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Plutonium-238 Decision Analysis

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ABSTRACT

Five transuranic (TRU) waste sites in the Department of Energy (DOE) complex, collectively, have more than 2,100 cubic meters of Plutonium-238 (Pu-238) TRU waste that exceed the wattage restrictions of the Transuranic Package Transporter-II (TRUPACT-II). The Waste Isolation Pilot Plant (WIPP) is being developed by the DOE as a repository for TRU waste. With the Waste Isolation Pilot Plant (WIPP) opening in 1999, these sites are faced with a need to develop waste management practices that will enable the transportation of Pu-238 TRU waste to WIPP for disposal. This paper describes a decision analysis that provided a logical framework for addressing the Pu-238 TRU waste issue. The insights that can be gained by performing a formalized decision analysis are multifold. First and foremost, the very process of formulating a decision tree forces the decision maker into structured, logical thinking where alternatives can be evaluated one against the other using a uniform set of criteria. In the process of developing the decision tree for transportation of Pu-238 TRU waste, several alternatives were eliminated and the logical order for decision making was discovered. Moreover, the key areas of uncertainty for proposed alternatives were identified and quantified. The decision analysis showed that the DOE can employ a combination approach where they will 1) use headspace gas analyses to show that a fraction of the Pu-238 TRU waste drums are no longer generating hydrogen gas and can be shipped to WIPP "as-is," 2) use drums and bags with advanced filter systems to repackage Pu-238 TRU waste drums that are still generating hydrogen, and 3) add hydrogen getter materials to the inner containment vessel of the TRUPACT-II to relieve the build-up of hydrogen gas during transportation of the Pu-238 TRU waste drums.

INTRODUCTION

The Transuranic Package Transporter-II (TRUPACT-II) has been designed and selected as the Type B packaging to ship contact-handled transuranic (TRU) waste to the Waste Isolation Pilot Plant (WIPP) [1]. Payload criteria, established pursuant to the Certificate of Compliance issued by the U.S. Nuclear Regulatory Commission (NRC), constrain the U.S. Department of Energy's (DOE) ability to ship much of its heat-source plutonium-238 (Pu-238) TRU waste. The TRUPACT-II payload criterion of primary concern is the decay heat (wattage) limit. This criterion requires that waste packages meet the decay heat limits contained in the TRUPACT-II Content Codes [2]. Decay heat (wattage) limits are calculated values selected to ensure that the

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concentration of hydrogen in any layer of confinement in a payload container does not exceed five percent during a maximum 60-day shipping period.

Five DOE waste sites have an estimated 2,157 cubic meters, collectively, (approximately 10,373 drum equivalents) of Pu-238 TRU waste that exceed the wattage restrictions of the TRUPACT-II. These sites are faced with a need to develop waste management practices in the near term that will enable the transportation of Pu-238 TRU waste to the WIPP in a manner that is both cost effective and minimizes the number of shipments. The DOE must decide to what extent Pu-238 TRU waste should be repackaged or treated, or whether the DOE can establish sufficient technical bases that would enable the NRC to modify the TRUPACT-II payload restrictions.

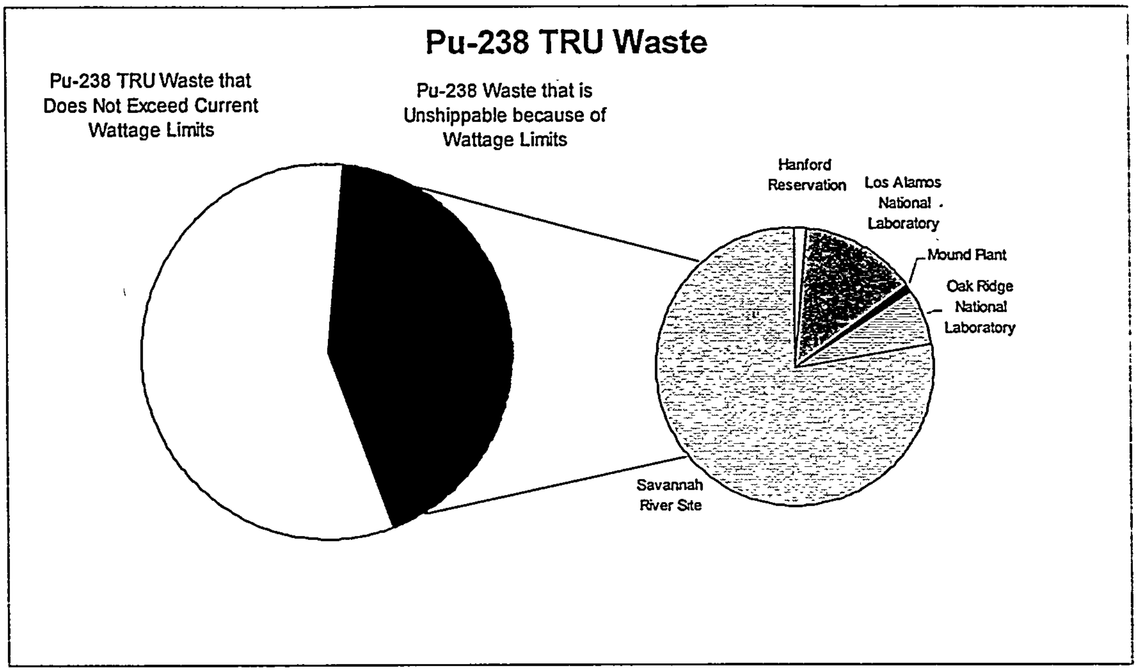

Figure 1. Pu-238 TRU Waste Volumes at DOE Generator Sites

To illustrate the magnitude of the decision to be made, the repackaging of the 2,157 cubic meters (10,373 drum equivalents) of waste to meet the current wattage limits would result in about 32,000 cubic meters (about 152,716 drum equivalents) of Pu-238 TRU waste to be shipped[1]. This would require 20 percent of the WIPP's contact-handled TRU waste capacity of 168,500 cubic meters to accommodate the disposal of Pu-238 TRU waste. It also would require 50 percent of the shipping resources allotted for contact-handled TRU waste in *The National TRU Waste Management Plan, Revision 1* [3], while the pre-packaged volume (2,157 cubic meters) is now only 5 percent of the total stored contact-handled-TRU waste volume.

For these reasons, **the issue of concern** can be stated as:

> **What are the most appropriate means for the DOE Complex to manage Pu-238 TRU waste, thus enabling the efficient transportation to the WIPP?**

TECHNICAL APPROACH

Decision analysis was selected as the tool to address this issue. Decision analysis is a method that provides a logical framework for addressing complex problems and provides the decision maker with a quantitative means to evaluate the merits of decisions in light of the technical and regulatory uncertainties inherent in any decision.

The decision analysis process to assess the Pu-238 TRU waste problem included the following steps:

1. **identification of strategic decisions** that could lead to the improved management of Pu-238 TRU waste. In this context, decisions involve strategies (alternatives) that are being, or have been, considered to alleviate the inefficiencies associated with the use of the TRUPACT-II for transporting Pu-238 TRU waste.

2. **identification of uncertainties** associated with those strategic decisions. Each of the strategic decisions has an associated uncertainty (e.g., degree of effectiveness, regulatory uncertainty) about the outcome of the decision. Uncertainties are quantified through the use of expert elicitation (judgment).

3. **compilation of the decision tree.** The decision tree is the strategy-by-strategy vehicle that links the decisions with their associated uncertainties in such a way as to enable analysis of a variety of outcomes. It provides the basis for the decision analysis model.

4. **definition of performance measures.** Performance measures are used to quantify the relative merits of each possible outcome of the decision tree. The performance measures include total system life-cycle cost, volume disposed of by 2006, and volume of "overflow" waste remaining at the sites.

5. **development of the decision analysis model.** The decision analysis model is the analytical tool used to quantify the possible outcomes of the decision tree in terms of the performance measures. Separate computational models for each performance measure are developed and linked to the decision tree for evaluation.

6. **data collection and expert elicitation.** Data collection involves the development of source information to support calculation of the individual performance measures. Data collection also includes development of background information needed to conduct expert elicitation. Expert elicitation focuses the professional judgment of subject matter experts to develop probability distributions that in turn are used to quantify the uncertainties in the decision tree.

7. **model analysis and results evaluation.** Once supporting information has been collected and the experts have been polled about the uncertainties in the decision tree, each strategy is evaluated in terms of the performance measures. Sensitivity analyses are run to

determine the key uncertainties in the decision tree, and expected values for the performance measures are calculated. The path with the best-expected outcome can be identified.

ALTERNATIVES ANALYZED

Five strategies (paths) to address the issue of concern were analyzed. Each strategy, if approved by the NRC, would either reduce the number of drums that would be generated during repackaging (Paths 1 and 5), or would increase the number of drums that could be shipped without further modification (Paths 2, 3, and 4):

- *Path 1* – The DOE petitions the NRC to allow hydrogen getter materials to be added to the headspace of the drums during repackaging.
- *Path 2* – The DOE petitions the NRC for a change in the wattage limits based on the results of matrix depletion and hydrogen generation studies.
- *Path 3* - The DOE petitions the NRC to allow the use of hydrogen headspace gas analysis as a method to certify containers for shipment in a TRUPACT-II, based on studies that demonstrate the relationship of hydrogen concentration in the headspace of the drum to the hydrogen concentration in the innermost layer of confinement.
- *Path 4* – The DOE petitions the NRC to allow the use of hydrogen getter materials in the inner containment vessel of the TRUPACT-II.
- *Path 5* - The DOE petitions the NRC to approve the use of advanced filters in the repackaging of all waste.

For each path, if the NRC denies the petition, a further decision is made to either treat[2] or repackage the Pu-238 TRU waste.

In addition, two alternatives that combine the benefits of various strategies are considered:

- *Combination 1* - A combination of matrix depletion (Path 2), getters in the inner containment vessel of the TRUPACT-II (Path 4), and repackaging with advanced filters (Path 5).

- *Combination 2* - A combination of matrix depletion, hydrogen headspace gas sampling (Path 3), getters in the inner containment vessel, and repackaging with advanced filters.

The decision analysis model used to evaluate each path, plus combinations of multiple paths, was composed of a waste volume model and a cost model. The waste volume model was based on a container-specific inventory provided by each of the five sites that store heat-source Pu-238 TRU waste. *The National TRU Waste Management Plan, Revision 1* [3], provided the underlying assumptions regarding each site's planned waste processing logic, shipping rates and durations. The cost model was based mainly on information provided by the Savannah River Site [4], Idaho National Engineering and Environmental Laboratory [5], and the Carlsbad Area Office [6].

RESULTS

Three performance measures were used to quantify the relative merits of the alternatives represented by the paths of the decision tree. These measures provide an index to compare the relative merits of the various paths. As such, they may not reflect the outcome if the DOE pursued a particular path. For example, the cost estimates may not be "accurate" because the assumptions may prove unrealistic, because certain activities are not considered, or because costs may vary among sites. However, the performance measures are constructed to enable a consistent comparison among the paths.

1. **Volume Disposed by 2006.** This measure is defined as the volume (55-gallon drum equivalents) of Pu-238 TRU waste that can be disposed of by the end of fiscal year 2006. This measure was chosen as a means to discriminate among the strategies by reflecting the time requirements to implement various technical solutions, and thus the ability to maximize disposal of the waste in the near-term. For example, the time to complete research programs and obtain NRC approval of the use of hydrogen getters when compared to the time to construct a thermal treatment facility affects the extent to which TRU waste can be disposed of by 2006 [7].

2. **Volume of "Overflow" Waste.** This measure is defined as the volume (55-gallon drum equivalents) of Pu-238 TRU waste that exceeds current projected shipping rate as stated in the *National TRU Waste Management Plan* [3]. The *National TRU Waste Management Plan* describes each site's planned waste processing logic, shipping rates, and durations. Only a fraction of the total waste shipments from each site (proportional to the volume fraction of Pu-238 TRU waste) are available for shipping Pu-238 TRU waste. Strategies that produce relatively large volumes of Pu-238 TRU waste during processing will create an "overflow" volume that could not be shipped, given the current shipping assumptions of the *National TRU Waste Management Plan.*

3. **Total System Life-Cycle Cost.** This measure is defined as the entire suite of costs associated with the implementation of each strategy. Life-cycle costs (1998 dollars) were chosen as a means to discriminate among strategies, recognizing that costs are an important component of the decision-making process to allocate waste management funds. Thus, life-cycle costs include those associated with the conduct of each study (e.g., advanced filter research) and the NRC regulatory review process. Life-cycle costs also include those from the transport of Pu-238 TRU waste, and those from initial design through closure of repackaging and treatment facilities and their ancillary facilities (e.g., characterization and loading facilities).

Strategies for management of Pu-238 TRU waste have merit if relatively significant volumes of waste can be shipped "as is" by 2006, volume expansion is minimized upon repackaging or treatment, and total system life-cycle cost is minimized.

The merit of the five paths and two combinations is reported in this paper as the "median value." The "median value" is the value calculated assuming median values for all of the uncertainties in the decision tree. Here, the median value can give the reader an idea of the performance of an alternative without consideration of the probability of success.

Decision analysis also can provide the decision maker with a better understanding of the effect of all potential uncertainties involved with a decision and how those uncertainties affect the overall probability of success. A proposed management strategy for Pu-238 TRU waste may have outstanding technical merit (median value), but, if the combined technical and regulatory uncertainties are high, the probability of successfully implementing the strategy will be low. The probability of success hinges, therefore, on these uncertainties.

Expected value is a measure of both the benefit that can be derived from a strategy and the probability of success (i.e., technical and regulatory uncertainty) for that strategy. For each performance measure expected values are calculated for each branch and then summed. As an example, the expected value for the volume of Pu-238 TRU waste disposed of by 2006 is calculated as:

$$(DE)_{expected} = \Sigma_{branches}(DE) * p_t * p_r \qquad \text{Eq. 1}$$

where

$(DE)_{expected}$ = the expected value for drum equivalents disposed
(DE) = drum equivalents disposed following a branch in the decision tree
p_t = probability of technical success
p_r = probability of regulatory success

Figures 2, 3, and 4 show both the median value and expected value for each of the three performance measures. Each figure is organized with the "best" strategy (for that performance measure) on the top and the "worst" strategy (for that performance measure) on the bottom. The strategy employed for shipping drums "as is" to WIPP is annotated on the left hand side of each figure, and the repackaging or treatment strategy for the path is annotated on the right hand side of each figure.

Figure 2 shows the drums disposed by 2006. All of the paths that rely on the use of headspace gas measurements to certify drums for shipment have a median value of 3,600 drums disposed by 2006 and expected value of 2,100. The expected value is lower than the median value because of uncertainty about NRC approval of the new certification method. All paths that rely on matrix depletion/hydrogen generation studies to show that some Pu-238 TRU drums can be shipped "as is" have a median value of 1,338 drums disposed by 2006 and an expected value of 500. The NRC approval uncertainty has a larger impact in the expected value for these alternatives than it does on the first three alternatives because there is more uncertainty about NRC approval of matrix depletion/hydrogen generation results than about NRC approval of using headspace gas results to certify drums. The median value for the paths that rely on the use of hydrogen getters in the inner containment vessel so that the drums could be shipped "as is" is 277 and the expected value is 277.

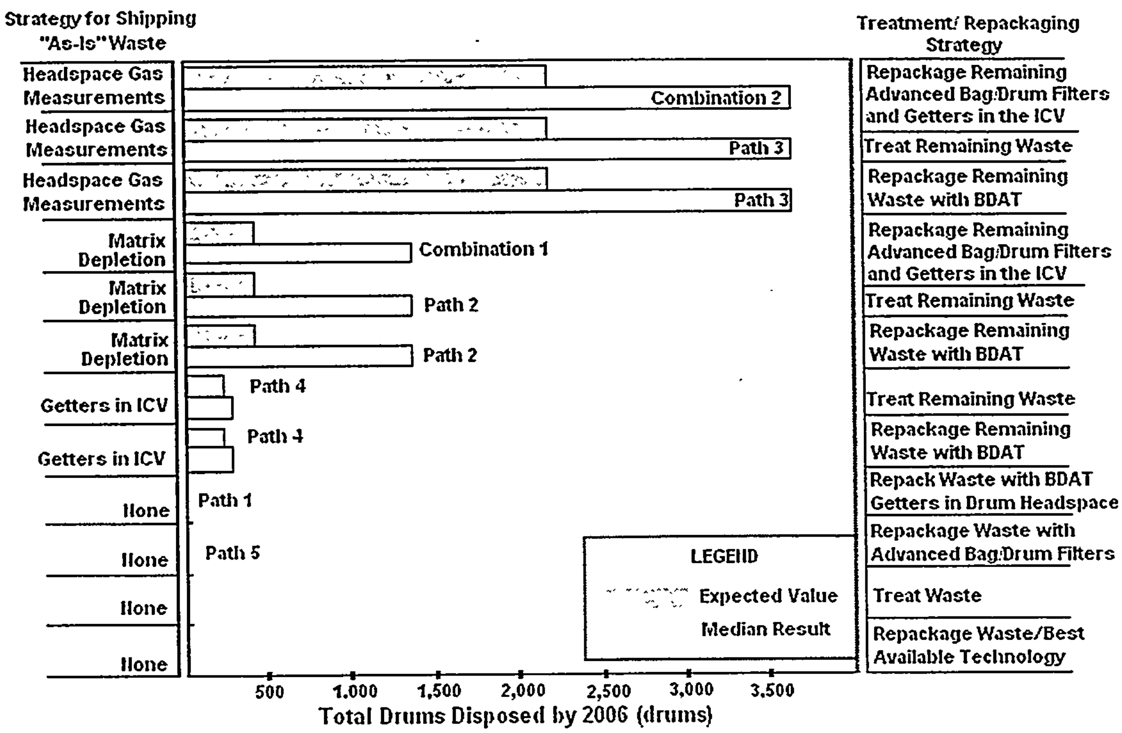

Figure 2. Total Drums Disposed by 2006 for Seven Alternatives Considered

Figure 3 shows the percent of allotted shipping resources required for Pu-238 TRU waste for each of the alternatives. Any alternative that involves repackaging requires greater than 100% of the allotted shipping resources. Only the alternatives that involve treatment requires less than 100% of the allotted shipping resources. The combination alternatives are the best repackaging alternatives and come close to producing results as beneficial as treatment. The discrepancy between the median value and the expected value for the two combination scenarios is due to uncertainty about NRC approval of placing getters in the inner containment vessel and NRC approval of advanced bag/drum filters.

Figure 4 shows the life-cycle cost of each of the alternatives. Any alternative that involves repackaging is less expensive than an alternative that involves treatment. Alternatives that involve repackaging with the best available technology are the most cost effective. Using advanced bag/drum filters or hydrogen getters increases the cost.

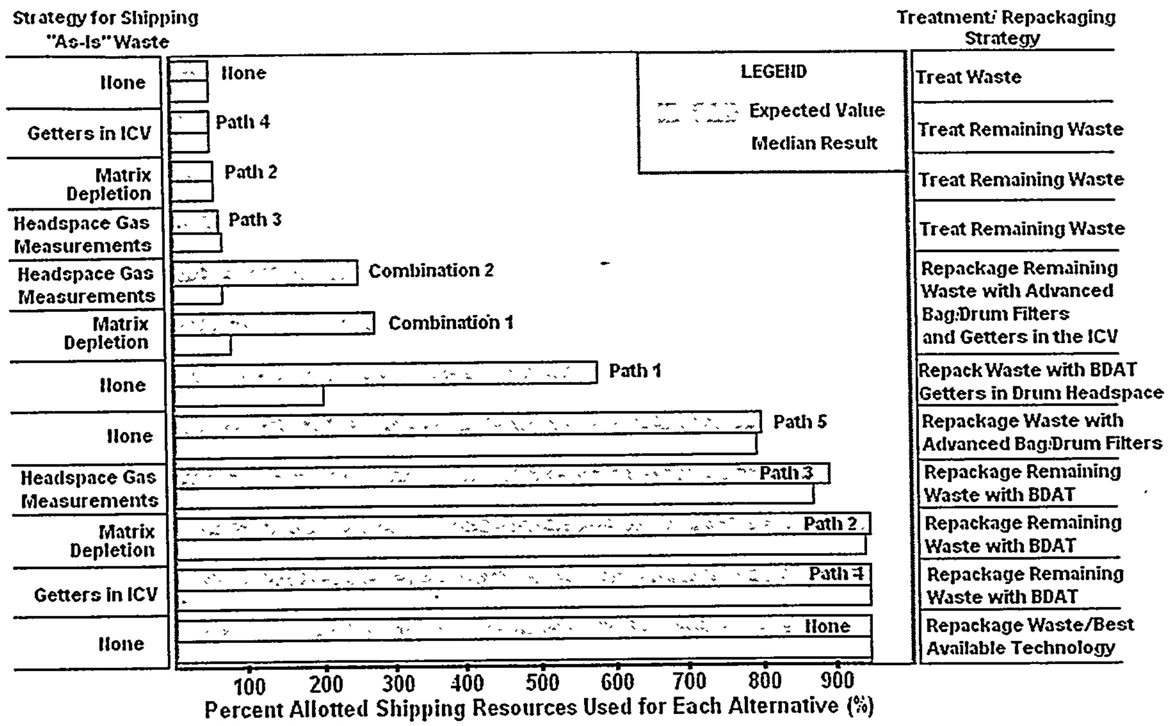

Figure 3. Percent Allotted Shipping Resources Used for Seven Alternatives

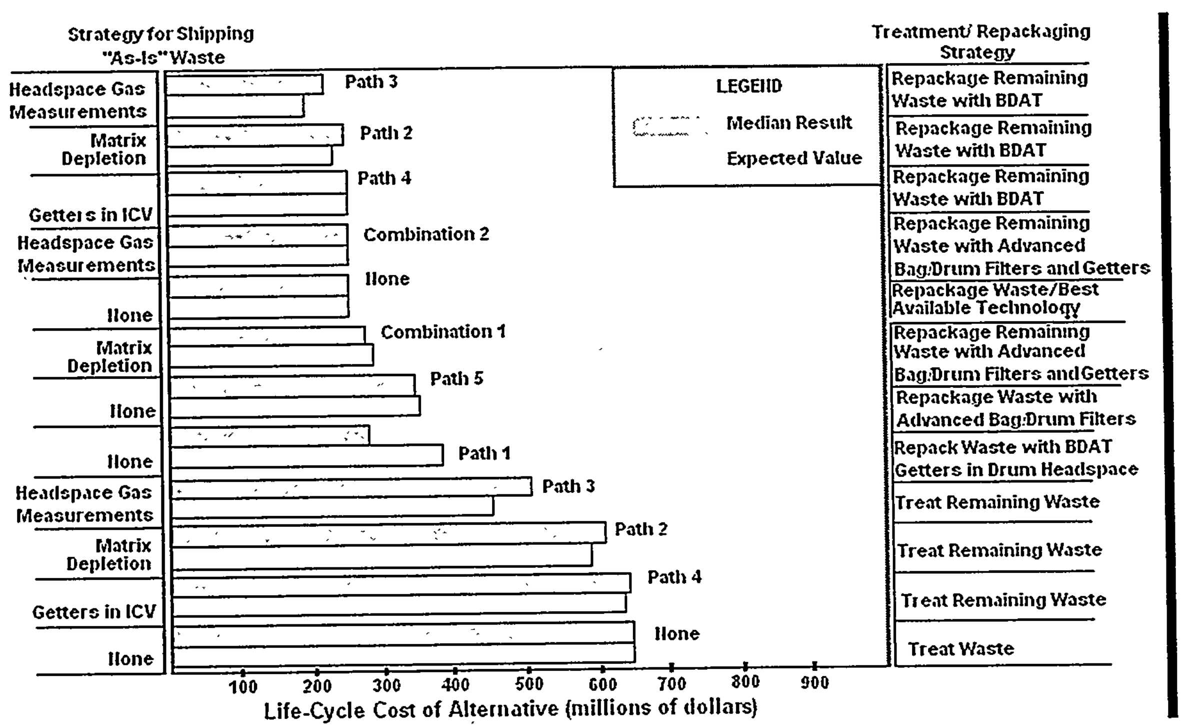

Figure 4. Life-Cycle Cost of Seven Alternatives

CONCLUSIONS

The decision analysis demonstrated that none of the strategies under consideration will fully enable the DOE to transport Pu-238 TRU waste without repackaging or treatment. However, when considering both the technical and regulatory uncertainties (i.e., expected value), drum certification based on headspace gas sample analysis (Path 3) offers the best single strategy to maximize near-term waste disposal (volume disposed by 2006) and minimize total system life-cycle cost. If samples of the headspace gas from Pu-238 TRU waste drums in storage show that hydrogen concentrations are indeed within the range analyzed, between 1,000 and 3,000 drums of the 10,373 drum equivalents in the inventory could be transported and disposed of in the WIPP without treatment or repackaging. The actual outcome of headspace gas sample analysis is uncertain, but by initiating a program to sample the headspace gas on a population of Pu-238 TRU waste drums and seek the NRC's approval for this certification method, the uncertainties will be reduced. Such a program may demonstrate that individual drum testing is a viable strategy that will enable the transportation of a significant part of the Pu-238 TRU waste inventory.

Most Appropriate Means to Manage Pu-238 TRU Waste

Performance Measure	Best Strategy for Achievement
Near-term disposal	Headspace hydrogen samples
Volume reduction	Thermal treatment
Cost efficiency	Repackaging

From a volume reduction perspective, thermal treatment to remove organic materials and water from the Pu-238 TRU waste is the best single strategy for overall volume reduction of the Pu-238 TRU waste inventory. In the context of this decision analysis treatment has little uncertainty, however, it is also the highest cost option, with a total system life-cycle cost more than double that required for repackaging. If volume reduction is the decision maker's highest priority, the Pu-238 TRU waste inventory should be treated in its entirety.

Repackaging is the lowest cost single strategy. It is also the option that produces the largest volume of Pu-238 TRU waste for disposal. Most of the research studies that are being pursued will tend to reduce the volume produced when Pu-238 TRU waste is repackaged. However, because of the limitations on the overall effectiveness of these studies and the associated technical and regulatory uncertainties, repackaging will produce a shipping need that far exceeds the current baseline planning resources as described in *The National TRU Waste Management Plan* [3], regardless of the strategy. If cost efficiency is the decision maker's highest priority, the Pu-238 TRU waste inventory should be repackaged.

When multiple strategies are considered in combination in light of only technical uncertainties, as much as 3,000 drums of Pu-238 TRU waste could be shipped from all sites by 2006. The remaining inventory could then be repackaged in as few as 11,000 drum equivalents if advanced bag and drum filters are used in conjunction with hydrogen getters in the inner containment vessel of the TRUPACT-II. These estimates, while impressive, must be considered in light of the uncertainties of whether the NRC would approve higher wattage limits because of matrix depletion, the use of hydrogen headspace gas sampling to certify waste containers, the use of hydrogen getters in the inner containment vessel of the TRUPACT-II, and advanced drum and bag filters when repackaging. These estimates also could be refined, as noted above, by initiating programs to collect data needed to reduce uncertainties.

In attempting to fully address the fundamental question concerning the decision maker, it should be recognized that the analyses presented herein are strategic in nature. Tactical decisions to implement a selected strategy must be made at the TRU-waste site level. Tactical decisions should target specific portions of the inventory with the appropriate mix of remedial strategies. For example, a few drums of very high wattage waste could be repackaged to stay below wattage limits instead of focusing on volume limits of the TRUPACT-II. In other words, repackaging waste to ship maximum wattage may be more prudent in some instances than repackaging to fill TRUPACT-IIs – the primary advantage being the cost avoidance associated with creating and maintaining a facility for processing large waste volumes.

This decision analysis was conducted within the context of existing regulations; evaluating possible changes to existing regulations was beyond the scope of this analysis. These regulations result in decay heat limits that ensure that the concentration of hydrogen in any layer of confinement in a payload container does not exceed five percent. Even the best strategy, drum certification by gas generation testing and sampling, or a combination of strategies, does not allow shipment of all the Pu-238 TRU waste without some repackaging or treatment of the waste. Continued development of technology to mitigate or prevent gas generation and to understand the phenomena is required. The goal is to increase the wattage limits of waste that can be safely and legally transported. Increased knowledge of this waste may also identify additional options.[3]

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ENDNOTES

[1] One large liner bag, one small filtered bag, one-inch punctured liner, two-inch carbon composite filter. This is the "Best Demonstrated Available Technology" referred to in Figures 2, 3, and 4.

[2] In this analysis, treatment of Pu-238 TRU waste would involve thermal treatment to remove residual moisture and destroy organic materials in the waste.

[3] Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-ACO4-94AL85000.