOGY

As an illustration of the methodology, the reductions in vulnerability brought about by stabilization of various forms of plutonium at a DOE facility were calculated and are presented in Figure 2. Reductions in vulnerability were determined for different fractions of inventory stabilized (f_j), and are presented as the quantity ($\Sigma_k f_j \times \Delta v_{jk}$) as a function of f_j, with the normalization $\Sigma_j \Sigma_k \Delta v_{jk} = 1.0$, the quantity v_{jk} referring to worker vulnerabilities. For the facility in question, low assay plutonium oxides and metals (residue) make the largest contribution to the total vulnerability, metals and oxides above 50% assay make the next largest contribution, while solutions make the smallest contribution. These results provide a straightforward means of prioritizing repackaging and stabilizing activities at the facility in question if reducing vulnerabilities is the main criterion for scheduling these activities. If the stabilization fractions, f_j, are available as functions of time, then the methodology also provides a direct means of tracking the reduction in vulnerabilities with time.

CONCLUSIONS

A methodology for measuring and tracking the reduction in vulnerability resulting from stabilizing and repackaging plutonium has been developed. The methodology makes use of the extensive results obtained by the DOE Working Group, and thereby promotes efficient and consistent monitoring of vulnerability reductions brought about by plutonium stabilization efforts. The methodology could be easily extended to develop metrics such as vulnerability reduction per unit inventory stabilized, or vulnerability reduction per unit cost.

REFERENCES

1. Plutonium Working Group Report on Environmental, Safety and Health Vulnerabilities Associated with the Department's Plutonium Storage, U.S. Department of Energy, November 1994 (DOE/EH-0415).

2. Plutonium Vulnerability Management Plan, U.S. Department of Energy, March 1995 (DOE/EM-0199).

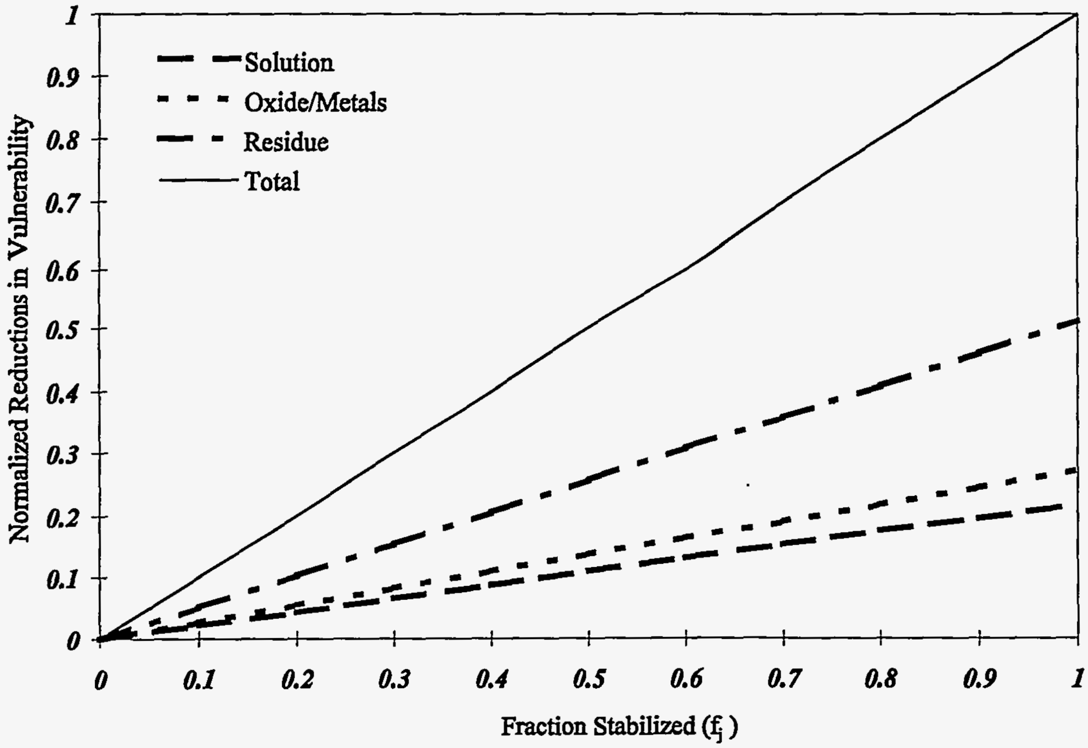

Figure 2. Normalized reductions in vulnerability as functions of inventory stabilized (see text for explanation).