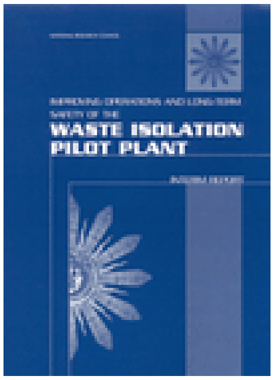

Improving Operations and Long-Term Safety of the Waste Isolation Pilot Plant: Interim Report

Committee on the Waste Isolation Pilot Plant, Board on Radioactive Waste Management, National Research Council

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IMPROVING OPERATIONS AND LONG-TERM SAFETY OF THE

INTERIM REPORT

Committee on the Waste Isolation Pilot Plant
Board on Radioactive Waste Management
Commission on Geosciences, Environment, and Resources
National Research Council

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NOTICE: The project that is the subject of this interim report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

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Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council (NRC) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

Tom Borak, Colorado State University
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Although the individuals listed above have provided constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by E-an Zen, appointed by the Commission on Geosciences, Environment, and Resources, and Frank Parker, appointed by the Report Review Committee, who were responsible for making certain that an independent examination of this report was carried out in accordance with NRC procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the NRC.

Preface

This report is the product of a National Research Council (NRC) committee study sponsored by the U. S. Department of Energy (DOE). The first NRC Committee on the Waste Isolation Pilot Plant (WIPP) began in 1978, and this committee and its successors issued eight letter reports during 1979-1992 and two full reports in 1984 and 1996. The current WIPP committee study is operating under a revised statement of task (see box) derived from a DOE request (Dials, 1997). This interim report addresses selected issues associated with the task statement, as explained below. The committee will comprehensively address the statement of task in the final report.

The specific approach taken in this interim report was to consider how to assess (1) the performance of WIPP in isolating waste from the environment and (2) the basic, minimal requirements and procedures that should be applied to waste management operations. The committee provides recommendations on several issues that it believes merit immediate consideration and action by DOE. Specifically, these issues include the determination of the natural background radioactivity in the area surrounding WIPP, and improvements in TRU waste operations.

This study is organized within the NRC's Board on Radioactive Waste Management and is being conducted by a 15-member committee. Committee members were chosen for their expertise in relevant technical disciplines such as nuclear engineering, health physics, chemical and environmental engineering, civil and transportation engineering, performance assessment, analytical chemistry, materials science and engineering, plutonium geochemistry, hydrogeology, rock and fracture mechanics, petroleum engineering, and mining engineering. As is normal practice of the National Academies, committee members do not represent the views of their institutions, but form an independent body to author this report.

To conduct the study and prepare this interim report, the committee gathered information principally through meetings and reviews of relevant literature. The committee met several times in open public sessions to hear from DOE and its contractors, as well as from other invited speakers such as regulatory agency personnel and groups with an interest in the WIPP program. Committee members prepared this report using these inputs together with their collective knowledge and experience. The report reflects a consensus of the committee and has been reviewed in accordance with NRC procedures.

STATEMENT OF TASK

The purpose of this study is to identify the limiting technical components of the WIPP program, with a two-fold goal of (i) improving the understanding of long-term performance of the repository and (ii) identifying technical options for improvements to the National TRU Program (i.e., the engineering system that defines TRU waste handling operations that are needed for these wastes to go from their current storage locations to the final repository destination) without compromising safety.

To accomplish this goal, the study will address two major issues:

(1) The first is to identify research activities that would enhance the assessment of long-term repository performance. This study would examine the performance assessment models used to calculate hypothetical long-term releases of radioactivity, and would suggest future scientific and technical work that could reduce uncertainties.

(2) The second is to identify areas for improvement in the TRU waste management system that may increase system throughput, efficiency, cost effectiveness, or safety to workers and the public. This study will examine, among other inputs, the current plans for TRU waste handling, characterization, treatment, packaging, and transportation.

Contents

Summary

The National Research Council convened a committee of experts to advise the U.S. Department of Energy (DOE) on the operation of the Waste Isolation Pilot Plant (WIPP), a geologic repository for disposal of defense transuranic (TRU) waste near Carlsbad, New Mexico. The committee was asked to provide recommendations on the following two issues: (1) a research agenda to enhance confidence in the long-term performance of WIPP; and (2) increasing the throughput, efficiency, and cost-benefit without compromising safety of the National TRU Program for characterizing, certifying, packaging, and shipping waste to WIPP.

The committee has written this interim report to provide DOE with recommendations on several issues that the committee believes merit immediate consideration and action. In developing this report, the committee has been guided by the principle of “reasonableness” with respect to risks, costs, and the ALARA (as low as reasonably achievable) principle. In the committee's judgment, implementing the recommendations contained in this report will contribute to the continued safe operation of WIPP. The committee will provide a more comprehensive response to its task statement (see the Preface) in the final report, which is scheduled for completion in the spring of 2001.

RESEARCH TO ENHANCE CONFIDENCE IN LONG-TERM REPOSITORY PERFORMANCE

There has been extensive monitoring of radioactivity in the air, soils, fluvial sediments, surface water, and shallow groundwater in the area surrounding WIPP. However, the committee has determined that radiological baseline information is not available for subsurface brines and hydrocarbons near the WIPP site. This baseline information is important for environmental monitoring in the operational and post-operational phases of the repository.

Recommendation: The committee recommends that DOE should develop and implement a plan to sample oil-field brines, petroleum, and solids associated with current hydrocarbon production to assess the magnitude and variability of naturally occurring radioactive material

(NORM) in the vicinity of the WIPP site. Samples should be collected and analyzed for the radionuclides that will be present in transuranic waste emplaced at WIPP and the radionuclides common in NORM. These sampies should be archived to permit subsequent analysis for constituents that may be of interest in the future. The committee recommends that a sampling plan be implemented prior to the closure of any underground rooms in WIPP that contain TRU waste.

IMPROVEMENTS TO THE NATIONAL TRU PROGRAM

The National TRU Program is administered by the DOE Carlsbad Area Office and is designed to meet all applicable external regulations and internal requirements associated with the characterization, certification, packaging, and transportation of waste to WIPP. A reasonable goal for the National TRU Program is to send DOE TRU waste to WIPP at a minimum risk (from all sources of risk, including radiological exposure and highway accidents) and cost. The current system for managing TRU wastes does not achieve this goal. **The committee recommends that waste management procedures be reviewed and revised, with reduction of risk and cost as the guiding principles.**

The committee offers recommendations in this interim report to improve the following three aspects of the National TRU Program: (1) waste characterization and packaging requirements, (2) gas generation, and (3) the transportation system.

Waste Characterization and Packaging Requirements

The committee found inadequate legal or safety bases for some of the National TRU Program requirements and specifications. That is, some waste characterization specifications have no basis in law, the safe conduct of operations to emplace waste in WIPP, or long-term performance requirements. The National TRU Program waste characterization procedures involve significant resources (e.g., expenditures of several billion dollars) and potential for exposure of workers to radiation and other hazards. Insofar as some of this waste characterization may be unnecessary, such characterization is inconsistent with economic efficiency or the ALARA principle that guides radiation protection practices.

Recommendation: DOE should eliminate self-imposed waste characterization requirements that lack a legal or safety basis. One way to justify a reduction in waste characterization requirements is through implementation of joint U.S. Nuclear Regulatory Commission–U.S. Environmental Protection Agency guidance (62 Federal Register 62079; see Appendix B), which appears to the committee to provide appropriate guidelines for implementation and integration of Resource Conservation and Recovery Act (RCRA) requirements for mixed TRU waste. Another way to justify a reduction is to identify the origins of all waste characterization requirements and to eliminate those requirements that lack a technical or safety basis. Such reductions may require modifications to exist ing permits granted by external regulating authorities such as the Environmental Protection Agency and New Mexico Environment Department.

Gas Generation

The extreme assumptions used in DOE's current gas generation model results in gross overestimates of hydrogen (H_2) concentrations in waste packages to be shipped to WIPP. As a consequence, DOE plans to repackage some of the waste to dilute the hydrogen-producing components. These repackaging operations result in additional risks of radiation exposure to workers and highway accidents, the latter due to the increased number of truckload shipments required to transport waste in diluted form.

Recommendations:

1. DOE should derive a more realistic radiolytic gas generation model, validate it through confirmatory testing, use the results to recalculate gas generation limits, and seek regulatory approval to implement them.
2. DOE should perform a safety analysis to determine the concentration and quantity of hydrogen that, upon ignition, could damage the seals of the TRUPACT-II shipping container. The goal of the safety analysis would be to demonstrate whether such an event could occur inside a waste package, and whether the energy associated with such an event could result in rupturing the containment provided by the TRUPACT-II. This analysis could provide the rationale to obtain relief from the 5 percent hydrogen flammability limit and should form the basis for a future modification to the present TRUPACT-II license.
3. DOE should consider technical approaches for reducing hazards from hydrogen generation, such as filling the headspace of the waste containers or the shipping containers with an inert gas.
4. DOE should reevaluate the technical and regulatory feasibility of shipping high-wattage TRU waste using a railcar shipping system.

The goal of these recommendations is to expedite the transport of TRU waste to WIPP by increasing the amount of waste that can be safely carried in each truckload or trainload, without compromising the level of safety and containment that is provided by the shipping container. These recommended options would reduce the number of truckloads required to transport the waste to WIPP and the associated transportation risks.

Transportation Communication and Notification

DOE bases its system of communication and notification on the TRANSportation tracking and COMmunication (TRANSCOM) system, a satellite-based system initially developed more than a decade ago and used to track all DOE shipments of radioactive materials. Users have found the current level of performance of TRANSCOM to be less than fully reliable. Although efforts are being made by DOE to keep the system current, it has not kept pace with the rapid development of information technology. As a result, the TRANSCOM system is obsolete when compared to presently available communications systems.

Recommendations: DOE should consider cost-effective ways to improve the reliability and ease of use of the TRANSCOM system, either by improving or replacing it. If DOE decides to replace the current system, the committee strongly encourages the use or adaptation of existing commercial systems. In the near term, the DOE should develop an interim plan for maintaining an adequate communication and notification system until any such alternative system or TRANSCOM upgrade is ready for full-scale implementation. This plan should be driven by a comprehensive assessment of TRANSCOM component performance based on anticipated usage. In the long term, DOE should ensure that the system it employs is designed to meet the needs of WIPP shipment users and other major stakeholders in a timely and cost-effective fashion.

Transportation Emergency Response

The responsibility for emergency response is divided between DOE and the states along WIPP shipment corridors. In the committee's view, a system to maintain up-to-date information on response capability would contribute significantly to the effectiveness of the transportation system. The WIPP emergency response program has not assessed sufficiently whether adequate and timely emergency response coverage for a transportation incident exists along the full extent of each WIPP route. No formal system presently exists to identify areas where coverage may be inadequate.

Recommendations: The committee recommends that DOE explore with states and other interested parties how to develop processes and tools for maintaining up-to-date spatial information on the location, capabilities, and contact information of responders, medical facilities, recovery equipment, regional response teams, and other resources that might be needed to respond to a WIPP transportation incident. This assessment should explore which organization(s) should develop and maintain the capability to generate and maintain such information. DOE should also determine where emergency response capability is currently lacking, identify organization(s) responsible for addressing these deficiencies, and take action to address them.

Introduction

The Waste Isolation Pilot Plant (WIPP)[1] is a series of excavations in a Permian-age bedded salt formation approximately 660 m below the surface near Carlsbad, New Mexico (see Figure 1). Since the mid-1970s, this site has been studied for use as a geologic repository for the disposal of transuranic[2] (TRU) waste resulting from the nation's defense program. This waste contains transuranic isotopes, predominantly plutonium isotopes, which are characteristically long-lived radionuclides and therefore a long-term safety hazard. Removing these wastes from the biosphere, for example, through isolation in geologic repositories, is an appropriate strategy for protection of human health and the environment.

At WIPP, packaged waste is disposed by emplacing it in rooms excavated in the salt. Because salt under pressure flows (or "creeps") and because of the underground pressure exerted on the room ceiling, floor, and walls, over time the salt rock at these surfaces will consolidate around the waste. In time, the salt heals so as to be essentially impermeable, isolating the waste-filled rooms from the rest of the environment.

WIPP is the first deep geological repository that has been designed and engineered for radioactive waste disposal and approved by an external regulatory authority. Operations at WIPP to receive TRU waste and emplace it underground began in 1999, when TRU waste shipments were received from three U.S. Department of Energy (DOE) sites. Drums of TRU waste from the Los Alamos National Laboratory, the Idaho National Engineering and Environmental Laboratory, and the Rocky Flats Environmental Technology Site were first sent to WIPP in March, April, and June 1999, respectively.

The committee has prepared this report to provide findings and recommendations that it considers important for the safe and cost-effective operation of WIPP. The perspective of the committee has been the establishment of "reasonableness" with respect to risks, costs, and the ALARA (as low as reasonably achievable) principle (see footnote 8). The committee believes that the implementation of these recommendations will contribute to the continued safe operation of WIPP.

[1]A complete list of acronyms used in this report appears in Appendix D.

[2]Transuranic waste contains radionuclides with atomic numbers greater than 92 and half-lives greater than 20 years in concentrations exceeding 100 nanocuries per gram.

As noted in the preface to this report, the first component of the statement of task is "to identify research activities that would enhance the assessment of long-term repository performance" (see Appendix A). The committee considers that data from radiological site characterization measurements would provide a necessary baseline to compare against future measurements, should the integrity of WIPP ever be challenged. This issue is explored in the next section.

The second component of the statement of task pertains to improvements of the DOE TRU waste management system. To address this issue, the committee sought to identify the technical, regulatory, legal, and/or safety bases of waste management activities that significantly impacted the overall system throughput, efficiency, cost, and safety. These issues are addressed in the last section of this report.

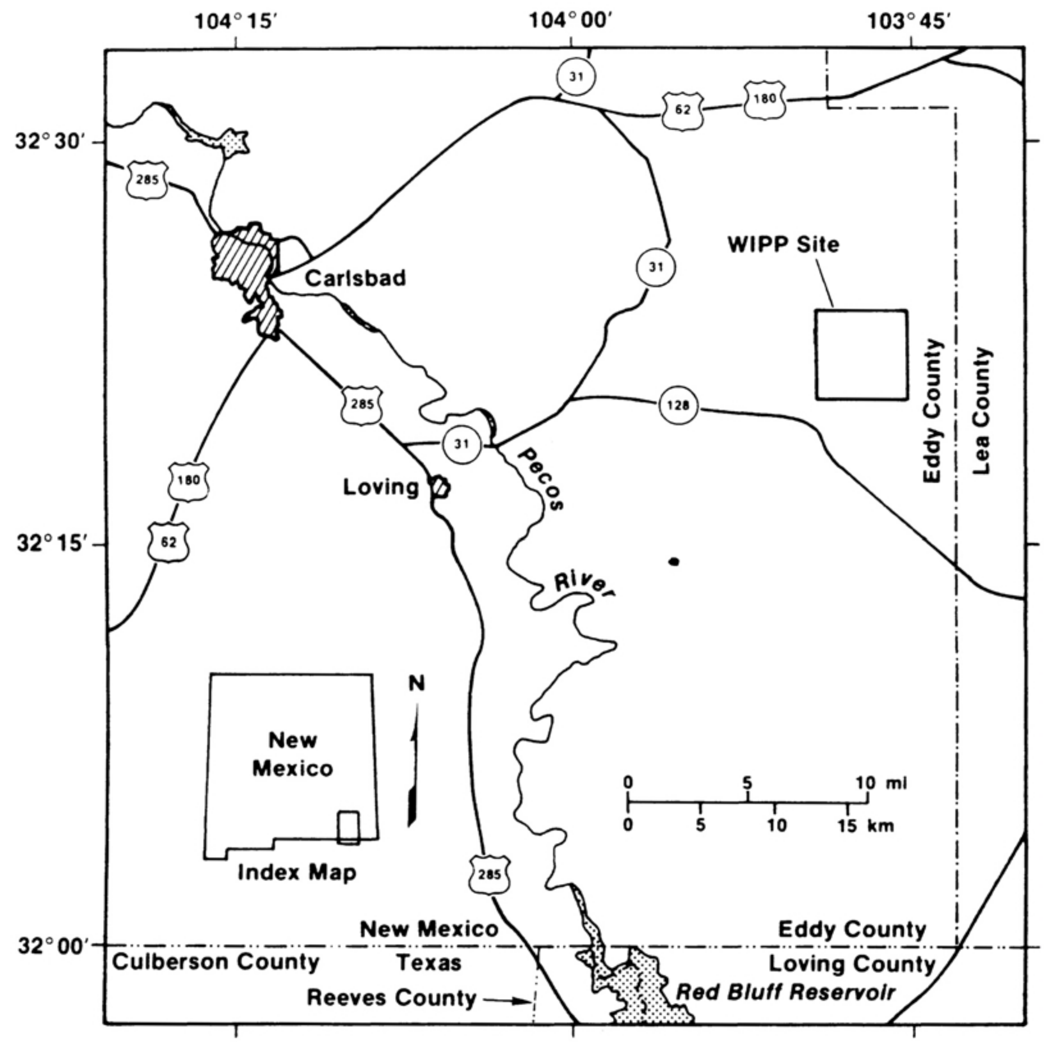

FIGURE 1 Location of the Waste Isolation Pilot Plant. Inset shows the approximate location of the map area in New Mexico. SOURCE: NRC (1996, Figure 1.1.).

Baseline Radiogenic Analysis of Subsurface Fluids

In this section the committee provides recommendations on research activities to enhance confidence in the long-term performance of WIPP. In particular, the committee considered how "baseline" studies undertaken during the early phases of repository operation could be used to support future efforts to assess repository performance.

Finding: There has been extensive monitoring of radioactivity in the air, soils, fluvial sediments, surface water, and shallow groundwater in the area surrounding WIPP.[3] However, the committee has determined that radiological baseline information is not available for subsurface brines and hydrocarbons near the WIPP site. This baseline information is important for environmental monitoring in the operational and post-operational phases of WIPP.

Recommendation: The committee recommends that DOE should develop and implement a plan to sample oil-field brines, petroleum, and solids associated with current hydrocarbon production to assess the magnitude and variability of naturally occurring radioactive material (NORM) in the vicinity of the WIPP site. Samples should be collected and analyzed for the radionuclides that will be present in transuranic waste emplaced at WIPP and the radionuclides common in NORM. These samples should be archived to permit subsequent analysis for constituents that may be of interest in the future.[4,5] The committee recommends that a

[3]See, for example, Conley (1999); DOE (1997c); Herczeg et al. (1988); and Kenney et al. (1999). Additionally, previous Environmental Evaluation Group studies on radiation monitoring of air, surface soil, and biota samples near the WIPP site include Neill et al. (1998); Kenney et al. (1990, 1995, 1998); Kenney and Ballard (1990); and Kenney (1991, 1992, 1994). Ramey (1985) summarizes U.S. Geological Survey data on simple radiological characterization (i.e., gross alpha, gross beta, dissolved radium, and dissolved uranium) of fluids in the Rustler Formation. References to other studies are contained in annual reports of the Carlsbad Environmental Monitoring Research Center (CEMRC, 1999) and on the CEMRC website, http://www.cemrc.org.

[4]A reanalysis of a sample using a different detection method could yield a different value. These detection limitations should be understood and distinguished from true natural differences in background radiation.

sampling plan be implemented prior to the closure of any underground rooms in WIPP that contain TRU waste.

Rationale: Early studies discounted the potential for hydrocarbon production in the vicinity of WIPP, but over the past 20 years this way of thinking has changed dramatically. The site is now surrounded by wells (see Figure 2) for hydrocarbon production (Broadhead et al., 1995), and drilling activities continue. Furthermore, it is relatively common for brines associated with hydrocarbons to be radiogenic (Bloch and Key, 1981; Fisher, 1995). Oil-field brines in the Delaware Basin share this property (Fisher, 1995). The information available on oil-field brines and petroleum resources generally consists of gross radiation measurements (i.e., gross activity), rather than analytical data on the radionuclide constituents. Such analytical data on the radioactivity of oil-field brines and petroleum resources at the WIPP site have not been made available to the committee and may not exist.

If, during or after WIPP operations, increased radioactivity in the vicinity of WIPP is observed, is this the result of a failure of the WIPP to contain its waste, or is it due to NORM? This question cannot be answered easily unless the oil-field brines, petroleum, and solids associated with hydrocarbon production (e.g., suspended solids, precipitated scale, sludges, and formation fragments) are analyzed for their naturally occurring radiation. Analyses for radioactivity and radionuclides will be necessary if disputes arise about potential releases of radionuclides from the repository. An example of the need to obtain adequate NORM background data already has been observed with occurrences of natural surface contamination on the exterior of truck transportation packages while en route to WIPP during the first three months of operation.

"Human intrusion scenarios" involving hydrocarbon exploration and production are now considered processes through which radionuclides might be released from WIPP (Kirkes, 1998). If brines have a measurable NORM content, then human intrusion that results in brine flow through WIPP to the surface is a means by which radioactivity could be carried to the surface that is not due to the TRU waste emplaced in WIPP. If oil-field brine NORM is present, then it is conceivable that NORM releases would be greater than releases from the TRU waste contents of WIPP, even if drilling breaches the repository.

Transport and disposal of oil-field brines that have high NORM contents are also potential mechanisms for localized increases in radiation. Any such increases in radiation in the vicinity of WIPP cannot necessarily be attributed to WIPP operations or the failure of WIPP to contain its waste.

There are data suggesting that oil-field brines near WIPP might contain NORM. Otto (1989, reproduced in Fisher, 1995; see Figure 3)

[5]The archiving of monitoring data, as well as samples, is also a long-term challenge due to the evolution of information technology and the changes in state-of-the-art storage media that will likely take place over the three decades in which WIPP is projected to be open and operational. Any data records not in paper form would be subject to such challenges.

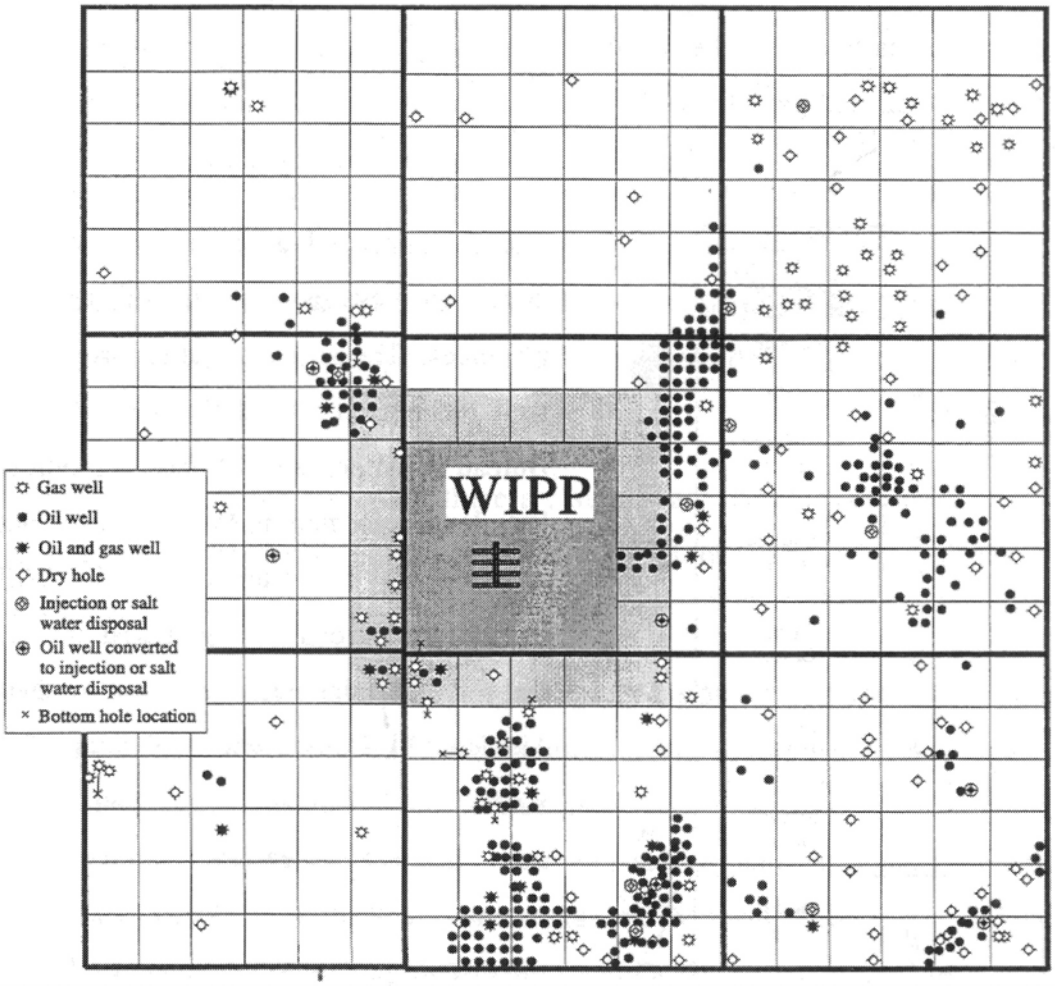

FIGURE 2 Petroleum wells in the vicinity of the WIPP site. See Figure 1 for an inset map showing the WIPP site's approximate location within New Mexico. SOURCE: Silva (1996, p. 24).

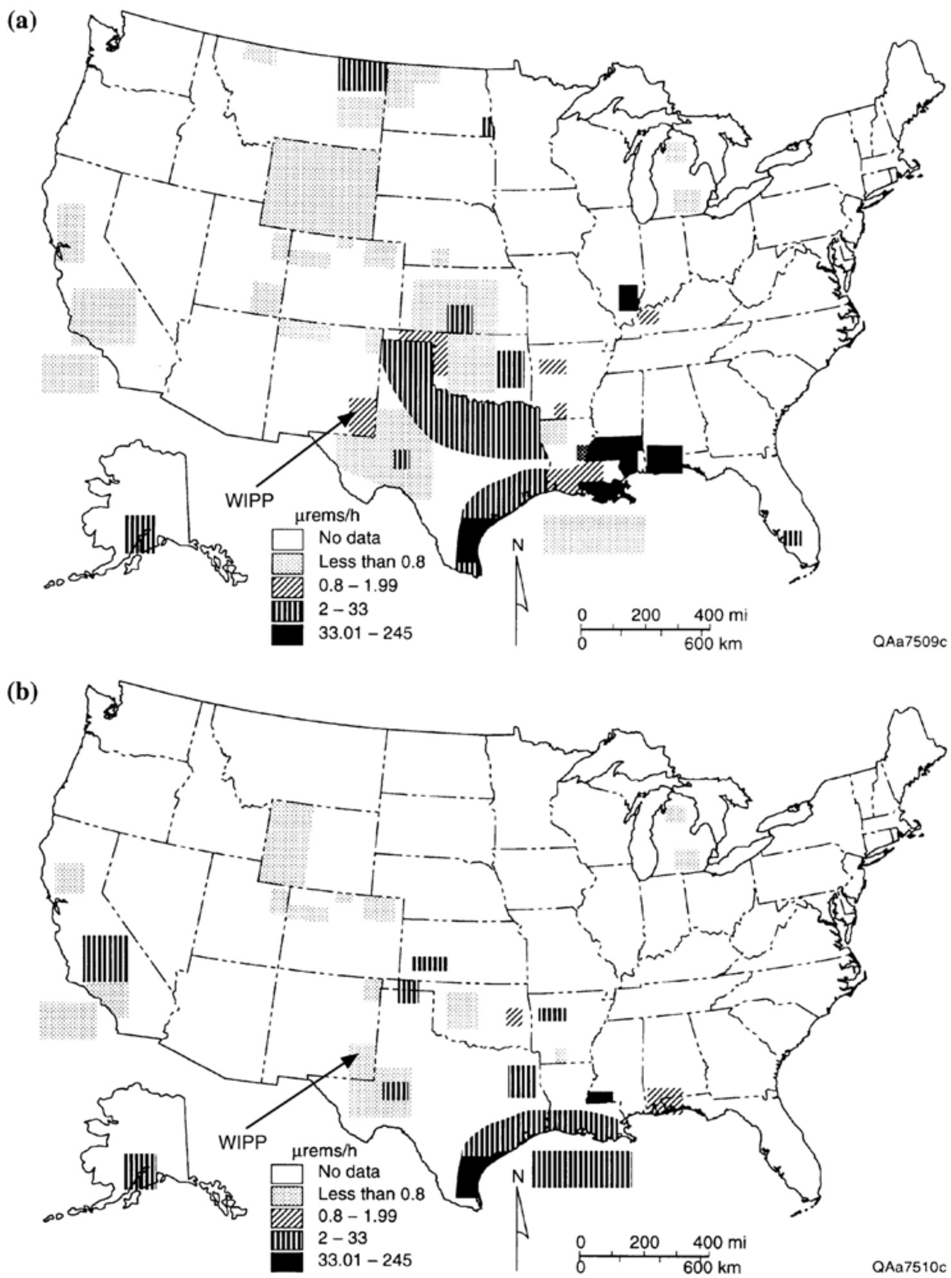

FIGURE 3 Regions of high activity from NORM in the United States from (a) oil-producing facilities and (b) gas-producing facilities. Values are aggregated median differences over background. The legend shows various shadings corresponding to various ranges of dose rates measured in microrems per hour (µrem/h). These dose rates are radioactivity measuremerits of NORM deposits in piping and in fluids brought to the surface. These measurements describe the concentration of radioactive species, a characteristic of the NORM deposits at any locality that is not directly dependent on the local production rate (of hydrocarbons or brine) or on the amounts of fluid that were extracted to produce the deposits. SOURCE: Fisher (1995), after Otto (1989).

shows the Delaware Basin of southeast New Mexico as a region of NORM activity in oil-and gas-producing facilities. Fisher states that "(1) not every major oil or gas field has associated high NORM levels, and (2) no major hydrocarbon-producing basin in Texas is exempt from high levels of radioactivity." The major hydrocarbon-producing basins in Texas described by Fisher include the Delaware Basin, which contain producing formations near the WIPP site, and the adjacent Central Basin Platform (Hill, 1996, p. 26).

In response to committee requests for information, DOE has answered that no data have been collected on "naturally occurring radionuclides in the underground brines and hydrocarbons near WIPP by DOE. In addition, DOE is unaware of any related information collected by the oil and gas industry" (Mewhinney, 1998b).

The need for these data is clear—no effective monitoring of the WIPP area can be successful without understanding potential sources of radiation in the environment. Air, soils, sediments, ground and surface waters, biota, and people have been analyzed to provide a database (e.g., through CEMRC activities). NORM from local hydrocarbon operations must also be analyzed. The NORM data will

- identify sources of future contamination events that might (wrongly) be attributed to a failure of WIPP;
- place any radioactivity releases from human intrusion scenarios (e.g., from petroleum exploration and production) in perspective; and
- improve the monitoring efforts.

The committee recommends near-term action to collect and analyze these data based on an appropriate sampling plan. The plan must include frequency of sampling and analyses; radionuclides to be analyzed; collection of data to assess NORM radioactivity and to estimate its variability; sampling, analysis, and archiving protocols; and producing formations to be tested. These formations should include both past (if applicable) and present producing zones, new producing zones as they become exploited in the future, and formations from which brine is (or likely will be) extracted.

Samples could come from ongoing well-based operations that generate separator streams of oil, gas, and water. These separators and separator streams are owned by the operators of the leases. The drilling of new wells would be justified if data from separator streams prove to be inadequate.

The radionuclides of interest include both those that contribute to the site's NORM background radioactivity and those in the DOE TRU inventory destined for WIPP. The NORM activity may include contributions from potassium-40, isotopes of uranium and thorium, and daughter products such as isotopes of radium. Radionuclides in TRU waste include isotopes of uranium and TRU elements and, in remote-handled[6] TRU

[6]Remote-handled waste is classified as that with a surface dose rate greater than or equal to 200 mrem per hour. Such waste contains fission products and activation products such as cobalt-60, strontium-90, yttrium-90, ruthenium-106, cesium-137, barium-137, and europium-152. These and other radioisotopes emit penetrating beta and gamma radiation that requires shielding.

waste, fission and activation products. Since some TRU inventory radionuclides are not commonly found in nature, sampling to determine whether such radionuclides are present in the environment may be a good way to distinguish radioactivity due to NORM from that due to TRU waste.

For the reasons given above, the committee supports the collection of NORM data on deep subsurface fluids, even though the isotopic signatures of NORM and TRU waste radioactivity are expected to differ and therefore to be readily distinguishable. In the committee's view, DOE would be better served to possess these NORM data prior to any reported discovery of significant radioactivity in the region; hence, in its recommendation the committee proposes that this survey to sample deep subsurface fluids be conducted in the near term. This survey need not continue once the measurement objectives, as proposed in this recommendation, have been met.

Transuranic Waste Management Program

Transuranic waste management operations are performed under the auspices of the DOE National TRU Program administered by the DOE Carlsbad Area Office. This program has been designed and developed, based on initial efforts in the 1980s and subsequent modifications, to accommodate all applicable external regulations and internal requirements that are associated with the characterization, certification, packaging, and transportation of TRU waste to WIPP. These procedures, described briefly in Appendix A, were applied in 1999 for the first contact-handled TRU waste shipments to WIPP from DOE sites that have generated and stored such waste. The remote-handled TRU waste management system is still under development and is not reviewed in this report.

The committee considered three topics associated with TRU waste management: (1) waste characterization and packaging requirements, (2) gas generation, and (3) transportation. These topics are discussed in the following subsections.

WASTE CHARACTERIZATION AND PACKAGING REQUIREMENTS

Finding: The committee found inadequate legal or safety bases for some of the National TRU Program requirements and specifications. That is, some waste characterization specifications have no basis in law, the safe conduct of operations to emplace waste in WIPP, or long-term performance requirements.[7] The National TRU Program waste characterization procedures involve significant resources (e.g., expenditures of several billion dollars) and potential for exposure of workers to radiation and other hazards. Insofar as some of this waste characterization may be unnecessary, such characterization is inconsistent with economic efficiency and the ALARA principle that guides radiation protection practices.[8] The committee regards the 30+ years of waste emplacement op

[7]A recent study (DOE, 1999c) has also shown that some waste characterization procedures are not prescribed by safety or legal requirements.

[8]ALARA requires that all operations be done with the lowest possible radiation exposure consistent with other requirements of safety and basic programmatic objectives. See, for example, 10 CFR 835, which are requirements for worker protection referenced in DOE radioactive waste management practices (specifically, in DOE Order 435.1 [DOE, 1999a]).

erations and related worker safety issues at WIPP as posing no significant needs for waste characterization information, because no use of characterization data is made in any handling, shipping, or emplacement operations.

Recommendation: DOE should eliminate self-imposed waste characterization requirements that lack a legal or safety basis. One way to justify a reduction in waste characterization requirements is through implementation of joint U.S. Nuclear Regulatory Commission (USNRC)–U.S. Environmental Protection Agency (EPA) guidance (62 Federal Register 62079; see Appendix B), which appears to the committee to provide appropriate guidelines for implementation and integration of Resource Conservation and Recovery Act (RCRA) requirements for mixed TRU waste. Implementation of this regulatory guidance could significantly reduce the testing protocols and associated radiation exposure of personnel. Another way to justify a reduction is to identify the origins of all waste characterization requirements and to eliminate those requirements that lack a technical or safety basis. Such reductions may require modifications to existing permits granted by external regulating authorities such as the EPA and New Mexico Environment Department.

Rationale: The National TRU Program has developed waste restrictions, as described in the waste acceptance criteria (DOE, 1996a, 1999d), and requirements for waste generating sites presented in the quality assurance program plan (DOE, 1998b). These criteria and plans impose many required procedures on waste-generating sites. EPA and DOE Carlsbad Area Office audits are conducted to certify (i.e., approve for shipment) TRU waste streams. Additionally, each container of waste from a certified waste stream must be characterized, and shipping sites must prepare documentation on characterization data for each waste container. At the Los Alamos National Laboratory, the time to obtain all the requisite documentation and administrative approvals was greater than the time to process a drum of waste through the characterization and packaging protocols that had been developed. At all sites, the assembly, management, and storage of waste characterization information are resource-intensive activities, and drum handling is a major source of worker exposure. Of interest to the committee is the origin of these required procedures, because they increase the cost or risk or decrease the efficacy of operations.

The committee sought to identify the connection between the National TRU Program procedures and the various regulatory, legal, and technical requirements that the procedures should be devised to meet. The committee views these requirements in a hierarchy, at the top of which are legal and safety requirements, with regulatory specifications at the next tier, procedures proposed by DOE to meet regulatory requirements at the third tier, and the DOE protocols for these procedures at the fourth tier.

The approach used by the committee was to focus on six primary National TRU Program procedures representative of high-level requirements that drive operational activities in waste characterization and repackaging (see Appendix A for an overview of these activities):[9]

1. determination that the TRU waste is of defense origin;
2. sampling and analysis of homogeneous waste;
3. headspace gas sampling and analysis;
4. radioassay of the plutonium content;
5. real-time radiography; and
6. visual examination.

These procedures are incorporated into the terms of the WIPP facility's RCRA “Part B” permit, which was issued in October 1999. The EPA guidelines that are specific to RCRA requirements are presented in Appendix B. However, the committee notes that the permit terms are subject to negotiation in a regulatory permitting process, based on the procedures proposed by DOE that became accepted as meeting regulatory requirements. A recent study (DOE, 1999c) has traced these and other TRU waste characterization requirements to their root origins in either (1) Carlsbad Area Office mandates, (2) regulatory certification and permit terms, (3) regulatory requirements or DOE orders, or (4) legal requirements.

A review of these six procedures revealed that one may be interpreted too strictly by DOE and three are without a technical or legal foundation:

Procedure 1: Determination that the TRU waste is of defense ori gin. WIPP is limited to defense-related waste as stipulated in the Land Withdrawal Act, with defense activities defined in the Nuclear Waste Policy Act of 1982. The committee notes that this definition includes the words “in whole or in part”, which can be interpreted to include mixtures of defense and nondefense waste, although DOE does not appear to take advantage of this (see DOE, 1997a; Nordhaus, 1996). That is, waste such as plutonium-238 (^{238}Pu)-contaminated scrap from a facility used for both defense and nondefense missions at Los Alamos National Laboratory would appear to qualify as defense waste under the definition, without the need for waste segregation restrictions.

Procedure 2: Sampling and analysis of homogeneous waste. DOE has written, “There is no regulatory requirement to conduct homogeneous waste sampling and analysis, however, in an effort to meet the intent of 40 CFR 264.13, WIPP has imposed additional characterization requirements on the waste generators” (Nelson, 1999a, p. 2). No operational decisions are made based on these data; that is, the results of the sampling and analysis do not affect how waste is handled, so it is not clear what justifies the additional radiation exposure risk and cost of this procedure. In the committee's view, this sampling and analysis applied only to homogeneous waste is unnecessary: If acceptable knowledge documentation

[9] A more comprehensive list of TRU waste characterization procedures and their origin is found in DOE (1999c).

(see Appendix A) provides sufficient characterization information for heterogeneous waste, the committee can identify no technical reason why acceptable knowledge should not also be adequate for homogeneous waste.

Procedure 3: Headspace gas sampling and analysis. DOE informed the committee that "there is no regulatory requirement to conduct headspace gas sampling and analysis, however, in an effort to meet the intent of 40 CFR 264.13, WIPP has imposed additional characterization requirements on the waste generators" (Nelson, 1999a, p. 3). The headspace gas sampling and analysis was developed as a means of checking on conformance with USNRC and the U.S. Department of Transportation (DOT) requirements (see Appendix A for relevant sections of these regulations); however, these requirements can be met by other means (see the recommendations that follow on the issue of gas generation).

Procedure 6: Visual examination. Visual examination is done on a fraction of the waste containers to confirm the real-time radiography and acceptable knowledge waste characterization information (Nelson, 1999a, p. 5). However, there is no requirement for verification of real-time radiography results. An alternative way to confirm these results without operator exposure would be to use standardized test drums. The visual examination confirmation is a self-imposed procedure that yields no benefit but results in increased risk of exposure and cost.

A DOE study (1999c) also confirms that procedures 2, 3, and 6 identified above are based on terms negotiated in a permit and not on a required regulation or legal mandate. The committee sees no utility in the information that these procedures provide. Any speculative benefits of acquiring this information must be weighed against the risks and costs. The committee's judgment is that the collection of these data from superfluous procedures increases, rather than decreases, the risk and safety of the overall TRU waste operations.

These superfluous characterization and intrusive procedures also represent a conflict with the ALARA principle. The issue of how to handle conflict between regulatory requirements for waste characterization information and ALARA is beyond the scope of the committee's statement of task. At issue, however, is whether the present TRU waste management program results in significantly more worker radiation exposure than is justified to satisfy safety and nonnegotiable regulatory requirements.

GAS GENERATION

Finding: The extreme assumptions used in DOE's current gas generation model result in gross overestimates of hydrogen concentrations in waste packages to be shipped to WIPP. As a consequence, DOE's plans to repackage some of the waste to dilute the hydrogen-producing components. These repackaging operations result in additional risks of radiation exposure to workers and highway accidents due to the increased number of truckload shipments required to transport waste in diluted form.

Recommendations:

1. DOE should derive a more realistic radiolytic gas generation model, validate it through confirmatory testing, use the results to recalculate gas generation limits, and seek regulatory approval to implement these limits.
2. DOE should perform a safety analysis to determine the concentration and quantity of hydrogen that, upon ignition, could damage the seals of the TRUPACT-II shipping container. The goal of the safety analysis would be to demonstrate whether such an event could occur inside a waste package, and whether the energy associated with such an event could result in the rupture of containment provided by the TRUPACT-II. This analysis could provide the rationale to obtain relief from the 5 percent hydrogen flammability limit and should form the basis for a future modification to the present TRUPACT-II license.
3. DOE should consider technical approaches for reducing hazards from hydrogen generation, such as filling the headspace of the waste containers or the shipping containers with an inert gas to displace air and thereby reduce the flammability hazard.
4. DOE should reevaluate the technical and regulatory feasibility of shipping high-wattage TRU waste using ATMX[10] railcar shipping system.

The goal of these recommendations is to expedite the transport of TRU waste to WIPP by increasing the amount of waste that can be carried safely in each truckload or trainload, without compromising the level of safety and containment that is provided by the shipping container. These recommended options would reduce the number of truckloads required to transport the waste to WIPP and the associated transportation risks.

Rationale: The amount of TRU waste in each waste drum and truck shipment is limited because of the potential for radiolytic generation of hydrogen gas (H_2). Within TRU waste, radiolytic hydrogen gas generation is due primarily to the co-disposal of alpha emitters with organic materials. The DOE has developed a radiolysis model to calculate hydrogen generation rates and the hydrogen concentration in each headspace[11] inside a waste container. Limiting any H_2 concentration to 5 percent leads to a restriction, expressed as maximum allowable wattage, on alpha activity (i.e., the amount of alpha-emitting radionuclides) within each waste container (e.g., a 55-gallon drum). The value of 5 percent H_2 (as a mole

[10]"ATMX" is an acronym to denote the railcars used by DOE to ship nuclear weapons components and TRU waste. The "AT" stands for Atchison Topeka, the rail carrier. The "M" signifies munitions, and the "X" on a railcar signifies private ownership (in this case, by the U.S. government), rather than ownership by the railroad company. As noted elsewhere in this report, these railcars have been used to ship TRU waste for decades.

[11]In many waste containers, waste is contained in one or more plastic bags that were used for radiological protection against any inadvertent spread of radioactivity. These plastic bags provide resistance to diffusive transport of hydrogen gas, thereby providing multiple headspaces.

fraction) in air as a "flammability limit" can be used in any USNRC license application on a transportation package without the need for further safety analysis because of its conservatism. This allowable wattage is a function of the G value[12] of the solid matrix of the waste materials adjacent to each alpha emitter and the total resistance to the flow of hydrogen gas that the waste and packaging contents provide, due primarily to the layers of plastic bags in the waste.

Wattage limits based on this model determine whether or not a waste container may be transported to WIPP without repackaging. The gas generation model, and the wattage limits derived from it, specify the terms of operation that are contained in the DOE safety analysis report for the TRUPACT-II transportation package. These terms of operation are also specified in DOE's application to the USNRC for regulatory approval of the TRUPACT-II transportation package. The certificate of compliance for TRUPACT-II issued by the USNRC is subject to modifications (and in fact has been amended several times since the original certificate was issued in the late 1980s), provided that DOE can offer sufficient adequate safety assurances and comply with applicable regulations, principally the USNRC's 10 CFR 70-71 and DOT's 49 CFR 171-173.

The current model is based on worst-case scenario of H_2 generation and wattage limits. Because of this worst-case approach and the extreme assumptions used in the model, the calculations often exceed experimental observations by orders of magnitude. The explanations for these large discrepancies are only beginning to be studied (see Idaho Engineering and Environmental Laboratory, 1998; Mewhinney, 1998a). Specific examples follow.

1. A G value of 3.4 is used for the plastic bags in the safety analysis report for the TRUPACT-II (DOE, 1997b). In this analysis, no credit is taken for matrix depletion (i.e., exhaustion of the H_2 source). Therefore, DOE is seeking relief from unrealistically large G values in revisions 17-19 of the safety analysis report and certificate of compliance for the TRUPACT-II (DOE, 1999b).
2. The model assumes that all layers of plastic bags are intact and behave as a new bag (i.e., no credit is taken for changes in permeability with age).

The results of these gas generation model assumptions have severe consequences.[13] Repackaging is carried out to redistribute waste in containers (e.g., 55-gallon drums) in order to meet the wattage limits derived from the gas generation model for each container. This repackaging of waste exposes workers to radiation and increases the number of containers, thereby diluting the waste into a greater volume.

[12]The G value is the number of electrons (or, equivalently, the number of electron-ion pairs, with H^+ the chief ion produced in materials containing hydrogen compounds) produced in a material per 100 eV of energy that is deposited within it by irradiation.

[13]In general, the use of extreme assumptions that result in overestimating consequences is not a conservative approach, because attending to these overestimated consequences results in unnecessary actions, each of which has its own risks, thus potentially increasing the risks of the overall operations.

Transportation-related risks (and costs) are also incurred in repackaging, because the extra containers require additional shipping loads with many additional truck trips. DOE estimates reveal that this repackaging of ^{238}Pu contact-handled TRU waste may increase the number of ^{238}Pu shipments by more than a factor of ten, to as many as 150,000 extra drums (Lechel and Leigh, 1998).[14] Another consequence of such volume expansions that should be considered is the impact on WIPP's volume limit.[15] Therefore, the maximum allowable wattage imposed by the gas generation model is a major technical restriction of the National TRU Program.

Recent information (DOE, 1999b; Gregory, 1999) suggests that significant progress is being made toward developing technical information to support planned future applications to the USNRC to amend the terms of the TRUPACT-II safety analysis report and certificate of compliance. Research continues to investigate the use of hydrogen getters[16] (Mroz et al., 1997, 1999), methods for puncturing bags, use of vented bags (Gregory, 1999), and relief from the restrictive G values (Idaho Engineering and Environmental Laboratory, 1998).

To provide containment of its radioactive contents, the TRUPACT-II shipping container uses outer O-rings that generate a vacuum seal. In this package design, internally generated gas, such as H_2, builds up to pressurize the internal gas volume. Other transportation package designs are possible that are less sensitive than the TRUPACT-II to the potential for H_2 gas generation. One such system for transport of TRU wastes was the ATMX railcar system, which DOE used for hundreds of shipments over several decades to safely transport TRU waste from the Mound Laboratory in Ohio and from the Rocky Flats Environmental Technology Site in Colorado to the Idaho National Engineering and Environmental Laboratory. Based on the integrity provided by the railcar, this system was exempted (DOT exemption number DOT-E 5948) from the double-containment and vacuum seal requirements for packages used to transport plutonium (classified as “Type B” fissile packages). As a result, this system did not suffer limitations of the kind that are imposed on the TRUPACT-II due to radiolytic gas generated and trapped within the shipping container.

[14]The actual number of containers to be repackaged and procedures to be used have not yet been determined by DOE but are under active study, as is an analysis of technical options. If each truck carried the maximum number of TRUPACT-II transporters per shipment to WIPP, and each TRUPACT-II carried the maximum number of 55-gallon drums, 150,000 drums would be equivalent to 3,600 additional truck shipments.

[15]The Land Withdrawal Act (P.L. 102-579) specifies a total TRU waste volume limit of 175,600 m^3 if waste were sufficiently diluted, WIPP would be filled to this volume limit without having disposed the total TRU inventory in curies. Therefore, there is a minimum “filling ratio” of curies to volume that must be achieved, on average, for WIPP to contain the total TRU inventory in curies by the time the volume restriction is reached.

[16]A getter is a material designed to absorb gas such as hydrogen.

TRANSPORTATION

The committee has examined various aspects of the WIPP transportation system, focusing on system safety and the cost-effectiveness of planned and ongoing activities. Based on this review (see DOE, 1999b; Mewhinney, 1998a,b), the committee has identified two issues—DOE's communication and notification system (TRANSCOM[17]) and DOE's emergency response program—that warrant immediate attention.

DOE's Communication and Notification Program

Finding: DOE bases its system of communication and notification on TRANSCOM, a satellite-based system developed more than a decade ago and used to track all DOE shipments of radioactive materials. Users have found the current level of performance of TRANSCOM to be less than fully reliable. Although efforts are being made to keep the system current (Nelson, 1999b), it has not kept pace with the rapid development of information technology. As a result, TRANSCOM is obsolete compared to presently available communications systems (for a summary of recent transportation communication initiatives using information technology, see Allen [1998]).

Recommendations: DOE should consider cost-effective ways to improve the reliability and ease of use of the TRANSCOM system, either by improving or replacing it. If DOE decides to replace the current system, the committee strongly encourages the use or adaptation of existing commercial systems. In the near term, DOE should develop an interim plan for maintaining an adequate communication and notification system until any such alternative system or TRANSCOM upgrade is ready for full-scale implementation. This plan should be driven by a comprehensive assessment of TRANSCOM component performance based on anticipated usage. In the long term, DOE should ensure that the system it employs is designed to meet the needs of WIPP shipment users and other major stakeholders in a timely and cost-effective fashion.

Rationale: Public confidence in a transportation communication and notification system is essential. This will become increasingly important with the growing number of shipments to WIPP. The magnitude of shipping activity and the public interest in WIPP transportation safety dictate the need for a state-of-the-art communications system.

As a means of obtaining information on the current effectiveness of TRANSCOM, the committee contacted 27 users located across the nation, requesting information on their experience with the system. Serious concerns were raised about system reliability and ease of use, giving the impression that key transportation stakeholders have little confidence in TRANSCOM. Comments of the 11 users who responded (from two tech

[17] The DOE TRANSportation Tracking and COMmunication System, or TRANSCOM, is a satellite-based telecommunications system designed to enable users to track WIPP truck shipments in essentially real time while en route to WIPP on the approved highway routes.

nology companies and various institutions involved in emergency response monitoring in Colorado, Illinois, Pennsylvania, Idaho, Wyoming, Oregon, Arizona, North Carolina, and Utah) to a committee survey are shown below. On a scale of 1 to 5, with 1 = inadequate, 2 = poor, 3 = average, 4 = good, and 5 = excellent, the average scores for TRANSCOM system on five issues were as follows:

Category	Average Score on Scale of 1 to 5
Accuracy	3.5
Cost	3.4
Ease of use	3.2
Communication capability	3.0
Reliability	2.5

Most survey responders also wrote either explicitly or by using examples that the system was (1) unreliable (citing frequent downtime, connection or access problems, or other hardware or software problems), (2) not user friendly (citing features such as slow data rates, the time required to download information, and “old technology”), and (3) not economical because of the high costs for modem connections. Of those survey responders who had experience with at least one other transportation tracking system, each provided written comments attesting to the “unreliable” and/or “not user-friendly” features of TRANSCOM.

The committee concludes from this survey and from other materials received (e.g., presentations at committee meetings in October 1998, May 1999, and July 1999) that the TRANSCOM system has failed to give its users confidence in its reliability, ease of use, and the timeliness with which accurate information can be accessed. The committee regards these features as important for engendering public confidence and trust in WIPP's transportation program, especially for incidents in which some sort of emergency response is required.

The committee considers that given the potential interest in and visibility of WIPP shipments, the tracking system should provide reliable, real-time, and user-friendly access to information for the state users and other interested parties. In principle, this could be accomplished through upgrades to the current TRANSCOM system. However, rather than maintaining and upgrading a technically obsolete system, the committee believes that it would be more prudent for DOE to implement a less expensive, higher-quality system using a currently available commercial communications product (for a summary of transportation communication initiatives using information technology, see Allen [1998]). Careful screening of vendors is necessary to ensure that the desired system can perform to specification and be delivered on schedule and within budget.

Recent DOE efforts (Nelson, 1999b) are aimed at developing upgraded information technology capabilities (“TRANSCOM 2000”) for the TRANSCOM system. Specifically, modem connections to access data of interest (e.g., the commercial bill of lading for a shipment) are to be replaced in the near future by internet postings. These plans for improved user interface and data distribution capabilities do not address other parts of the system, such as the speed with which data are acquired and proc essed prior to posting. These data acquisition and processing activities appear to introduce time delays that limit system performance; for example, position updates showing the locations of trucks along routes are delayed by several (up to seven) minutes (Nelson, 1999b). An as-yet-unspecified element of these planned upgrades is the extent to which future stakeholder participation will be solicited and used to provide sufficient feedback to ensure that the product ultimately developed addresses user concerns. Moreover, the timetable for off-the-shelf availability of TRANSCOM 2000 appears to the committee to be several years in the future, a problematic scenario for a WIPP shipping activity that is already underway.

One issue relevant to these planned information disclosures in TRANSCOM 2000 is the extent to which such information is needed or useful, by which parties, and to what ends. For example, the terrorist hazard and/or the potential for deliberate sabotage would presumably increase as this information is disseminated more broadly. If restricted access to certain information were important, security firewalls could be used to prevent internet information from being accessed outside of the TRANSCOM user community.

At present, the National TRU Program is one of many DOE users of the TRANSCOM system that is managed by another DOE program unit, the DOE transportation center in Albuquerque, New Mexico; other DOE transportation users include shippers of low-level waste and spent nuclear fuel. If the DOE transportation program that maintains TRANSCOM cannot provide sufficient improvements to fully implement the above recommendations, another approach would be for the National TRU Program to adapt a commercially available tracking system for use on WIPP shipments only. If the tracking system need only meet WIPP shipment requirements, the system specifications would likely be simpler, with a correspondingly greater likelihood that a commercially available product could be adapted for use. For example, WIPP shipments involve unclassified material, which may allow relief from the full suite of TRANSCOM system requirements that have been developed for all of DOE shipping needs.

DOE's Emergency Response Program

Finding: The responsibility for emergency response is divided between DOE and the states along WIPP shipment corridors. In the committee's view, a system to maintain up-to-date information on response capability would contribute significantly to the effectiveness of the transportation system. The WIPP emergency response program has not assessed sufficiently whether adequate and timely emergency response coverage for a transportation incident exists along the full extent of each WIPP route. No formal system presently exists to identify areas where coverage may be inadequate.

Recommendations: The committee recommends that DOE explore with states and other interested parties how to develop processes and tools for maintaining up-to-date spatial information on the location, capabilities, and contact information of responders, medical facilities, re covery equipment, regional response teams, and other resources that might be needed to respond to a WIPP transportation incident. This assessment should explore which organization(s) should develop and maintain the capability to generate and maintain such information. DOE should also determine where emergency response capability is currently lacking, identify organization(s) responsible for addressing these deficiencies, and take action to address them.

Rationale: To respond appropriately to any accident or other incident associated with a WIPP shipment, an emergency response system has been developed involving the DOE and state and local governments. Four levels of emergency response teams have been established. The first responders, typically the local police or local fire department, are to alert others. Their “911” call routes the incident to the attention of the second responders, the state emergency management agency, which then involves the state police and any state hazardous material (HAZMAT) or radiological response teams. The third responders are DOE Radiological Assistance Program teams that would be sent from major DOE sites (e.g., Idaho Engineering and Environmental Laboratory or the DOE Carlsbad Area Office) to conduct radiological emergency (medical) response. The fourth level of response is DOE remediation teams who perform measures such as righting a truck and any necessary site cleanup and restoration activities (DOE, 1998a).

Because of the required integrity of the TRUPACT-II shipping container, which is tested and certified to conform to the USNRC's 10 CFR 71 regulatory requirements, the containment offered by this container normally cannot be breached in an accident scenario. Therefore, emergency response procedures in these four levels of response normally would preclude any consideration of releases of materials from the TRUPACT-II. Under normal conditions, the emergency response procedures would still be needed for traffic management and other necessary operations in accident-related situations.

DOE's emergency response program relies heavily on WIPP corridor states to conduct emergency responder training and develop response plans in the event of a transportation incident. DOE also maintains its own specialized response capabilities that can be deployed on an as-needed basis. Although this approach offers certain advantages in terms of state and local involvement, system-level integration is a significant concern.

Maintaining an effective emergency response program necessitates that, if an incident should occur anywhere along a WIPP route, qualified responders can reach the scene in a timely fashion. Emergency preparedness is a formidable challenge given the thousands of miles of highway that comprise WIPP routes.

While WIPP corridor states are coordinating with DOE to ensure the safe transport of WIPP shipments[18] (DOE, 1995, 1999b; Klaus, 1999; Ross, 1999; Wentz, 1999), the public may view this responsibility as ulti

[18]These activities have included training drills that have been conducted over the past several years to simulate real transportation procedures and accident scenarios.

mately resting with DOE as the system manager. The public might well expect qualified emergency response coverage along the entire length of each WIPP route, and in the committee's view, DOE could be heavily criticized if an event occurs that demonstrates weaknesses in the emergency response program, regardless of whether serious consequences are involved. Hence, although the recommendations in this section are not legal requirements, these assessments of the emergency response capabilities are, in the committee's view, important for providing a well-orchestrated transportation system.

The system-level integration necessary to ensure adequate emergency response would have to manage the jurisdictional boundaries between the various responsible government agencies. For example, under the federal Occupational Safety and Health Act (specifically, 29 CFR 1910.120), an employer is responsible for providing training; consequently, the state has the responsibility to determine the extent and adequacy of training (i.e., who is trained and in what capabilities) for first- and second-level responders. States have, to date, offered free WIPP-related training opportunities. No “quality assurance” program yet exists to evaluate periodically and systematically the extent of training and response capabilities within states. Moreover, the database lists trained personnel by state only, rather than by local region (e.g., county). As required by the Land Withdrawal Act, DOE provides the states with WIPP-specific hazard information, but DOE does not furnish protective, detection, monitoring, or communication equipment to states.

These and other demarcations of responsibilities should be managed to ensure that prompt and effective response capability for any transportation incident exists anywhere along a WIPP route. Although the training and response time associated with the first and second responders are not under DOE's direct control, a system to assess the extent and adequacy of this response coverage would be useful for DOE to properly prepare for and manage WIPP transportation incidents.

COMMITTEE PERSPECTIVE ON NATIONAL TRU PROGRAM REQUIREMENTS

A reasonable goal for the National TRU Program is to send DOE TRU waste to WIPP at a minimum risk (from all sources of risk, including radiological exposure and highway accidents) and cost. The current system for managing TRU wastes does not achieve this goal. The current transportation system cannot be used to ship a large fraction of the TRU waste volume without significant repackaging (Connolly and Kosiewicz, 1997; DOE, 1999b; Mroz et al., 1997). For the waste inventory that does qualify for shipment in this system, risk and cost considerations have not been optimized.

The terms and activities selected by DOE Carlsbad Area Office for submission to its regulatory authorities to satisfy applicable regulations and other concerns do not produce an optimum balance between risk and cost, in the spirit of ALARA. **The committee recommends that waste management procedures be reviewed and revised, with reduction of risk and cost as the guiding principles.**

As experience is gained in the WIPP shipping program, empirical data could be gathered to improve upon the initial estimates of risk and cost that are associated with each operation. The effort to reduce risks and costs necessarily would include some consideration of uncertainty, the procedures needed to adequately bound this uncertainty, and an assessment of which TRU waste program elements are the most important to control.

For example, the current National TRU Program has many procedures to control certain program elements. Over time, the most effective of such controls could be identified and retained. The reduction of risks and costs is possible in a management approach that takes into consideration public preferences for certain restrictions and implements procedures to minimize relevant uncertainties. As empirical data and experience are gathered, estimates of risks and costs of various components of the TRU waste operations can be refined. Such risk and cost estimates are useful to probe the elements of the waste management system that need to be controlled most restrictively, whether to meet legal or technical safety restrictions or to address public preferences for how radioactive waste is to be managed and transported.

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Appendix A

Background Information

The material in this appendix provides background information on the long-term performance of the Waste Isolation Pilot Plant (WIPP) as well as waste characterization and transportation activities associated with the National TRU Program.

ASSESSMENT OF LONG-TERM PERFORMANCE

The ability of WIPP to isolate radioactive waste from the accessible environment has been studied and modeled in a performance assessment calculation. The performance assessment organizes information relevant to long-term (i.e., over a 10,000-year period) repository behavior by assessing the probability and consequence of major scenarios by which radionuclides can be released to the environment surrounding the WIPP site. Important scenarios include those due to human activities, whether deliberate or unintentional, that might occur near the WIPP site and potentially compromise the integrity of the repository. For example, drilling for hydrocarbon resources in formations underlying WIPP is currently practiced in the Delaware Basin on land surrounding the WIPP site; therefore, stylized "human intrusion" scenarios in which future boreholes are drilled through WIPP have been analyzed in the performance assessment model.

Using this performance assessment, the U.S. Department of Energy (DOE) has modeled the long-term performance of the WIPP repository to meet regulatory requirements. As specified by the 1992 Land Withdrawal Act (P.L. 102-579) passed by the U.S. Congress, the U.S. Environmental Protection Agency (EPA) is the external regulatory authority for WIPP, using as a regulatory standard the rule 40 CFR 191.[1] The performance assessment model formed the basis of the 1996 DOE application to the EPA to obtain a certificate of compliance with the 40 CFR 191 standard to open and operate WIPP. The EPA granted this certificate in 1998, and EPA oversight continues in periodic (i.e., every five years)

[1]For compliance with the standard of 40 CFR 191, the EPA issued rule 40 CFR 194 in 1996 to provide a regulatory interpretation of how these requirements would apply to WIPP.

recertifications. Changing some of the repository features (e.g., the design of the engineered seals to close underground rooms once they are filled with waste or the design of the seals to close the vertical shafts to the surface) would require regulatory approval because of their importance to the model of long-term performance.

DOE MANAGEMENT OF TRU WASTE

Transuranic (TRU) wastes are stored and managed at several DOE sites nationwide. To dispose of these wastes at WIPP, they must be retrieved from storage, characterized, repackaged (if necessary), and transported to WIPP, where they are unloaded from shipping containers and sent underground for emplacement in the disposal rooms.

These activities are conducted under the auspices of the National TRU Program administered by the DOE Carlsbad Area Office. DOE sites sending waste to WIPP must meet the waste characterization and transportation specifications that are contained in the WIPP waste acceptance criteria. The specifications on characterization and transportation operations are designed to meet all applicable regulations that have been promulgated by the EPA (chiefly through the Resource Conservation and Recovery Act, or RCRA), the U.S. Nuclear Regulatory Commission (USNRC), and the U.S. Department of Transportation (DOT). The waste characterization activities and the transportation system are described in more detail below.

Waste Characterization Activities

The characterization program described here has been developed for contact-handled[2] TRU waste and applied to date on non-mixed waste.[3] The methods, equipment, procedures, determination of uncertainty, and other protocols used at DOE sites to perform these characterizations are approved by both the DOE Carlsbad Area Office and the EPA. The major procedures are as described in the following sections:

Determination of the Origin and Composition of the Waste by Acceptable Knowledge. Acceptable knowledge of the origin and composition of the waste must be available in documentation to prove that the waste is of defense origin (by the terms of the Land Withdrawal Act, only defense-related TRU waste may legally be sent to WIPP) and to provide

[2]Contact-handled waste is that for which the maximum radiation dose rate at the surface of the waste container is less than 200 mrem per hour. Essentially no shielding other than the waste container is needed. Much of the DOE TRU waste has radioactivity due primarily to alpha-emitting actinides. Because alpha particles are relatively easy to shield, such waste would have a low surface dose rate and therefore would be classified as contact-handled waste.

[3]Mixed waste is waste with radioactive constituents regulated under the Atomic Energy Act mixed with hazardous chemical materials regulated under RCRA. Non-mixed radioactive waste is waste that can be shown not to contain RCRA-regulated materials.

characterization information on the waste constituents. The DOE Carlsbad Area Office and EPA use the acceptable knowledge documentation to certify each "waste stream" (i.e., waste-generating process), and TRU waste sent to WIPP must come from a certified waste stream.

Sampling and Analysis of Homogeneous Waste for RCRA Constituents. Most of the TRU waste is heterogeneous in nature and requires no further characterization beyond acceptable knowledge to satisfy the regulatory requirements of RCRA. For homogeneous waste, a fraction of the waste containers (e.g., 55-gallon drums or standard waste boxes) are cored to extract representative samples that are analyzed for constituents (e.g., volatile and semi-volatile organic compounds, toxic metals, and other hazardous chemicals) regulated by RCRA. Both the acceptable knowledge procedure (for heterogeneous waste) and the sampling and analysis procedure (for homogeneous waste) were proposed by DOE for the terms of operation that would be specified in its RCRA Part B permit. These terms have been accepted by New Mexico, which has authority delegated by the EPA to regulate RCRA materials and mixed waste and which issued the RCRA Part B permit in October 1999.

Real-Time Radiography. A real-time radiography procedure using x-rays is performed on all waste containers to look for items such as pressurized cans or free-standing liquids that are prohibited from being transported under DOT regulations. If any of these items are present in a waste container, its contents are repackaged, at which time the prohibited materials are removed. Another purpose of the radiography examination is to confirm the acceptable knowledge characterization information.

Visual Examination. A visual examination is performed on a fraction of the waste containers, by spilling the waste contents into a glovebox, to verify the acceptable knowledge and real-time radiography information. The value of this fraction was proposed by DOE to be two percent of the initial population of containers of each waste stream, and if these evaluations resulted in few miscertifications, then the percentage of subsequent waste containers to undergo visual examination would be reduced. In October 1999, New Mexico in its RCRA Part B permit stipulated the initial fraction of containers to undergo visual examination to be 11 percent.

Radioassay and Determination of Fissile Isotope Content. The number of curies of each transuranic isotope is determined by radioassay (e.g., gamma scans) to a specified precision and accuracy. The fissile isotope content is assessed using methods such as passive-active neutron systems. This information is used to ensure criticality safety, a USNRC requirement, which imposes a restriction on the amount (several hundred grams) of each fissile species per container. This restriction is less stringent than the amount derived from the gas generation model, discussed below.

Headspace Gas Sampling. Headspace gas sampling is carried out on all waste containers for flammable gases (specifically, volatile organic compounds, hydrogen, and methane). This procedure has been proposed as a means of checking on conformity with the DOT regulations (e.g., 40 CFR 173 and 40 CFR 177) and USNRC regulations (e.g., 10 CFR 71) that address the transport of flammable and/or gas-generating substances with radioactive materials (Mewhinney, 1998b). These regulations include the following statements:

- 49 CFR 173.21(g): "Packages which give off a flammable gas or vapor, released from a material not otherwise subject to this subchapter, likely to create a flammable mixture with air in a transport vehicle" are forbidden.
- 49 CFR 173.21(h): "Packages containing materials which will detonate in a fire" are forbidden.
- 49 CFR 173.24(b)(3): "There will be no mixture of gases or vapors in the package which could, through any credible spontaneous increase of heat or pressure, significantly reduce the effectiveness of the packaging."
- 49 CFR 177.848 specifies that flammable gases and radioactive materials "may not be loaded, transported, or stored together in the same transport vehicle or storage facility during the course of transportation unless separated in a manner that, in the event of leakage from packages under conditions normally incident to transportation, commingling of hazardous materials would not occur."
- 10 CFR 71.43(d): "A package must be made of materials and construction that assure that there will be no significant chemical, galvanic, or other reaction among the packaging components, among package contents, or between the packaging components and the package contents, including possible reaction resulting from in leakage of water, to the maximum credible extent. Account must be taken of the behavior of materials under irradiation."

DOE has proposed the headspace gas sampling procedure in its application to the USNRC for a licensing certificate on the transportation package (named the TRansUranic PACkage Transporter, or TRUPACT-II) that is loaded with waste containers for transport by truck to WIPP.

Repackaging of Waste to Meet Wattage Limits Imposed by a Radiolytic Gas Generation Model. Gas generation can occur during the transport of a waste container to WIPP. The radiolytic generation of hydrogen gas in TRU waste comes from the co-disposal of organic materials (containing hydrogen) with alpha-emitting radionuclides, which irradiate the organic matter to produce H^+ ions that combine to form H_2 molecules. The current gas generation model is based on assumptions about the configuration of organic materials and radionuclides. It relates the concentration of hydrogen gas in any headspace to the alpha activity (i.e., activity from alpha-emitting radionuclides) within each waste container. More than one gaseous headspace can exist in a waste container, primarily because TRU waste, when generated and disposed in DOE facilities, was contained within layers of confinement provided by plastic bags that may still be intact and thereby inhibit the flow of hydrogen.

By placing a 5 percent (mole fraction) limit on the maximum H_2 concentration within any headspace, this gas generation model calculates an upper limit, commonly expressed as a maximum thermal wattage, on the alpha activity allowed for the entire waste container. These wattage limits are a function of the waste materials and the number of layers of confinement provided by plastic bags. Because of its conservatism, the value of 5 percent H_2 (as a mole fraction) in air as a "flammability limit" can be used in any USNRC license application for a transportation package without the need for further safety analysis.

For example, for a 55-gallon drum containing a plastic liner and heterogeneous debris with plutonium inside three layers of sealed plastic bags, the wattage limit is approximately 0.028 W (DOE, 1996b, p. 5-6e), which corresponds to a limit of 14 g (0.89 Ci) of plutonium-239 or 0.049 g (0.84 Ci) of plutonium-238. Waste containers containing more wattage than the maximum value allowed by the model have their waste contents repackaged to distribute the TRU waste into configurations that will meet these wattage limits. This is accomplished by spilling these contents into shielded gloveboxes and dividing the waste into several new containers, each filled with a fraction of the contents of the original waste container. At Los Alamos National Laboratory in 1998-1999, gas generation restrictions resulted in the repackaging of 36 drums of plutonium-238 waste from the waste stream "TA-55-43" into approximately 120 drums that were placed inside standard waste boxes.[4]

The output of the characterization program is a set of characterization data for each waste container. If the characterization information is within acceptable limits as determined by the waste acceptance criteria and quality assurance program plan (or waste analysis plan) specifications, the waste container is certified and approved for shipment to WIPP.

Truck Transportation to WIPP

At the DOE sites containing TRU waste, the certified TRU waste containers are loaded inside TRUPACT-II shipping containers that are then sealed with a vacuum-tight seal. The TRUPACT-II is classified and regulated as a "Type B" package for fissile materials.[5] To ensure that the waste contents are safely contained during normal shipment conditions and accident scenarios, this transportation package must meet design features such as double containment (i.e., it must have an inner and outer container) and a vacuum seal. Within the inner container, two standard waste boxes, fourteen 55-gallon drums, or one standard waste box and seven 55-gallon drums can be placed. These waste containers are loaded into the TRUPACT-II using an overhead crane in a bay of a building that a truck can drive into to avoid the need to unfasten the TRUPACT-II from the trailer.

[4] A 55-gallon drum has a volume of approximately 0.2 m^3, whereas a standard waste box is a 1.9m^3 container that can hold three 55-gallon drums.

[5] This designation is a regulatory term to designate packages used to transport plutonium isotopes, which are contained in TRU waste.

The trucks travel to WIPP on approved highway routes during approved times and maintain communication with a DOE control center. In addition to a cellular telephone and a citizens band radio, each truck contains a satellite transponder that enables it to be tracked en route using DOE's satellite-based telecommunications system, the TRANSportation Tracking and COMmunication (TRANSCOM) System. The TRUPACT-IIs are inspected at the WIPP site and their contents (waste-filled drums or boxes) are unloaded and delivered to an underground elevator for emplacement into rooms excavated in the subsurface salt bed.

Appendix B

Joint USNRC and EPA Guidance on Mixed Waste

A joint U.S. Nuclear Regulatory Commission (USNRC) and U.S. Environmental Protection Agency (EPA) document (62 FR 62079, 1997) provides regulatory guidance outlining the testing requirements for mixed radioactive and hazardous waste. In this dual agency guidance document, the EPA and USNRC position is that a combination of common sense, modified sampling procedures, and cooperation between state and federal regulatory agencies will minimize any hazards associated with sampling and testing mixed waste.

Waste generators may determine whether their waste is a Resource Conservation and Recovery Act (RCRA) hazardous waste based on knowledge of the materials or chemical processes that were used. That is, RCRA regulations do not require testing of the waste.

Therefore, where sufficient knowledge of materials or of the process exists, the generator need not test the waste to determine that it possesses a hazardous characteristic, which would necessitate that RCRA be applied (although generators and subsequent handlers would be in violation of RCRA if they managed hazardous waste erroneously classified as nonhazardous outside the RCRA hazardous waste system). For this reason, facilities wishing to minimize testing often assume that a questionable waste is hazardous and handle it accordingly.

Flexibility exists in the hazardous waste regulations for generators; operators of treatment, storage, and disposal facilities; and mixed waste permit writers to tailor mixed waste sampling and analysis programs to address radiation hazards. For example, upon the request of a generator, a person preparing a RCRA permit for such a facility has the flexibility to minimize the frequency of mixed waste testing by specifying a low testing frequency in a facility's waste analysis plan. The EPA position, as stated in 55 FR 22669 (1990), is that the frequency of testing is best determined on a case-by-case basis by the permit writer.

The joint USNRC-EPA agency guidance document (62 FR 62079, 1997) appears to the committee to provide appropriate guidelines for implementation and integration of RCRA requirements for mixed TRU waste. Implementation of this regulatory guidance could significantly reduce the testing protocols and associated radiation exposure of personnel. At present, the procedures specified in the waste acceptance criteria and quality assurance program plan documents and in the RCRA Part B permit for the testing of mixed waste seem at odds with the ALARA (as low as reasonably achievable) principle.

Appendix C

Biographical Sketches of Committee Members

B. John Garrick, *Chair,* independent consultant, is a co-founder of PLG, Inc., an international engineering, applied science, and management consulting firm in Newport Beach, California. He received his B.S. degree from Brigham Young University and his M.S. and Ph.D. degrees in engineering and applied science from the University of California, Los Angeles. His professional interests involve risk assessment in applications in fields such as nuclear energy, space, and defense, and in the chemical, petroleum, and transportation industries. He has received numerous awards, including the Society for Risk Analysis Distinguished Achievement Award. He was appointed to the U. S. Nuclear Regulatory Commission's Advisory Committee on Nuclear Waste in 1994, for which he is now Chairman. Dr. Garrick was elected to the National Academy of Engineering in 1993. He has been a member of the Committee on the Waste Isolation Pilot Plant since 1989.

Mark Abkowitz, professor of civil engineering at Vanderbilt University and director of the Center for Environmental Management Studies, has many years of experience in hazardous materials transport. He has published widely on transportation issues such as the risks of transporting high-level radioactive waste. He is a member and former chairman of the NRC Transportation Research Board standing committee on hazardous materials transport.

Alfred W. Grella, independent nuclear and hazardous materials transportation consultant, retired in 1990 from a career in U.S. government service, first at the Department of Transportation and later at the U.S. Nuclear Regulatory Commission. His distinguished career spans 40 years as a professional in health physics, health protection, transportation, inspection and enforcement, training, and related regulatory activities. Mr. Grella received a Bachelor's degree in chemistry from the University of Connecticut and completed the one-year management program at the National Defense University Industrial College of the Armed Forces. He has authored over 30 published papers. He is a member of the American Nuclear Society and a Fellow of the Health Physics Society. Mr. Grella received the M. Sacid (Sarge) Ozker Award in 1996 for distinguished serv ice and eminent achievement in the field of radioactive waste management.

Michael Hardy, president of Agapito Associates, Inc., has experience in numerical modeling and field experimentation in practical, engineering-oriented studies to gather characterization data and to evaluate the merits of design features of proposed high-level waste repositories. Dr. Hardy is a member of the Society of Mining, Metallurgical and Exploration Engineers, Inc., and the American Society of Civil Engineers (ASCE). He is Chairman of the Underground Technical Research Council, a joint ASCE/American Institute of Mining, Metallurgical, and Petroleum Engineers Committee.

Stanley Kaplan, principal of Kaplan & Associates, Inc., is one of the early practitioners of the discipline now known as Quantitative Risk Assessment and a major contributor to its theory, language, philosophy and methodology. Dr. Kaplan is a Fellow of the Society for Risk Analysis and the author of a number of the seminal papers in this field. He is one of the first contributors to the Russian science TRIZ, the Theory of the Solution of Inventive Problems, and currently consults and teaches in this area. He is a founder and board chairman of Bayesian Systems, Inc., a Washington-based company developing diagnostic, decision, simulation, and business management software. Dr. Kaplan is the recipient of several awards and honors, including the Society for Risk Analysis Distinguished Achievement Award in 1996. Dr. Kaplan was elected to the National Academy of Engineering in 1999.

Howard M. ‘Skip' Kingston is professor of chemistry in the Department of Chemistry and Biochemistry and in the Center for Environmental Research and Education. Also at Duquesne University, he is director of the Center for Microwave and Analytical Chemistry. His research interests include the development, automation, and standard encapsulation and transfer of analytical analysis methods. For the past several years, he has been actively involved in advancing the area of microwave sample preparation through basic research and the development of procedures that have been adopted by the EPA as standard methods. From 1976 to 1991 he was a supervisory research chemist in the Inorganic Analytical Research Division of the National Institute of Standards and Technology (NIST), where he conceived and managed the Consortium on Automated Analytical Laboratory Systems dedicated to developing automated analytical capability for industry. He has received numerous awards for his pioneering work in several areas, including R&D 100 Awards in 1996 and 1998, the IR 100 Award in 1987, the 1988 “Pioneer in Laboratory Robotics” award, the 1990 NIST Applied Research Award, the Department of Commerce Bronze Medal in 1990, the Award of Merit from the Federal Laboratory Consortium in 1991, and the EPA RCRA Service to Others Award in 1998. He has co-edited and co-authored the American Chemical Society professional reference texts *Introduction to Microwave Sample Preparation: Theory and Practice* (1988) and *Microwave Enhanced Chemistry: Fundamentals, Sample Preparation, and Applications* (1997).

He holds multiple patents in the field of speciation, microwave chemistry, and chelation chromatography.

W. John Lee, Peterson Chair and professor of petroleum engineering at Texas A&M University and formerly executive vice-president of technology at S. A. Holditch & Associates, Inc., has expertise in petroleum reservoir imaging, flow tests in low-permeability formations, and enhanced recovery practices. Professor Lee was elected to the National Academy of Engineering in 1993.

Milton Levenson, independent consultant, is a chemical engineer with over 50 years of experience in nuclear energy and related fields. His technical experience includes work in nuclear safety, fuel cycle, water reactor technology, advanced reactor technology, remote control technology, and sodium reactor technology. His professional experience includes research and operations positions at Oak Ridge National Laboratory, Argonne National Laboratory, the Electric Power Research Institute, and Bechtel. Mr. Levenson is the past president of the American Nuclear Society; a fellow of the American Nuclear Society and the American Institute of Chemical Engineers; and the recipient of the American Institute of Chemical Engineers' Robert E. Wilson Award. He is the author of over 150 publications and presentations and holds three U.S. patents. He received his B.Ch.E. from the University of Minnesota. He was elected to the National Academy of Engineering in 1976.

Werner F. Lutze, professor of chemical and nuclear engineering at the University of New Mexico and director of the UNM Center for Radioactive Waste Management (CeRaM), has over 25 years of research experience in materials science and geochemical issues relevant to the management of radioactive wastes, including selective mineral ion-exchange processes, repository near-field chemistry, waste form development, and trace analyses. He has published widely on weapons plutonium immobilization, waste disposal, and the chemistry of nuclear materials. Professor Lutze is a member of several professional organizations, including the Materials Research Society, the German Nuclear Society, and Sigma Xi.

Kimberly Ogden, associate professor of chemical and environmental engineering at the University of Arizona, has conducted research with Los Alamos National Laboratory collaborators to design treatment methods for remediating hazardous waste sites containing both toxic metals and organics, including plutonium-cellulose mixtures. She is also engaged in collaborations with ECO Compliance Inc. in preparing proposals and reports for the remediation of hazardous waste sites. Professor Ogden has authored or co-authored several book chapters, papers, and presentations in environmental science and technology. She is a member of the American Institute of Chemical Engineers, the American Association for the Advancement of Science, and the American Chemical Society.

Martha Scott, associate professor of oceanography at Texas A&M University, is a researcher in marine radiochemistry and geochemistry. Her present research involves radionuclide distribution in the Russian Arctic. Her work has dealt with the interaction between oceans and rivers, transport of materials in the marine environment, and chemistry of manganese nodules. The behavior of plutonium isotopes in rivers, estuaries, and marine sediments has been one of her longstanding research interests. She served for two years as an associate program director for chemical oceanography at the National Science Foundation (1992-1993). She received the Ph.D. degree from Rice University and was a National Science Foundation post doctoral fellow at Yale University.

John M. Sharp, Chevron Centennial Professor of Geology at The University of Texas at Austin, leads an active research program in hydrology. Professor Sharp has authored and co-authored over 200 journal articles, books, reports, and presentations. He is a fellow of the Geological Society of America and recipient of its O.E. Meinzer award (1979) and the American Institute of Hydrology's C.V. Theis Award (1996). Dr. Sharp is the current editor of *Environmental and Engineering Geoscience.* He received his B. Geological E. with Distinction from the University of Minnesota and his M.S. and Ph.D. degrees in Geology from the University of Illinois.

Paul G. Shewmon, emeritus professor of materials science and engineering at the Ohio State University, received a B.S. degree in metallurgical engineering from the University of Illinois and M.S. and Ph.D. degrees, also in metallurgical engineering, from the Carnegie Institute of Technology. He recently retired as Humbolt Senior Scientist at the Max Planck Institute Metallforschung in Stuttgart. He has received the ASM deMille Campbell Lecture and Award and the TMS Institute of Metals Lecture & Mehl Medal. He was elected to the National Academy of Engineering in 1979.

James Watson, Jr., professor of environmental sciences and engineering and the Director of the Air, Radiation, and Industrial Hygiene Program at the University of North Carolina at Chapel Hill, holds an M.S. degree in physics from North Carolina State University and a Ph.D in environmental sciences and engineering from the University of North Carolina at Chapel Hill. Professor Watson is accomplished in the fields of environmental radioactivity and radioactive waste management. He has received the Underwood and McGavran Awards for excellence in teaching and the Greenberg Alumni Endowment Award for excellence in teaching, research, and service. He is a past president of the Health Physics Society and a past chairman of the Radiological Health Section of the American Public Health Association. He has served on the Environmental Protection Agency's Radiation Advisory Committee and the executive committee of the agency's Science Advisory Board. He is a past chairman of the North Carolina Radiation Protection Commission and currently chairs the commission's Committee on Low-Level Radioactive Waste Management.

Ching H. Yew, an independent consultant and emeritus professor from The University of Texas at Austin, has specialized in the study of hydraulic fracturing and borehole stability. Dr. Yew is a fellow of the America Society of Mechanical Engineers and a member of the Society of Petroleum

Engineers. Dr. Yew has authored a text and published several articles concerning hydraulic fracturing and borehole stability. The computer code developed by him has been adopted for field use by many oil and gas industries.

Appendix D

Acronyms

ALARA	as low as reasonably achievable
ATMX	Atchison Topeka Munitions private railcar
CFR	Code of the Federal Regulations
CEMRC	Carlsbad Environmental Monitoring Research Center
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
NORM	naturally occurring radioactive material
NRC	National Research Council
RCRA	Resource Conservation and Recovery Act
TRANSCOM	TRANSportation Tracking and COMmunication system
TRU	transuranic
TRUPACT	TRansUranic PACkage Transporter
USNRC	U.S. Nuclear Regulatory Commission
WIPP	Waste Isolation Pilot Plant