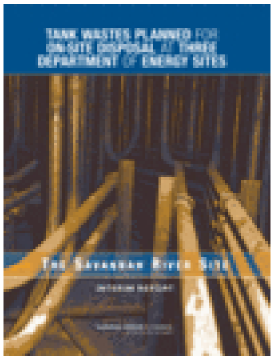


**Tank Wastes Planned for On-Site Disposal at Three Department of Energy Sites: The Savannah River Site - Interim Report**

Committee on the Management of Certain Radioactive Waste Streams Stored in Tanks at Three Department of Energy Sites, National Research Council

ISBN: 0-309-55172-2, 88 pages, 6x9, (2005)

# Tank Wastes Planned for On-Site Disposal at Three Department of Energy Sites: The Savannah River Site

## Interim Report

Committee on the Management of Certain Radioactive Waste Streams Stored in Tanks at Three Department of Energy Sites

Nuclear and Radiation Studies Board

Division on Earth and Life Studies

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THE NATIONAL ACADEMIES PRESS
Washington, D.C.
**www.nap.edu**

**THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001**



Support for this study was provided by the U.S. Department of Energy under cooperative agreement number DE-FC01-04-EW07022. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number 0-309-09693-6

Cover photograph: Taken from Tank 4 Interior Photo Study - 1954 Pre-Startup. T.B. Caldwell, CBU-PIT-2005-00111. Aiken, S.C. Westinghouse Savannah River Company. May 5, 2005.

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu



Printed in the United States of America.

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[1] Dr. Rodney Ewing resigned from the committee on May 10, 2005 and was appointed as a consultant.

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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's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its 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 content of 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 review of this report:

Edward L. Albenesius, Consultant, Aiken, South Carolina
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Chris G. Whipple, ENVIRON International Corporation, Emeryville, California

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the report's conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Richard A. Conway, Union Carbide Corporation (retired), Charleston, West Virginia, and John F. Ahearne, Sigma Xi and Duke University, Research Triangle Park, North Carolina. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional 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 institution.

# Contents

# Summary

In the Ronald Reagan National Defense Authorization Act of 2005 (Section 3146 of Public Law 108-375), Congress directed the Department of Energy (DOE) to request a study from the National Academies that evaluates DOE's plans for managing certain radioactive wastes stored in tanks at its sites in Idaho, South Carolina, and Washington.[1] The wastes addressed in this study are from reprocessing of spent nuclear fuel, exceed certain concentration limits,[2] and are planned for disposal at the sites mentioned above.

Congress asked the National Academies[3] for an interim and a final report addressing this task. According to the Defense Authorization Act, the interim report "shall address any additional actions the Department should consider to ensure that the Department's plans for the Savannah River Site, including plans for grouting the tanks, will comply with the performance objectives [of 10 CFR 61[4]] in a more effective manner" (Section 3146 (e)(A)). This document fulfills the interim report request.

Congress requested this study at the same time another provision of the same law (Section 3116) provided the basis for DOE, in consultation with the U.S. Nuclear Regulatory Commission (USNRC), to determine that tank wastes at the South Carolina and Idaho sites meeting certain listed criteria are not high-level waste (HLW).[5] Such wastes may then be disposed of on-site.

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[1] The full statement of task can be found in Appendix A.

[2] These limits define the maximum radionuclide concentrations for Class C low-level waste for radioactive waste disposal facilities regulated by the U.S. Nuclear Regulatory Commission. The limits are found in Part 61, Title 10 of the Code of Federal Regulations (10 CFR 61) titled "Licensing Requirements for Land Disposal of Radioactive Waste." For the purpose of this study, the committee interprets this concentration criterion to apply to the waste streams stored in tanks prior to waste processing.

[3] The National Academies appointed a committee to carry out this study. Biographical sketches of committee members can be found in Appendix C.

[4] The performance objectives of 10 CFR 61 can be found in Appendix A and contain four mandates: (1) protect the general population from releases of radioactivity, (2) protect individuals from inadvertent intrusion, (3) protect individuals during operations, and (4) provide stability of the site after closure. Regulatory guides use a time period of 10,000 years for the performance period.

[5] The term "high-level waste" is used in this report according to its legal definition in the U.S. Code, Title 42, Chapter 108, Nuclear Waste Policy, Section 10101 (see page 13, footnote 8). There is no particular radioactivity concentration or dose limit associated with this definition.

## TECHNICAL BACKGROUND

The Savannah River Site has 51 underground tanks that are used for storing 138,000 cubic meters (36.4 million gallons) of hazardous and radioactive waste from chemical processing of spent nuclear fuel and related operations.[6] Tank construction and characteristics vary, but the typical tank is a large cylindrical carbon steel and reinforced concrete structure buried at a shallow depth (1 to 3 meters below the surface). The tanks' sizes range from about 2,800 cubic meters ($m^3$) to 4,900 $m^3$ (750,000 to 1.3 million gallons). The largest tanks are approximately 26 meters (85 feet) in diameter and 11 meters (35 feet) from the inner tank floor to the center of a domed ceiling. Most of the tanks are equipped with dense networks of vertical and horizontal cooling pipes, referred to as cooling coils (see Figure S-1). These cooling coils are used to remove heat produced by radioactive decay in the waste.

Twenty-seven of the tanks have a full secondary containment (i.e., a tank inside another tank) and are considered "compliant tanks" under the site's Federal Facility Agreement,[7] which regulates storage and disposal of hazardous waste at the site. The remaining tanks do not have complete secondary containment and are considered noncompliant. Visual inspections and conductivity probes in the tanks and in the annuli of the tanks have shown that about half of the noncompliant tanks have leaked in the past (although the leaks were confined to the tank's annulus in all but one case).


FIGURE S-1 Photograph of the interior of a Type I tank (Tank 4) prior to receipt of wastes.
SOURCE: Caldwell (2005a).

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[6] Reprocessing operations at the Savannah River Site started in 1953 and continue on a reduced scale to this day. A map of the site can be found in Appendix E.

[7] This is an agreement among DOE, the Environmental Protection Agency, and the South Carolina Department of Health and Environmental Control and contains the plan for tank closure.

Although the composition of waste in each tank varies, the tanks generally contain a bottom layer of a peanut-butter-like deposit of insoluble solids (referred to as sludge), a layer of crystalline solids (the saltcake), and a salt solution (the supernate). The term “salt waste” is sometimes used to refer to saltcake and supernate. Although the sludge represents less than 10 percent of the volume, it contains about half of the radioactivity in the waste tanks,[8] mainly from insoluble actinides and strontium salts. The other half of the radioactivity is mostly in the supernate, where the soluble radionuclides, mainly cesium-137, are in solution. A fraction of the soluble radionuclides is also trapped as liquid in the interstices of the saltcake.

DOE has argued that it is impractical to dismantle and remove the tanks after the waste has been retrieved because of the exposures incurred by workers from radioactive residues and because of the overall prohibitive costs of exhuming such large structures. The committee has not seen analyses to support this claim. For each tank, the general plan is to retrieve the bulk of the waste, clean up the tank to the “maximum extent practical,”[9] and close the tank in place, according to milestones agreed to in the site’s Federal Facility Agreement. Because of practical limitations on waste retrieval, “emptied” tanks will still contain variable amounts of the radioactive waste (the “heel”), depending on the success of the retrieval and cleanup process.

DOE plans to close emptied tanks by placing layers of engineered grout to encapsulate and stabilize the tank heel and a controlled low-strength material to provide structural support against tank collapse and act as a physical barrier that inhibits the flow of water through the residual waste. Tanks that do not have a concrete roof would have a high-strength layer of grout that would serve as an intruder barrier. An engineered cover to retard infiltration to the tanks after closure is also under consideration.

DOE’s plan to manage the bulk of the waste retrieved from the tanks is to separate the radioactive from the nonradioactive components, the latter of which make up most of the waste volume. This processing generates two waste streams: (1) a high-activity waste stream, which will be immobilized and disposed off-site in a high-level waste repository,[10] and (2) a low-activity waste stream, which is to be disposed on-site.

At the Savannah River Site, DOE already retrieves sludge and then processes and immobilizes it in glass at its Defense Waste Processing Facility (DWPF). These operations generate as a secondary product a relatively low-activity liquid waste, referred to as the DWPF recycle stream, which is returned to the HLW tanks. To separate highly radioactive constituents of the salt waste, DOE proposes to utilize three different processes[11] that will be available at different times and have different capabilities. Two low-capacity processes are expected to be available sooner and are referred to as “interim” processing by DOE. These are the deliquification, dissolution, and adjustment (DDA) process, which could begin

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[8] The radionuclides of concern for this study are short-lived but highly radioactive isotopes, such as strontium-90 and cesium-137 and their decay products; long-lived (>30 years) radionuclides such as uranium and plutonium isotopes; and especially long-lived and highly mobile radioisotopes, such as iodine-129, technetium-99, tin-126, selenium-79, and neptunium-237.

[9] One of the criteria that DOE must use according to Section 3116 of the Defense Authorization Act to determine whether waste is not HLW and can be disposed as low-level waste (LLW) is if this waste has had highly radioactive radionuclides removed to the “maximum extent practical.” DOE is authorized to make this determination in consultation with the USNRC at the Savannah River and Idaho sites.

[10] The high-activity waste stream is outside the scope of this report, which focuses solely on waste disposed on-site.

[11] DOE refers to this as a two-phase, three-step approach. The committee has not adopted this way of describing the approach because it suggests that all wastes undergo each process, which is inconsistent with DOE’s plan.

immediately upon approval of the waste determination by the Secretary of Energy in accordance with Section 3116 of the 2005 National Defense Authorization Act, consultation with the USNRC, and permitting by the state of South Carolina; and the actinide removal, modular caustic-side solvent extraction process (ARP/MCU), which is expected to begin operations in 2007. A high-capacity chemical processing facility, called the Salt Waste Processing Facility, is scheduled to be available in 2009 and could be supplemented by the ARP, if needed.

DOE indicated to the committee that the Savannah River Site is facing a "tank space crisis" because of net waste inputs from current waste processing and waste removal operations. To alleviate the tank space crisis, DOE is proposing to begin processing salt waste using DDA as soon as possible (see Figure S-2). The low-activity waste streams from these three processes will have varying concentrations of radioactivity and will be mixed with cementitious material to form "saltstone" and disposed on-site as a monolith in near-surface concrete vaults.

## FINDINGS AND RECOMMENDATIONS

Although DOE, its regulators, and others worked with the committee to provide the information needed for this study, some data were not available (not yet collected, not yet generated, or not yet made public), and some plans had not yet been formulated or finalized

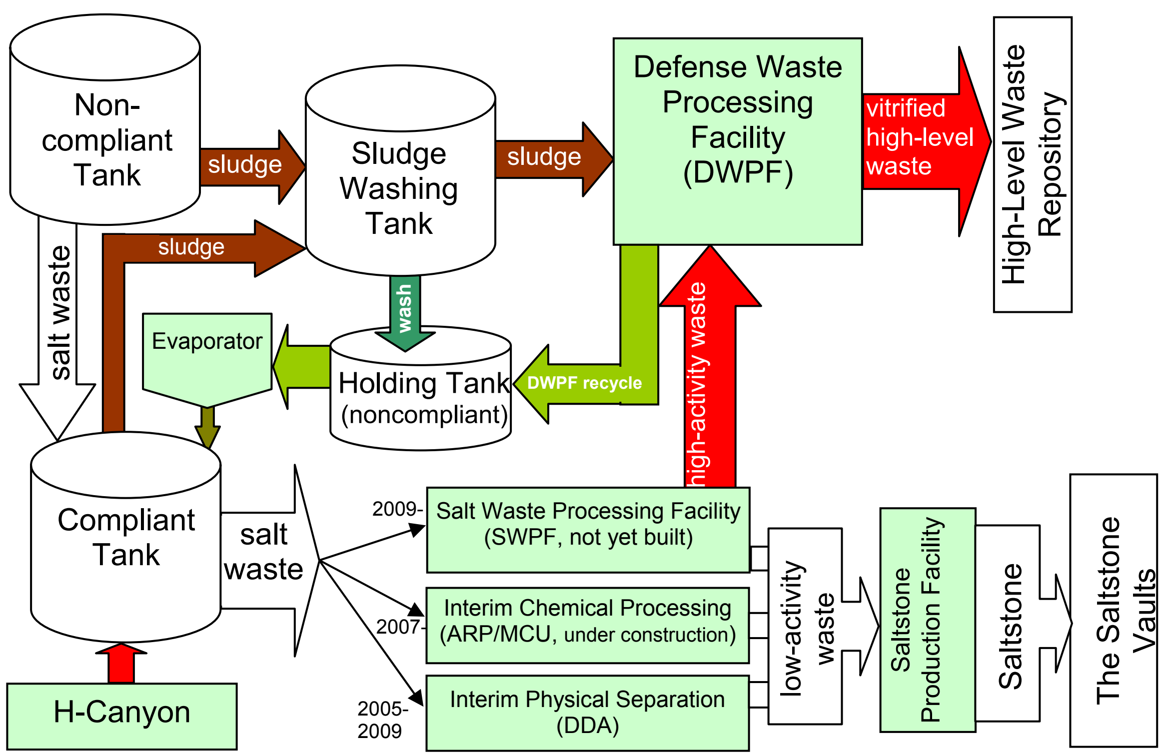


FIGURE S-2 Waste flows in the Savannah River Site waste management plans. Note that the sizes do not necessarily scale with the sizes of the waste flows.

when this report was written.[12] Appendix B describes the main documents to which the committee had access and the missing pieces of information to assess DOE plans for compliance with the performance objectives set forth in 10 CFR 61.

Therefore, the committee was unable to evaluate fully what, if any, actions are needed for DOE to comply with these performance objectives. However, the committee was able to evaluate factors that reduce risk and recommends actions to (1) reduce the waste left on-site and (2) increase DOE's understanding of the long-term performance of waste forms and other barriers to the release of radionuclides. These actions will increase confidence in DOE's ability to comply with the performance objectives in general and conform with the requirement to take actions to make releases of radioactivity to the environment as low as reasonably achievable (ALARA), with economic and social considerations taken into account. Findings and recommendations address four major issues: (1) near-term and long-term risks; (2) the tank space crisis; (3) Class C limits and performance objectives; and (4) research and development needs. The following findings and recommendations are based on the information available to the committee at the time of writing this interim report and may be extended in the committee's the final report.

### Near-Term versus Long-Term Risks

**Finding 1a: By far the greatest reductions in near-term probability and quantity of radionuclide and hazardous chemical releases to the environment are achieved by bulk removal and immobilization of liquid, salt, and sludge from the noncompliant high-level waste tanks. The tank heels that remain after bulk removal contain a smaller quantity of waste that is less mobile and constitutes a much lower near-term probability of release.**

**Finding 1b: The Savannah River Site Federal Facility Agreement has schedules for waste removal from and closure of the noncompliant tanks. For some tanks, the tank-closure step immediately follows the waste-removal step, making them appear to be coupled. This coupling could limit the time available for tank-waste removal and consequently could determine how much waste can be removed to "the maximum extent practical." A decoupled schedule is already planned for a limited number of tanks, as shown in Appendix F. Decoupling allows the consideration of a wider set of options for removing and/or immobilizing residual waste (especially for tanks that have significant obstructions that complicate waste removal), which could reduce long-term risks.**

**Recommendation 1: DOE should decouple tank waste removal and tank closure actions on a case-by-case basis where there are indications that near-term (5-10 year) techniques could become available to remove tank heels more effectively, safely, or at a lower cost. In evaluating schedules for each tank, DOE should consider the risks from postponing tank closure compared with the risk reductions that could be**

[12] The information-gathering phase for the interim report lasted from March through June 2005. Under the Federal Advisory Committee Act Amendments of 1997 (Public Law 105-153), any document provided to the committee from outside of the National Academies must be made available to the public, unless the document is exempt from disclosure under the Freedom of Information Act (Public Law 89-554) and its amendments. As a result, the committee could not accept any document that was undergoing security review, internal scientific review, or legal and policy review and was therefore not ready for public release.

**achieved if the postponement improves heel removal. Although the committee believes that postponing tank closure need not extend the closure dates of the tank farms, DOE should work with the State of South Carolina to revise the schedule for closure of a limited number of the tanks that contain significant heels, if necessary.**

The committee agrees with DOE's and South Carolina's overall approach to cleanup at the Savannah River Site: bulk removal of the waste containing the majority of the mobile radionuclides is the highest priority to reduce release of radioactive materials to the environment in the near term. The noncompliant tanks, about half of which have a history of leakage, demand attention first, but nearly all of the tanks are beyond their design lifetimes.

Filling a tank with grout is, from a practical point of view, an irreversible action, although it is conceivable to open a tank and excavate the grout if absolutely necessary. Moreover, postponing closure of some tanks for several years would appear to have essentially no effect on near- or long-term risk. The current approach of coupling cleanup and closure schedules forecloses options that may become available in the near future (e.g., using alternative technologies to reduce the radioactive heel [source] and/or using other types of immobilizing material to fill the tank).

DOE should decouple cleanup and closure schedules, keep as many options open as practical, and regularly assess technology developments and alternatives to reduce long-term risks presented by the tank heels. DOE should make additional investments in research and development to enhance tank waste retrieval (reducing the source term), improve residual waste immobilization (stabilizing the source term), or reduce the ingress of water once the tanks are closed (protect the source term), as stated in Recommendation 4. In some cases, tank closure need not be delayed, such as in tanks that have small heels (i.e., as small as the heels in Tanks 16, 17, and 20) and/or low concentrations of radionuclides, or if risks specific to the tank require early closure (i.e., as soon as waste removal is completed). Conversely, delaying closure may be warranted for tanks with large heels or high concentrations of radionuclides. This approach need not necessarily affect the final closure date of the tank farm, which will occur later than 2022, the milestone for closure of the noncompliant tanks. If new technologies become available in the near future (i.e., 5-10 years), it may be possible to clean up and/or close tanks faster (possibly leaving less waste behind), thus meeting the final milestone for the tank farms.

As DOE considers delaying closure for some tanks, it has to evaluate the advantages and disadvantages from both a risk and a cost perspective. If DOE can relax other constraints on tank waste removal, such as the tank space problem, delaying tank closure could free up funds planned for closure activities, and those funds could be devoted to enhancing waste removal, waste processing, and confidence in the near- and long-term performance of the waste immobilization and tank fill materials. Similarly, research and development require funds, but if they are successful they could result in lower costs and increased safety overall (see Finding and Recommendation 4).

### Tank Space Crisis

**Finding 2a: The lack of compliant tank space does appear to be a major problem because of continuing waste inputs and the anticipated future needs for space to support site operations and tank cleanup. As presently operated, sludge waste processing results in a net addition of waste to the compliant tanks. Salt waste processing will also require storage volume in compliant tanks for batch preparation and other operations.**

**Finding 2b: DOE plans to use the deliquification, dissolution, and adjustment process to free up space in compliant tanks. While DOE analyses so far suggest that the wastes from this process would meet the performance objectives in 10 CFR 61, it achieves less radionuclide separation than other planned processes. While waste from the DDA process represents only 8 percent of the volume of low-activity waste to be generated during salt waste processing, it contains 80-90 percent of the radioactivity that is projected to be sent to the Saltstone Disposal Vaults.**

**Recommendation 2: DOE and other involved parties should consider options other than DDA to alleviate the impending crisis in usable storage in compliant tanks. Options include actions that (1) reduce waste inputs to the tanks, such as redirecting the DWPF recycle stream for disposition in the Saltstone Facility; and (2) actions that free up usable volume in compliant tanks, such as using noncompliant tanks not known to have leaked for emergency storage volume.**

Waste retrieval, processing, and tank cleaning operations continuously add secondary wastes to the tanks; in addition, space in compliant tanks is needed to prepare feeds for the high-level and salt waste processing facilities. Moreover, DOE is maintaining the equivalent of a full tank capacity—4,900 $m^3$ (1.3 million gallons)—in empty compliant space for emergency purposes at all times. Hence the "tank space crisis."

DOE plans to address the tank space problem in the short term by implementing the DDA process. This process uses physical rather than chemical means to accomplish cesium separation (i.e., draining interstitial liquid present in the saltcake and then dissolving the saltcake and grouting it into saltstone (see Figure S-2).[13] The saltstone from this process is expected to contain cesium concentrations that are two orders of magnitude higher than the waste from the chemical processes that eventually will be used in the Salt Waste Processing Facility (albeit still considerably lower than Class C limits). Even these higher levels of cesium may not cause projected doses from the Saltstone Vaults to exceed dose limits, although as noted earlier, details underlying a performance assessment for DDA saltstone were not available for committee examination. However, this raises the following question: Does this process remove radionuclides to the maximum extent practical?

The tank space crisis forces DOE to engage in increasingly complex operations to ensure that there is sufficient space to continue waste processing. Hence, the tank space crisis may increase the possibility of accidental worker exposure to radiation, the chance of operational accidents, and the chance of waste leakage during transfers. In its recommendation, the committee suggests alternative options to DDA to mitigate the tank space crisis.

## Class C Limits and Performance Objectives

**Finding 3: The future site-specific risks posed by wastes disposed of on-site is the primary issue of concern in this study. Such risks are determined by the radionuclide and chemical quantities and concentrations, their conditioning, their interactions with the environment, and their bioavailability, not by the relationship of radionuclide concentrations to generic limits such as those for Class C low-level waste. The National Defense Authorization Act Section 3116 requires the use of the performance objectives in 10 CFR 61 to limit and minimize these risks.**

[13] DOE plans to send what it has identified as the least radioactive salt wastes from the tanks through the DDA process.

**Recommendation 3: When deciding what wastes may be disposed of on-site, DOE and other involved parties should ensure that discussions focus on how radionuclide and chemical quantities and concentrations, their conditioning, their interactions with the environment, and their bioavailability affect site-specific risk.**

The Class C limits are not a criterion for acceptability of on-site disposal of tank wastes from reprocessing of spent nuclear fuel under the present law but are sometimes discussed as if they were. The Class C limits were developed for a diverse commercial sector to establish limits on what is generally acceptable for near-surface disposal, based in part on assumptions about the overall set of wastes destined for disposal. According to Section 3116, comparison of radionuclide concentrations in waste to Class C limits is relevant to waste disposition decisions *only* procedurally, in that DOE must develop its disposal plans in consultation with USNRC.

Rather than Class C limits, site-specific risk assessments are the bases for determining whether the facility meets the performance objectives in the regulations. These risks depend on radionuclide quantities and concentrations, their conditioning, and their interactions with the environment.[14] The performance objectives and waste acceptance criteria constrain the overall quantity of radioactive material that can be disposed in a facility.[15]

Acceptable radionuclide concentrations (and/or inventories) and distributions should be determined as a result of a properly constituted and implemented risk assessment[16] that takes into account measured and/or projected radionuclide concentrations, spatial variability of the concentrations, and attendant uncertainties. Such a risk assessment was not available at the time of report writing (see Appendix B).

Congress recognized the importance of the performance objectives for evaluating site-specific near-surface disposal of waste in Section 3116 of the 2005 National Defense Authorization Act by explicitly including these objectives as the basis for determining whether waste is HLW instead of relying on the radionuclide concentrations that define the upper boundary of Class C waste. All substantive technical criteria that DOE's determination must meet (e.g., performance objectives, remove highly radioactive radionuclides to the maximum extent practicable) apply irrespective of whether a waste is less than or greater than Class C.

## Research and Development Needs

**Finding 4: Focused research and development could help DOE reduce the amount, improve the immobilization, and test some of the assumptions used in performance assessment of tank waste to be disposed of at the Savannah River Site. These actions could reduce the risks to humans and the environment and improve confidence in DOE's risk estimates. These research and development activities could**

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[14] Regulatory guides for 10 CFR 61 state that 10,000 years is an appropriate time frame for the performance assessments.

[15] Waste acceptance criteria take into account broader considerations than performance objectives, such as waste "processibility" (i.e., compatibility of waste and secondary products with the chemical and physical processes prior to disposal) and other site-specific requirements.

[16] A recent National Research Council report *Risk and Decisions about Disposition of Transuranic and High-Level Radioactive Waste* describes a framework for decision-making processes in the presence of risk and uncertainties (NRC, 2005).

**also increase DOE's ability to demonstrate compliance with the performance objectives in 10 CFR 61.**

**Recommendation 4: DOE should fund research and development efforts focused on providing deployable results within 5-10 years on the following topics: (1) in-tank and downstream processing consequences of chemical tank-cleaning options, (2) technologies to assist in tank-waste removal, including robotic devices, and (3) studies of the projected near- and long-term performance of tank-fill materials such as grout.**

To reduce long-term risks to the site and test the assumptions in the performance assessment, the committee recommends that DOE perform focused research and development to enhance tank waste retrieval and residual waste immobilization. Tank waste retrieval could be enhanced using better mechanical or chemical tools. Tank waste retrieval is currently performed using hydraulic technologies (i.e., water jets) and, to a certain extent, robotic devices and chemical cleaning agents (i.e., oxalic acid). The committee believes that additional research and development on mechanical tools, including but not limited to robotic devices and chemical cleaning could reduce the tank heels, especially in tanks with cooling coils. DOE should further evaluate the effectiveness of residual waste immobilization by conducting durability studies of grout (and alternative fill materials).

These activities may increase confidence in DOE's management plans or may cause DOE to revise some of the assumptions used in the performance assessment. Testing assumptions and improving DOE's knowledge base might increase its ability to comply with the performance objectives specified in the law. Research and development activities should be limited to those technologies that are promising and at a near-deployment stage (i.e., they could provide results within 5 to 10 years, in time to be implemented during the tank closure process). All noncompliant tanks are scheduled to be closed by 2022. A technology developed in the next 5-10 years could be deployed in time to address the most challenging tanks (i.e., those with cooling coils).

The committee believes that a nonradioactive test bed for retrieval technologies that can be adapted to simulate a variety of tank situations (i.e., recalcitrant heels, cooling coils, debris) should be maintained. The Pump Test Tank, a partial Type IV tank mockup at the mostly decommissioned TNX facility used for testing and equipment before deployment, and similar test beds at other sites, are candidates for this role. The Hanford Site also has a mockup of a single-shell tank used for similar purposes. The committee will further address the need for experimental retrieval facilities in its final report.

## FUTURE PLANS FOR THE STUDY

The committee's full task is to review and evaluate DOE's plans to manage radioactive waste streams from reprocessed spent fuel that exceed the Class C concentration limits and are planned for on-site disposal at the Savannah River Site, the Idaho National Engineering and Environmental Laboratory, and the Hanford Reservation. Congress requested assessments of the following: DOE's knowledge of the characteristics of the wastes; additional actions DOE should take in managing these wastes to comply with the performance objectives; monitoring plans; existing technologies and technology gaps for waste management; and any other matters that the committee considers appropriate and directly relevant. For its interim report, the committee was charged to examine whether DOE's plans to manage its radioactive waste streams at the Savannah River Site will comply with the performance objectives of 10 CFR 61.

Compliance with the performance objectives depends upon the amount of radioactive material left onsite, the manner in which it is immobilized, its interaction with the environment and its interaction with ecological and human receptors. As noted above, some critical data, analyses and plans were not available when this report was written: the performance assessment for closed tanks; plans for residual waste characterization; plans for tank annuli and tank-system piping; support for assumptions, estimated levels of conservatisms, and sensitivity analyses for performance assessment calculations; and long-term monitoring plans are examples of the missing information. In this interim report, the committee has fulfilled the charge to the extent possible by focusing mainly on the amount of waste left in the tanks and in the Saltstone Vaults at the Savannah River Site. The committee has made findings and recommendations on four major issues:

(1) near-term and long-term risks in the context of tank waste removal and the schedule for tank closure;
(2) the tank space crisis and options to alleviate the crisis;
(3) the roles of the Class C limits and the performance objectives in determining whether on-site disposal is acceptable; and
(4) research and development needs, particularly in-tank and downstream consequences of chemical cleaning options, technologies to assist in tank waste removal, including robotic devices, and studies of the projected near- and long-term performance of tank fill materials, such as grout.

The committee is still examining the interactions of the tanks and the saltstone with the surrounding environment; the role of environmental monitoring; the role of the point of compliance in meeting the performance objectives; and the role of modeling in the performance assessment. These topics are relevant to all three sites and will be addressed in the final report, along with the rest of the statement of task. For a substantive analysis, the information described above will be needed at all sites. In addition, because the wastes and the site conditions differ, the topics investigated in this report will also be examined at the Hanford and Idaho sites. These investigations at other sites will have an impact on the committee's views on the Savannah River Site. Hanford will likely offer the committee the greatest challenge because it is the oldest site, has many tanks that have leaked, and has the most complicated wastes because of the various management practices and several chemical processes that generated the wastes, including the earliest processing technologies. The committee may also extend the comments on the Savannah River Site found in this report as additional information on this site becomes available during the period of this study.

# I

# Introduction and Background

## THE TASK

In the Ronald Reagan National Defense Authorization Act of 2005 (Section 3146 of Public Law 108-375), Congress directed the Department of Energy (DOE) to request a study from the National Academies[1] evaluating DOE's plans to manage radioactive waste streams from reprocessed spent fuel that "exceed the concentration limits for Class C low-level waste as set out in Section 61.55 of Title 10, Code of Federal Regulations;[2,3] DOE plans to dispose of on the sites specified below rather than in a repository for spent nuclear fuel and high-level waste; and are stored in tanks at the Savannah River Site, South Carolina; Idaho National Engineering and Environmental Laboratory, Idaho; and the Hanford Reservation, Washington."

Congress asked the National Academies to assess the following:

(a) DOE's knowledge of the physical, chemical, and radiological characteristics of the waste in the tanks;
(b) actions that DOE should consider to ensure that management plans comply with the performance objectives for land disposal facilities;
(c) DOE's monitoring plans to verify compliance with the aforementioned performance objectives;
(d) existing technology alternatives for waste management;
(e) technology gaps for waste retrieval and management; and

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[1] The operating arm of the National Academies, the National Research Council, appointed a committee to undertake this study under the auspices of the Nuclear and Radiation Studies Board. Biographical sketches of committee members can be found in Appendix C.

[2] Through Part 61 of Title 10, Code of Federal Regulations (10 CFR 61) titled "Licensing Requirements for Land Disposal of Radioactive Waste," the U.S. Nuclear Regulatory Commission regulates the surface disposal of commercial low-level waste. Subpart 10 CFR 61.55 classifies low-level radioactive waste as Class A, B, or C, according to the concentration of key radionuclides in the waste. Class C waste must meet more rigorous waste form requirements to ensure stability and requires additional measures at the disposal facility to protect against inadvertent intrusion. The regulation states that low-level waste that exceeds Class C limits is not generally suitable for near-surface disposal.

[3] For the purpose of this study, the committee interprets the concentration criterion to apply to the waste streams stored in tanks prior to waste processing or immobilization.

(f) any other matters that the committee considers appropriate and directly related to the subject matter of the study.

The full statement of task and the performance objectives referred to in element (b) of the task can be found in Appendix A.

Task element (f) was reinforced by Representative John Spratt (5th District of South Carolina) and House Armed Services Committee staff, who presented the charge to the committee at its first meeting in March 2005. They asked the committee to interpret the charge broadly to include any relevant matters of importance, with emphasis on any portion of the tank waste that would be disposed at the sites.[4] Congress asked for an interim report on task element (b) for the Savannah River Site in six months (see below) and a final report on all of the sites in twelve months. This report fulfills the first requirement.

The National Defense Authorization Act states that the interim report shall address "any additional actions the Department should consider to ensure that the Department's plans for the Savannah River Site, including plans for grouting of tanks, will comply with the performance objectives [of Part 61 of Title 10, Code of Federal Regulations] in a more effective manner …" (Section 3146 (e)(A)). The committee worked with DOE, the South Carolina Department of Health and Environmental Control (DHEC), the U.S, Nuclear Regulatory Commission (USNRC), DOE's contractors, and others to obtain the information needed for the study. To this end, the committee obtained a large number of documents and held three public meetings to obtain information from experts and interested members of the public. Some data and analyses were not available to the committee (not yet collected, not yet calculated, or not yet made public[5]), and some plans had not yet been formulated or finalized by the time this report entered the National Academies report review process in early June 2005. Appendix B describes the main documents to which the committee had access and the missing pieces of information needed to assess DOE plans fully with respect to the performance objectives of 10 CFR 61.

Although the committee was unable to evaluate fully what, if any, actions are needed for DOE to comply with the dose limits in the performance objectives of the regulation, in this interim report the committee evaluates and recommends actions that it believes could (1) reduce the quantity of waste left on-site, and (2) increase DOE's understanding of other factors that reduce dose and risk—namely, the long-term performance of waste forms and other barriers to the release of radionuclides to the environment. The committee judges that these actions will increase DOE's ability to comply with the performance objectives in general and will help DOE fulfill its requirement to take actions to make releases of radioactivity to the environment as low as reasonably achievable (ALARA),[6] with economic and social considerations taken into account.

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[4] Specifically, Representative Spratt said "I thought it imperative that the scientific experts we were calling upon not be narrowly scoped by Congress, but rather have the authority and the latitude to look into matters unforeseen or unknown by Congress that may have a bearing on the subject."

[5] Under the Federal Advisory Committee Act Amendments of 1997 (Public Law 105-153), any document provided to the committee from outside of the National Academies must be made available to the public, unless the document is exempt from disclosure under the Freedom of Information Act (Public Law 89-554) and its amendments. As a result, the committee could not accept any document that was undergoing security review, internal scientific review, or legal and policy review and was therefore not ready for public release. The information-gathering phase for the interim report lasted from March through June 2005.

[6] The performance objectives of land disposal facilities for radioactive waste are defined in 10 CFR 61 Subpart C: (1) protect the general public from environmental releases and make releases as low as reasonably achievable, (2) protect individuals from inadvertent intrusion, (3) protect individuals during operations, and (4) provide stability of the site after closure.

Because some information was not yet available, as noted previously, and because the committee may gain insights from later meetings and site visits in Idaho and Washington State, the committee may choose to extend its comments on the Savannah River Site in its final report.

## Origin of This Study

In 2003, the Secretary of Energy asked Congress to grant DOE explicit authority to dispose of some of the waste stored in high-level waste (HLW) tanks on-site. DOE's impetus for requesting congressional action was that recent lawsuits and court rulings[7] threatened its cleanup schedules, in particular, at the Savannah River Site. DOE is taking actions that it characterized as implementing an "aggressive action to accelerate risk reduction," which entails an accelerated schedule for retrieval of waste and closure of tanks (DOE, 2004). In October 2004, Congress passed legislation that responded to DOE's request.

In addition to requesting a study from the National Academies, the Ronald Reagan Defense Authorization Act of 2005 (Section 3116) gives DOE the authority it sought for the Savannah River and Idaho sites (the Hanford Site is explicitly excluded from Section 3116, but is included in this study). Specifically, the act states that the term "high-level radioactive waste" does not include radioactive waste resulting from the reprocessing of spent nuclear fuel that "the Secretary [of Energy], in consultation with the Nuclear Regulatory Commission, determines (1) does not require permanent isolation in a deep geologic repository for spent fuel or high-level waste; (2) has had highly radioactive radionuclides removed to the maximum extent practical; and (3) disposal complies with the performance objectives of Subpart C of 10 CFR 61 and is pursuant to a State-approved closure plan or State-issued permit."[8] In addition, if the waste exceeds concentrations for Class C low-level waste (LLW), as set out in 10 CFR 61.55, DOE must dispose of the waste pursuant to plans developed by DOE in consultation with the USNRC.

Disposal actions for wastes that DOE determines under Section 3116 not to be high-level waste are to be monitored by the U.S. Nuclear Regulatory Commission in coordination with the host state. DOE already develops its plans for Savannah River Site tank waste disposition subject to the approval of the South Carolina Department of Health and Environmental Control under the Savannah River Site Federal Facility Agreement (FFA), and with input from the South Carolina Governor's Advisory Council.

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[7] The Natural Resources Defense Council and other environmental public interest groups challenged DOE's policy on "waste incidental to reprocessing," which provided DOE a way to manage waste from HLW tanks in a manner other than deep geologic disposal. In 2003, the U.S. District Court for the State of Idaho ruled against DOE in a summary judgment. In November 2004, the U.S. Court of Appeals for the Ninth Circuit overturned the decision because the subject of the complaint was not ripe for review.

[8] Before this law was signed, the full legal definition of high-level radioactive waste was waste that is "(A) the highly radioactive waste material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (B) other highly radioactive material that the Commission, consistent with existing law, determines by rule to require permanent isolation" (U.S. Code, Title 42, Chapter 108, Nuclear Waste Policy, Section 10101). There is no particular radioactivity concentration or dose limit associated with this definition.

## BACKGROUND

The Savannah River Site has 51 underground tanks[9] that are used for storing 138,000 cubic meters (36.4 million gallons) of hazardous and radioactive waste. The Savannah River Site started generating the waste in 1953 when a large chemical processing facility, called the F Canyon, was brought into service to separate uranium and plutonium from irradiated targets and spent nuclear fuel from reactors on the site to support the U.S. nuclear weapons program. None of the reactors is operating today and plutonium production has ceased at the site, but related operations in a second chemical processing facility, the H Canyon, and other waste processing operations continue to generate relatively small amounts of waste.

Each canyon facility piped liquid waste from the spent nuclear fuel processing operations to a set of tanks located in its area: the F-Area Tank Farm has 22 tanks and the H-Area Tank Farm has 29 tanks.[10] The tanks range in size from about 2,850 cubic meters ($m^3$) to 4,900 $m^3$ (750,000 to 1.3 million gallons) and are approximately 23-26 meters (75-85 feet) in inner diameter and 7.5-11 meters (24.5 to 35 feet) in height from the inner tank floor to the ceiling. They are buried at a shallow depth (1 to 3 meters below the land surface), with four nearly submerged in the saturated zone (below the water table).

Access to the interior of the tanks is attained through access portals, called risers, which rise from the top of the tank through the ground cover to the land surface. The number of risers in each tank ranges from 15 to 40, and the diameters of most of the apertures range from 58 to 107 centimeters (23 to 42 inches) depending on tank type. Some risers are larger: the center riser of a Type IV tank is approximately 2.7 meters (9 feet) (Fogle, 2002).

Most of the tanks have a carbon steel inner wall and an outer wall constructed of concrete, with an annular space between them. If the outer wall has a metal liner, then the liner provides what is called a secondary containment (i.e., a tank inside a tank). If the outer liner rises only partway up the outer wall, it provides only partial secondary containment. Eight of the tanks have no annulus or secondary containment (Type IV tanks), 16 have partial secondary containment (Type I and II tanks), and 27 have full secondary containment (Type III and IIIa tanks). Figure 1 illustrates the four general tank types. Only the Type III and IIIa tanks with full secondary containment are considered “compliant tanks” under the site’s Federal Facility Agreement, [11] which regulates management of hazardous waste at the site and uses the Resource Conservation and Recovery Act (RCRA) requirements for wastes stored in tanks (40 CFR 264.193 (b)). The “noncompliant” tanks are generally past their 30-year design life, and many (13, at last reporting; DOE, 2005b) have a history of cracks or leakage (either from the tank into the annular secondary region or from the surrounding media into the tank),[12] although only one tank is believed to have leaked a small quantity of waste to the environment. Waste levels have been lowered below the location of known leaks, and at present DOE believes that there are no active leaks.

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[9] Two tanks (Tanks 17 and 20) were filled with grout and closed in 1997, and one (Tank 16) was cleaned and taken out of service in 1980, so there are currently 48 tanks in service. Two more tanks (Tanks 18 and 19) have had waste removed and are waiting for closure as of July 2005.

[10] A map of the Savannah River Site and the General Separations Area, where the tanks are located, can be found in Appendix E.

[11] The Savannah River Site’s FFA is an agreement among DOE, the Environmental Protection Agency, and the South Carolina Department of Health and Environmental Control to regulate storage and disposal of hazardous waste at the site. The agreement also contains the schedule for noncompliant tank closure (see Appendix F). The last noncompliant tanks are to be closed by September 30, 2022. No date has been set for closing the compliant tanks.

[12] The leaks are detected by visual inspection or by conductivity probes in the annulus.

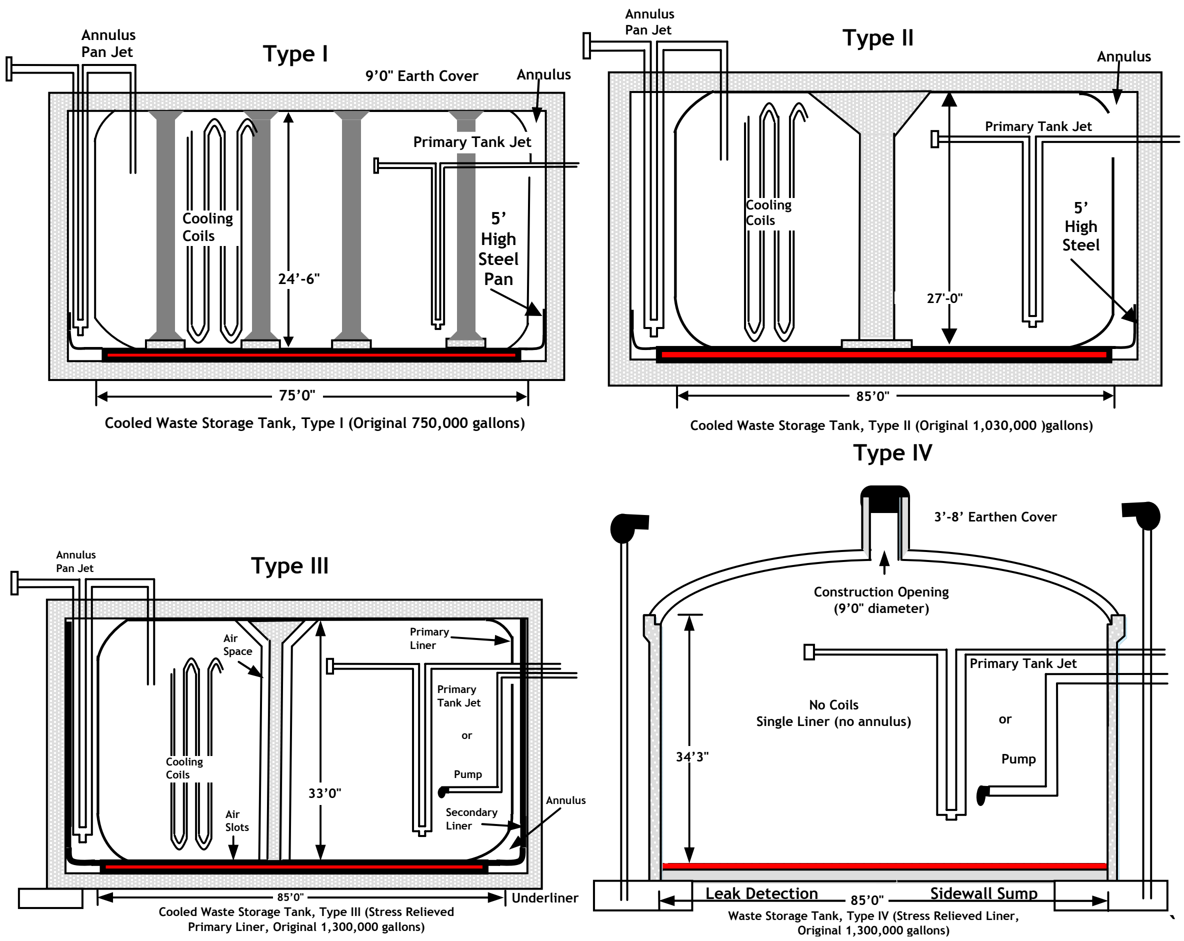


FIGURE 1 Diagrams of tank types at the Savannah River Site (not drawn to scale). There are twelve Type I tanks, four Type II tanks, twenty-seven Type III (and IIIA) tanks, and eight Type IV tanks in the tank farms. Risers are not depicted in most of these diagrams but are present on each tank.

All but the Type IV tanks contain dense networks of vertical and horizontal cooling pipes, referred to as cooling coils, which circulate chilled water. These cooling coils are used to remove heat produced from radioactive decay in the waste to prevent it from reaching high temperatures.

Waste from the canyons contains acids and other chemicals used in the separation processes, as well as the radionuclides (fission products such as cesium-137 and actinides such as neptunium-237) separated during recovery of plutonium and uranium. The wastes in the tanks exist mainly in three physical forms: sludge, supernatant liquid, and saltcake. Together, the supernate and saltcake are referred to as salt waste. To prevent corrosion of the carbon steel tanks, sodium hydroxide was added to neutralize the acid and make the waste alkaline before it was pumped to the tanks. This caused metals and most radionuclides to precipitate as an insoluble sludge,[13] which settled to the bottom of the

[13] The terms “insoluble” and “soluble” are used here to describe chemical species that exist preferentially in the solid phase or the liquid phase, respectively, in the larger medium (the waste in a tank). No species will exist exclusively in one phase. In the cases discussed here, however, all but a

tanks. The liquid remainder, or unconcentrated supernate, contains soluble salts and is referred to as a salt solution. If concentrated by evaporation, much of the salts initially in solution will precipitate to form a solid saltcake.

To conserve tank space, most of the salt solutions have been processed through an evaporator (a heated tank that evaporates water from waste) to produce saltcake, leaving relatively small volumes of concentrated supernate solution. Although there is disagreement about the contents of the individual tanks, the totals of the individual radionuclides and chemicals in the tank systems are relatively well known. The total radioactivity in each physical form is shown in Figure 2 and Table 1, which also lists the radioactivities for other wastes on- site.

The supernate contains more than 90 percent of the inventory of soluble radioactive species, mainly cesium-137. The saltcake is a solid material composed of more than 99 percent of salts, such as sodium nitrate, which contains lower (by approximately a factor of 10 to 20) concentrations of soluble and insoluble radioactive constituents. The waste in the tanks (see Figure 2) contains approximately 1.6 x $10^{19}$ becquerels (426 million curies [MCi]) of radioactivity; approximately half of the radioactivity is in the sludge and half in the salt waste. Most of the volume is in the salt waste, approximately 128,000 $m^3$ (33.8 million gallons), whereas the sludge represents approximately 9,800 $m^3$ (2.6 million gallons).

More than 95 percent of the radioactivity in the waste comes from cesium-137 (and its short-lived decay product barium-137) and strontium-90 (and its short-lived decay product yttrium-90). Both the cesium and the strontium isotopes have half-lives of approximately 30 years. The cesium poses a particular hazard for people working near the waste because it emits penetrating radiation (gamma rays). Other radioactive constituents in the waste are of

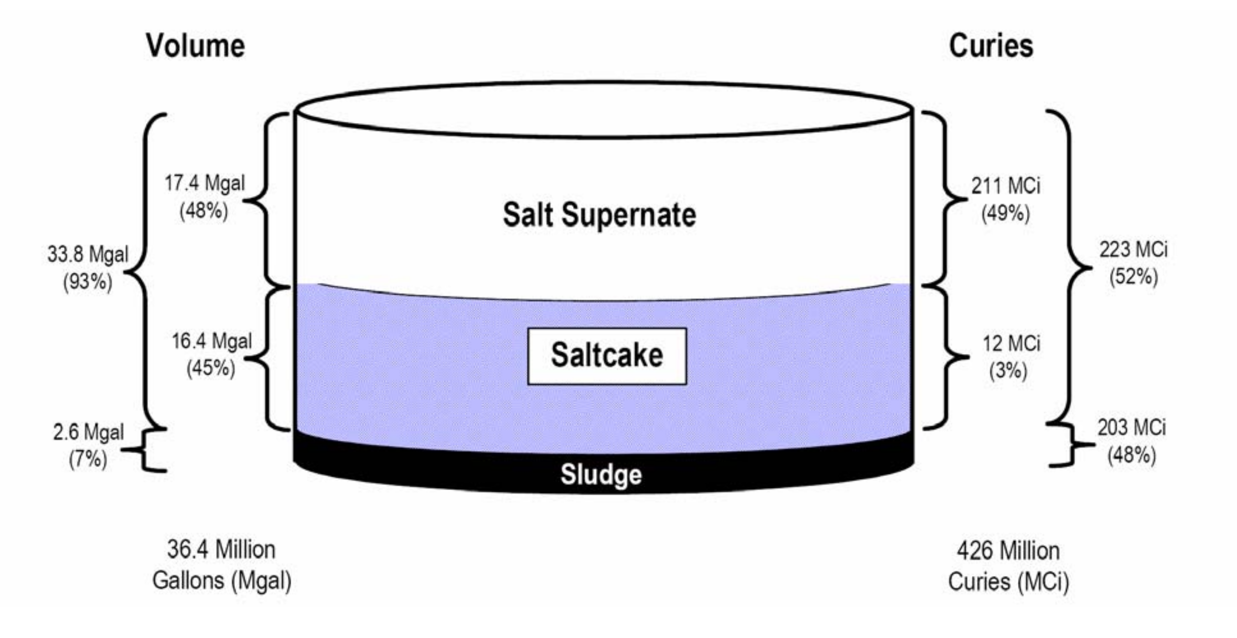


FIGURE 2 Aggregated volume and radioactivity distributions among the tank waste phases in all tanks at the Savannah River Site as of December 2004. SOURCE: DOE (2005a).

very small fraction of the chemical mentioned exists in the preferred phase in that medium. Also, the sludge entrains some soluble radioactive species.

TABLE 1 Inventory of Radioactive Waste by Type at the Savannah River Site

| Type of Waste | Volume ($m^3$) | Radioactivity (Ci) |
|---|---|---|
| Total high-level waste in the tanks comprising[a] | 138,000 | 426 million |
| Sludge | 9,800 | 203 million |
| Saltcake | 62,000 | 12 million |
| Supernate | 66,000 | 211 million |
| Vitrified high-level waste[b] | 1,754 logs | 7.8 million |
| Stored transuranic waste[c,d] | 11,000 | 490,000 |
| Buried transuranic-contaminated waste and soil[c] | 4,500 | 18,500 |
| Low-level waste stored[c] | 15,276 | Not available |
| Low-level radioactive waste in disposal cells[c] | 698,000 | 11 million[e] |

NOTE: These data are from different sources, are measured or estimated at different times, and did not indicate quantified uncertainties.
[a] DOE, 2005a.
[b] As of December 1, 2004.
[c] DOE, 2001a.
[d] As of 1996.
[e] Not decay corrected, hence an overestimate.

concern for other reasons: DOE has concluded that carbon-14, selenium-79, technetium-99, iodine-129, tin-126, and neptunium-237 dominate the long-term risk to the public from disposed waste because of their long half-lives and their mobility in the environment (Cook, 2005). The actinide isotopes, including isotopes of plutonium and americium, decay into a series of other radioactive substances (together referred to as a decay chain) and also constitute long-term hazards, particularly for inadvertent intruders who may disturb the waste.

DOE's plan to manage the waste retrieved from the tanks is to separate the radioactive from the nonradioactive components, the latter of which make up nearly the entirety of the waste volume. This processing generates two waste streams: (1) a high-activity waste stream, which will be immobilized and disposed off-site in a high-level waste repository, and (2) a low-activity waste stream, which is to be disposed on-site as low-level radioactive waste. Figure 3 illustrates the waste flows that DOE has described for tank wastes at the Savannah River Site. The reader should note that the wastes planned for repository disposition are not the subject of this study, because they are not planned for on-site disposal. They are included here because management of the tank wastes must be considered as a whole system of interconnected parts. For example, any chemical agents used to clean the tanks must be compatible with the processing of at least one of the two waste streams.

## Sludge

For nearly 10 years, DOE has been retrieving sludge from the tanks at the Savannah River Site for immobilization in glass. After retrieval from the tank, the sludge is transferred to a dedicated waste tank where it is "washed" to remove soluble salt constituents that will interfere with the glass-forming process and to reduce the volume of material that is sent to the Defense Waste Processing Facility (DWPF) for vitrification into logs of waste glass. The logs are to be disposed off-site in a high-level waste repository. The wash water and a low-activity liquid waste stream from the DWPF are sent back to the tanks (see Figure 3).

## Salt Waste

DOE is still developing facilities to process the salt waste. Three progressively more sophisticated and effective separation processes are to be brought into service for processing different batches of salt wastes: DOE proposes to use two "interim" processes (described in Section II) for what it calls "low-activity salt," that is, salt waste that contains what DOE considers to be "low concentrations of radionuclides," until the Salt Waste Processing Facility (SWPF) begins operations. The SWPF is scheduled to begin operation in 2009. The SWPF's processing capability may be supplemented by the interim processing facilities or they may be used to treat unique waste streams. Tank wastes are to be processed to concentrate the radionuclides into a high-activity waste stream that will be vitrified at the DWPF. The other separated fraction, consisting mainly of the nonradioactive salts and other constituents with low concentrations of radionuclides that make up the less contaminated, low-activity waste stream, is to be conditioned in the Saltstone Production Facility— an operation that mixes liquid waste with grout[14] to create a waste form referred to as saltstone, which is disposed on-site as a monolith in concrete vaults. Until now, the Saltstone Production Facility has handled very low activity waste. The higher radioactivity

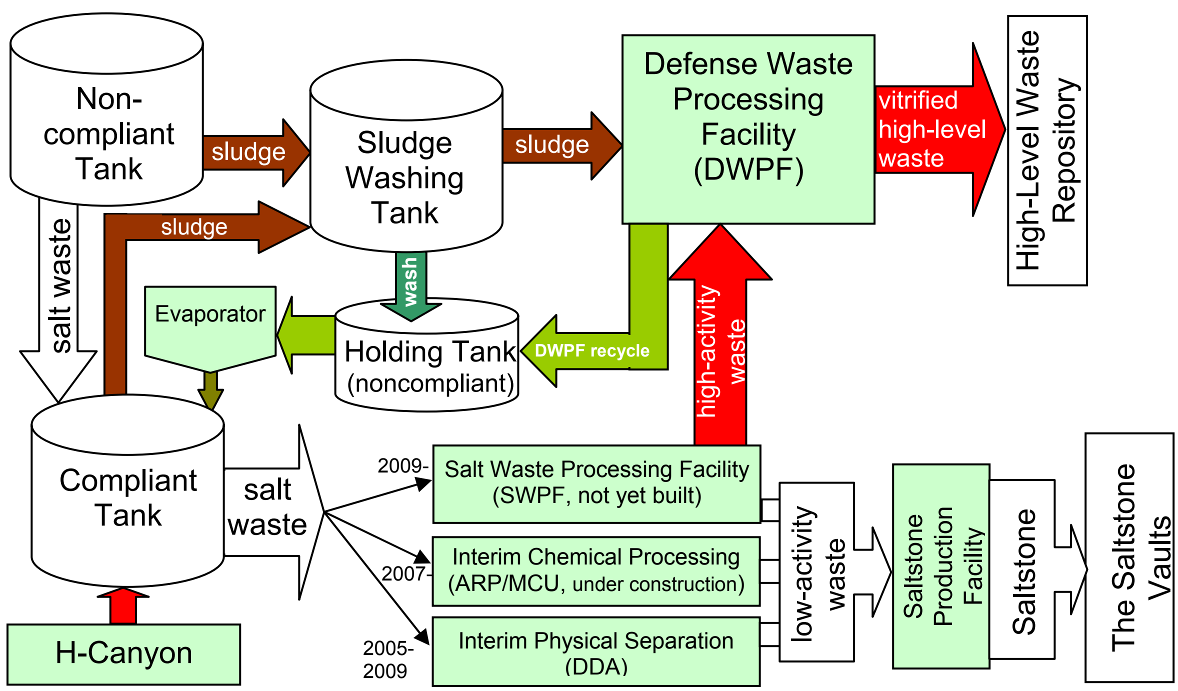


FIGURE 3 Waste flows in the Savannah River Site waste management plans. Note that the sizes do not necessarily scale with the sizes of the waste flows.

[14] Except where otherwise indicated, the term "grout" is used here to mean a cementitious material used for waste immobilization or tank fill.

anticipated in the liquid waste that DOE plans to send to the facility prior to SWPF start-up has required DOE to reconfigure the equipment and facility as well as add additional shielding in certain areas.

One of the functions of the saltstone is to stabilize some of these species (e.g., technetium and neptunium isotopes) by establishing reducing conditions.[15] The cementitious materials are a mix of ground granulated blast furnace slag, portland cement, and fly ash. Briefly, each material was selected for the following main properties: slag creates the reducing conditions, portland cement enables the waste form grout to set (solidify) and gain strength in a reasonable amount of time, and fly ash (a by-product of coal-fired power plants) helps minimize thermal cracking by limiting the heat generated by the grout in the saltstone during the curing process. The specific proportions of cementitious materials in the grout are modified to be better suited to the liquid that is being stabilized, based on an analysis of the waste. The saltstone grout is pumped directly into a concrete vault constructed on the site, which has a concrete roof and will eventually have an engineered cap (a physical barrier that sits atop the disposal site). The engineered cap retards water intrusion into the vault, thereby reducing the mobility of the radionuclides in the saltstone.

### Tank Residuals

After waste is removed from a tank, DOE plans to "close" the tank. The closure plans involve the emplacement of layers of engineered grout in each tank. If DOE uses the same approach it used for previous closures, the lowermost layers would be intended to partially encapsulate the residual sludge on the bottom of the tank with a reducing grout and to bind any remaining liquid as water of hydration (water absorbed by the grout as it sets). The middle layer would be a controlled low-strength material designed to lend structural stability to the tank to prevent collapse. The top layer, used only in the Type IV tanks, would be a stronger material designed as an intruder barrier. DOE plans to clean out and close the tanks one or a few at a time. Two Type IV tanks, Tanks 17 and 20, have already been grouted and closed in this manner, and DOE intends to close two neighboring tanks, Tanks 18 and 19, next.

## LEGAL CRITERIA

Tank waste at the Savannah River Site is regulated by different agencies. DOE regulates the radioactive component of this waste through the Atomic Energy Act and Section 3116 of the Ronald Reagan Defense Authorization Act of 2005; the state regulates the hazardous component of the waste through the South Carolina wastewater treatment and hazardous waste regulations (SCDHEC, 2004a, 2004b); and the U.S. Nuclear Regulatory Commission reviews waste determinations and monitors compliance in pursuing the cleanup of the tanks under Section 3116. The U.S. Environmental Protection Agency is involved indirectly through the Federal Facility Agreement for the Savannah River Site (DOE, 1996a).

In conjunction with the regulatory documents listed above, DOE has applied criteria from the following laws, regulations, and DOE orders in decision making regarding cleanup of wastes at the Savannah River Site (DOE, 1996a):

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[15] Many radionuclides and toxic heavy metals are less soluble (and therefore less able to be leached or to migrate in groundwater) if they are in their reduced valence state. Slag has the property of reducing the valence state of such elements, thus enhancing the effectiveness of saltstone.

- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) criteria described in 40 CFR 300.430(e)(9).[16]
- Resource Conservation and Recovery Act Section 3004(u) and (v),[17] and
- DOE Order 435.1, Waste Management.[18]

[16] DOE, 1996b.
[17] Langton et al., 2001.
[18] DOE, 1999, 2001b, 2001c.

# II

# Ideal Objectives and Real-World Challenges

The committee believes that as a starting point for analyzing options, developing plans, and making waste management decisions, it is useful to examine the life cycle of the wastes, identifying both their current condition and the desired end points. The choices and decisions that represent the different paths from the current condition to the desired end points can then be delineated. In this section, the committee examines what would be the ideal objectives or end points for the tank wastes and what real-world obstacles make those objectives difficult to achieve.

## IDEAL OBJECTIVES FOR THE TANK WASTES

In an ideal world—that is, if waste retrieval and processing facilities worked ideally and at an acceptable cost—the objectives would be the following:

1. Remove tank waste. The first priority for most, if not all, of the interested parties is to retrieve the waste from the tanks,[36] particularly the noncompliant tanks. If all of the waste could be retrieved, tank closure would be a minor concern because there would be virtually no residual radiological hazards. No real waste retrieval system, however, will retrieve all of the waste.
2. Separate the radioactive constituents from the salt solutions and sludge. Separations are carried out primarily to reduce the volume of high-level radioactive waste that must be immobilized, stored, and ultimately shipped to a repository for disposal. The radionuclides constitute only a small volume of waste. The more voluminous but less radioactive bulk would be disposed in a manner appropriate for the lower hazard it poses. It should be noted that in any real separation system, complete separation of the radioactive components is not possible.
3. Immobilize radioactive waste for disposal. The highly radioactive wastes must be immobilized in a manner suitable for a high-level waste repository (vitrified, in this case), and the less contaminated bulk salt wastes must be immobilized in a form that will prevent unacceptable accidental direct exposures and also inhibit leaching of contaminants.
4. Minimize public and occupational hazards. Worker safety is the top priority in the near term, before radionuclides and hazardous chemicals move into the accessible

[36] Throughout the report, “tank waste removal” refers to removal of waste from the tank and the annulus, if applicable.

environment. Regulations require DOE to keep exposures as low as reasonably achievable (ALARA), with economic and social considerations taken into account.

5. Minimize residual hazards to reduce long-term maintenance. The ideal situation for waste staying on-site, whether grouted waste residues in the tanks or saltstone in vaults (or even the tank structure, piping, and other internals), would be if the wastes were left in a condition that would not require institutional controls or long-term monitoring and maintenance to prevent unacceptable exposures to workers, the public, and the environment.

## REAL-WORLD CHALLENGES: STATUS AND DIFFICULTIES IN ACHIEVING IDEAL OBJECTIVES

While DOE and others may strive toward these ideal outcomes, reality makes it quite difficult to achieve them. This is not to say that anything less than the ideal is unacceptable. Rather, thorough examination of the disposition options, including technological capabilities, relative risks, costs, and other trade-offs, is needed to select an appropriate plan of action.

### Remove Tank Waste

The South Carolina Department of Health and Environmental Control and DOE have developed a list of common goals and values to guide tank waste cleanup activities. At the top of that list is to “reduce operational risk and the risk of high-level waste (HLW) leaks to the environment by removing waste from tanks” (Mahoney and Chew, 2004). The top priority is to remove waste safely from the noncompliant tanks that are more likely to leak. Some of these wastes will be sent to compliant tanks and some to the DWPF.

The waste removal process consists of two stages: a bulk waste removal stage and a “heel removal” stage.[37] The bulk waste removal phase entails the removal of the majority of waste from the tanks. It consists of several cycles of adding water to the tanks, mixing the waste, and pumping it out. DOE’s goal for the bulk removal stage is to leave no more than 76 $m^3$ (20,000 gallons) of settled sludge and residual liquids in tanks that have a significant amount of sludge (Hintze, 2005). This remainder is called the “heel” and corresponds to about 1.5 to 2.7 percent of the tank volume, depending on the tank design. For the heel removal stage, DOE uses jet pumps to dislodge the sludge and pump the slurry from the tank. This method was used to clean out four Type IV tanks (Tanks 17 through 20).[38] It is also possible to use acid to dissolve the heels, a method called chemical cleaning.

DOE has previously tested several different acids with sludge simulants, tested oxalic acid with real waste, and demonstrated chemical cleaning of a waste tank heel using oxalic acid (Adu-Wusu et al., 2003). The demonstration used two water washes, three oxalic acid washes, and a final water rinse to clean Tank 16, a Type II tank (West, 1980). This method yielded thorough tank waste removal: DOE reports that 99.98 percent of the waste by radioactivity, and 99.8 percent by volume, was removed from the tank (see Table 2). DOE regards oxalic acid to be the most promising of the chemical cleaning options, but it believes that there are some difficulties with the approach. These problems are associated

[37] The terminology for waste removal can be confusing because what remains after “bulk removal” is called the heel, but what remains after “heel removal” is also called the heel.

[38] DOE has also removed tank waste and cleaned tanks at the West Valley Demonstration Project and the Idaho National Laboratory, but the committee did not review the experience gained from those activities for this interim report.

with both in situ chemical cleaning (e.g., corrosion of the tanks)[39] and subsequent processing (e.g., foaming, precipitation, nuclear criticality safety[40]) of solutions containing metal oxalates and oxalic acid (Adu-Wusu et al., 2003).

Because the chemical composition of the waste in each tank is somewhat different, the problems listed above may have to be addressed anew for each tank, just as the chemical state of each waste batch is adjusted before processing and immobilization.
Without chemical cleaning, it may be quite difficult to remove the heels from Types I, II, III, and IIIa tanks, each of which has more than a thousand meters of cooling coils snaking through it vertically and horizontally. Figure 4 is a photograph of the interior of Tank 4 (a Type I tank) before it was brought into service, which illustrates the dense piping. As noted previously, access to the interior of the tanks is limited. There are no plans to remove the cooling coils, which are attached to both the roofs and the floors of the tanks. The Type IV tanks are the simplest tanks, with no cooling coils, and only minor obstructions on their bottoms. These tanks were selected to be the first ones for cleaning and closure at least in part because they posed fewer technological challenges. DOE estimates that the residual heels left in the Type I, II, and IV tanks after heel removal efforts will range in volume between 7.6 and 26.4 $m^3$ (2,000 to 7,000 gallons, or about 2.5 to 5 centimeters [1 to 2 inches] if spread uniformly over the bottom of a tank). The smaller of the two quantities is of the same order of magnitude as the experience gained in closing two tanks: DOE reports the Tank 17 residues as comprising approximately 2,400 Ci in about 9 $m^3$ of sludge (d'Entremont et al., 1997), and Tank 20 residues as comprising less than 500 Ci in about 3.8 $m^3$ (d'Entremont and Hester, 1997). Volume estimates are based on systematic measurements across the floors of those tanks. Radioactivity estimates are extrapolations based on process knowledge and concentrations in two samples multiplied by the volume of the heels. Inhomogeneities in the heels make the radioactivity estimates much less likely to be accurate than the volume estimates.

TABLE 2 Tank 16 Waste Removal Process and Curies Removed with Each Sequential Step

| Sequential Waste Removal Step | Curies Removed | Percentage of Curies | Cumulative Curies Removed | Cumulative Percentage Curies Removed |
|---|---|---|---|---|
| Bulk waste removal | $2.74 \times 10^6$ | 97 | $2.74 \times 10^6$ | 97 |
| Spray water washing | $2.78 \times 10^4$ | 0.98 | $2.77 \times 10^6$ | 97.98 |
| Oxalic acid wash and rinse | $5.82 \times 10^4$ | 2 | $2.83 \times 10^6$ | 99.98 |

SOURCE: (DOE, 2002a)

[39] Oxalic acid can also retard hydration of portland cement, which could reduce the effectiveness of engineered grout as a barrier both in tank grouting and in saltstone if the acid persists.

[40] The committee has not examined whether quantities and configurations of fissile and other materials make a criticality event in the waste possible, but iron is more soluble than uranium and plutonium in oxalic acid and "iron is the primary neutron absorber relied upon for nuclear criticality safety in DWPF sludges" (Adu-Wusu et al., 2003).


FIGURE 4 Photograph of the interior of a Type I tank (Tank 4) prior to receipt of wastes. SOURCE: Caldwell (2005a).

There will soon be experience upon which to base estimates for cleaning out the heel from a tank that has cooling coils without using oxalic acid: the site will start work to clean out the heel from Tank 11 (a Type I tank) in the summer of 2005. Figure 5 is a photograph of Tank 11 after recent bulk waste removal. The photograph shows little residual waste, although it should be noted that the area displayed is below a riser, where removal equipment is situated and where one would expect removal efforts to be most effective. The committee did not receive data showing how far the clean bottom extends laterally but notes that it may be possible to use other risers in the same tank to increase the overall efficiency of heel removal. The waste that is difficult to retrieve tends to be consolidated sludge that has high concentrations of radioactivity, and is difficult to mobilize.

Savannah River Site personnel also indicated that a few tanks have zeolite in them. Zeolite, a class of hydrated alumino-silicate minerals with an ability to “trap” cesium (and other cations), was used to remove cesium from the condensed steam recovered from an evaporator (a heated tank that evaporates water from waste). The zeolite has now agglomerated and is difficult to slurry out of the tank. For example, zeolite remains in Tank 19 despite attempts to retrieve it. Also, oxalic acid proved ineffective at removing zeolite from Tank 24, although the temperatures and quantities of oxalic acid used may have been too low (Adu-Wusu et al., 2003).

Finally, in tanks that have a history of leakage, there is waste in the tank annulus (the space between the inner tank wall and the outer containment shell; see Figure 1). DOE told the committee at its April 2005 meeting that DOE does not yet have a plan to remove waste from the annuli and the committee was given inconsistent opinions concerning how difficult removal of waste from the annuli will be. The waste in the annulus is salt waste and, presumably, readily dissolved, but the geometry of the annulus and the presence of obstructions such as ventilation ducts make access difficult. As previously mentioned, the interior of Tank 16 has been thoroughly cleaned, but the committee was told at its May 2005 meeting that removal of waste from the annulus was unsuccessful because of the difficulty of


FIGURE 5 A Type I tank (Tank 11) after undergoing bulk waste removal in March 2005.
SOURCE: Caldwell (2005b).

access and because the technology used to clean the annulus wall made the waste less soluble.

It is often reported that the waste projected to remain in the tanks after cleanup will be less than a few percent of the initial inventory. However, the committee notes that, common to many remediation projects, it is not the fraction that is removed from a source that determines the long-term risk, but what is left behind. Risks depend on radionuclide quantities and concentrations, their conditioning, and their interactions with the environment, not just the volume of the heels. It is difficult to predict the amount of waste that will be left behind before the removal efforts are actually undertaken. Most of the tanks have unique design features and waste may have different characteristics (although the variation in waste characteristics is not as great at the Savannah River Site as at the Hanford Site).

Characterization of waste residuals is important to make the determination that waste has been retrieved to the maximum extent practical and to meet performance objectives. During the first meeting at the Savannah River Site, the committee received a presentation on waste characterization but it was not specific to residual waste (see Appendix B); therefore, the committee has to gather additional information on this topic for its final report.

### Tank Space (usable storage volume)

Capacity in compliant tanks is needed to prepare batches of salt waste for processing through the interim and high-capacity salt waste processing facilities. In addition, sludge waste processing activities result in a net increase in the volume of liquid in the tank system. Also, newly generated waste will continue to be produced by ongoing operations in the H Canyon and other projected missions at the Savannah River Site. As a result, compliant tank space is scarce and in great demand. It is somewhat counterintuitive that retrieving sludge consumes rather than frees up tank space during this phase of cleanup, but DOE reports that for each liter of sludge retrieved from a tank and immobilized in glass, 1.3 liters of concentrated waste is added to compliant tanks. Even this 1:1.3 ratio is achieved only because of waste reduction efforts undertaken to conserve tank space (DNFSB, 2004). After sludge waste is retrieved from noncompliant tanks, the sludge is washed with fresh water to remove soluble species. In addition, liquid waste is generated in the DWPF and then recycled back into Type IV tanks (see Figure 3). What remains after these wastes are run through an evaporator is stored in the compliant waste tanks until it can be processed for disposal.

To carry out waste retrieval and other operations, DOE must track the space in the tanks closely and often must make multiple transfers among tanks, and even between tank farms, to ensure that there is sufficient open tank space where needed to support operations. This is a complex problem compounded by the continuing introduction of waste into the tanks.

The Defense Nuclear Facilities Safety Board (DNFSB) has raised concerns about tank space problems, the risks of accidents, and worker exposures incurred as a result of these operations (DNFSB, 2001, 2004). A 2001 DNFSB letter recommends a set of actions to relieve tank space problems, including (DNFSB, 2001, p. 5):

> Develop and implement an integrated plan for HLW tank space management that emphasizes continued safe operation of the Tank Farms throughout its life cycle. This plan should include enough margin to accommodate contingencies and reduce overall programmatic risk. The plan should also restore operating margin to the Tank Farms by including action to:
>
> a. reduce or eliminate the DWPF recycle stream,
> b. recover former ITP [in-tank precipitation] tanks for Tank Farm operations,
> c. assess the desirability of adding an additional HLW evaporator to support Tank Farm operations,
> d. assess the feasibility of constructing new HLW tanks, and
> e. resolve waste compatibility and equipment degradation problems to allow unconstrained operation of the three existing evaporators.

The committee discussed these options with DOE. DWPF recycle is a particular concern because it contributes more than half of the annual waste input to the tanks, adding approximately 5,700 $m^3$ (1.5 million gallons) of unconcentrated waste (prior to evaporation) to the tank farms every year. Sludge washing contributes about 5,700 $m^3$ to 7,600 $m^3$ (1.5 million to 2 million gallons) every one to two years, and ongoing operations at the H Canyon add approximately 760 $m^3$ to 1,150 $m^3$ (200,000 to 300,000 gallons) of waste to the tanks annually (Mahoney, 2005). The DNFSB letter explains that DOE has long considered, but never pursued, installing an evaporator at DWPF. DOE informed the committee that conceptual design for an evaporator has begun, but on the current schedule the evaporator would not be brought on-line until around 2010.

The DNFSB's action "b" refers to tanks used in the in-tank precipitation (ITP) process described in the next subsection. Only one tank, Tank 48, now contains ITP waste. Because of chemical compatibility and safety problems associated with this waste, DOE has concluded that other wastes cannot simply be added to utilize the open space in Tank 48.

Evaporator operations are becoming constrained by the buildup of salt in the tanks that receive evaporator concentrates and by the buildup of hydroxides in the tanks that feed the evaporators. It is not clear that adding an evaporator to one of the tank farms without additional open tank space would alleviate the space problem. The compatibility problem referred to in the DNFSB's action "e" above is that some of the tank wastes are high in silica and others are high in aluminum. If they are mixed, they form hydrous alumino-silicates (zeolite), which can clog evaporators and ancillary systems and are difficult to remove. DOE lost the use of an evaporator for two years, starting in 1999, because of this problem. Since then, it has instituted a policy of not mixing these wastes, which limits its ability to transfer waste between some tanks. This further constrains management of space in the tank farms.

At its April 2005 meeting, the committee asked representatives from DOE and the South Carolina Department of Health and Environmental Control whether a new tank might alleviate the tank space crisis. These parties have agreed to avoid, if possible, creating new tanks that will themselves eventually require remediation and closure. Further, DOE estimates that bringing a new tank into service would require five years, so it is not a solution to the near-term tank space crisis.

DOE has gone to great lengths to find tank space but says that it has run out of options in the tank farm operations. Tank space crises have loomed at the Savannah River Site for 15-20 years. However, recent actions to free up tank space, including the numerous tank waste transfers across the tank farms, illustrate that available options are diminishing. Until recently, DOE held open the equivalent of a full tank of compliant tank space in each tank farm as contingency space for leaks and other problems (DNFSB, 2004). DOE informed the committee that it has decided to reduce the contingent space to the equivalent of one tank overall. DOE now plans to address the tank space problem in large part by passing the waste through the interim salt processing facilities, described below.

## Separate Radioactive Constituents from the Salts

Once waste has been removed from a storage tank, DOE plans to separate it into high- and low-activity fractions. During the late 1980s and 1990s, DOE planned to use the ITP process to separate radionuclides from the salt waste. This process was to be implemented in parallel with sludge processing so that radionuclides from the sludge and from the salt waste could be immobilized together in the DWPF, which began production operations in 1996. By 1999, DOE concluded that the ITP approach could not meet processing demands and safety requirements. This conclusion led to two actions. First, DOE selected a new separation technology and is designing and building a new facility (NRC, 2000a). Second, DOE is managing the products from its failed attempt to implement the ITP process. DOE has concluded that no practical means of processing the ITP products exists, so it has proposed to mix this waste with other liquids and immobilize it in saltstone (see Sidebar 1).

DOE now proposes to process its salt wastes utilizing three different processes[41] that will be available at different times and have different capabilities (see Figure 6). Two low-capacity processes are expected to be available sooner and are referred to as "interim" processing by DOE (Phase 1, Figure 6). These are the deliquification, dissolution, and adjustment process (DDA), which could begin immediately upon approval of the waste determination by the Secretary of Energy in accordance with Section 3116 of the 2005 National Defense Authorization Act, consultation with the USNRC, and permitting by the State of South Carolina; and the actinide removal, modular caustic-side solvent extraction process (ARP/MCU), which is expected to begin operations in 2007.

[41] DOE refers to this as a two-phase, three-step approach. The committee has not adopted this way of describing the approach because it suggests that the all wastes undergo each process, which is inconsistent with DOE's plan.

**SIDEBAR 1 TANK 48**

In the early 1980s, DOE demonstrated the in-tank precipitation (ITP) process in tank 48. The ITP process was designed to separate the high- and low-activity fractions of the supernate by adding sodium tetraphenylborate and monosodium titanate. Sodium tetraphenylborate reacted with cesium to form cesium tetraphenylborate precipitate, and monosodium titanate targeted the separation of strontium and actinides. After this and a subsequent test in 1995, however, DOE determined that the ITP process could not be operated safely at the required production rates because the tetraphenylborate anion degraded into potentially flammable benzene (NRC, 2000a). Since then, DOE has concluded that no practical processing option for the waste in Tank 48 exists given the current design of the Savannah River Site tank system (DOE, 2005a). DOE proposes to dilute the contents of Tank 48 with DWPF recycle waste or other low-activity waste and immobilize the mixture in saltstone without radionuclide separations (DOE, 2005a).

DOE states that Tank 48 contains "relatively low-activity salt solution" (DOE, 2005a). DOE's current understanding of the radionuclide content of 900 $m^3$ of liquid waste and 16,000 kg of sludge in Tank 48 is summarized in a February 2005 document (Ketusky, 2005). DOE sampled the contents of Tank 48 in September 2003 and August 2004. In each case, DOE stirred up the contents of the tank by operating four slurry pumps in the tank for several hours and then drew a grab sample of the mixture within minutes after pump shutdown. DOE analyzed the slurry sample and then filtered the suspended solids and analyzed the supernate remainder. Based on these data, DOE has estimated the cesium-137 concentration (apparently without its decay product) in the slurry to be 455 Ci/$m^3$ and in the supernate to be 12.4 Ci/$m^3$. Joining the supernate concentration with the volume of liquid waste in the tank and comparing that to the total radioactivity in the tank, one finds that more than 97 percent of the cesium radioactivity is in the solids. The committee has not evaluated the practicality of the processing options available for the Tank 48 wastes. On one hand, it will be unfortunate if the precipitated cesium compound were to be mixed with the supernate and other low-activity salt waste for disposal as saltstone. On the other hand, processing the 910 $m^3$ (240,000 gallons) of waste as DOE suggests would free a compliant 4,900 $m^3$ (1.3-million-gallon) tank located in a particularly useful place, which would significantly help the tank capacity problem at the Savannah River Site.

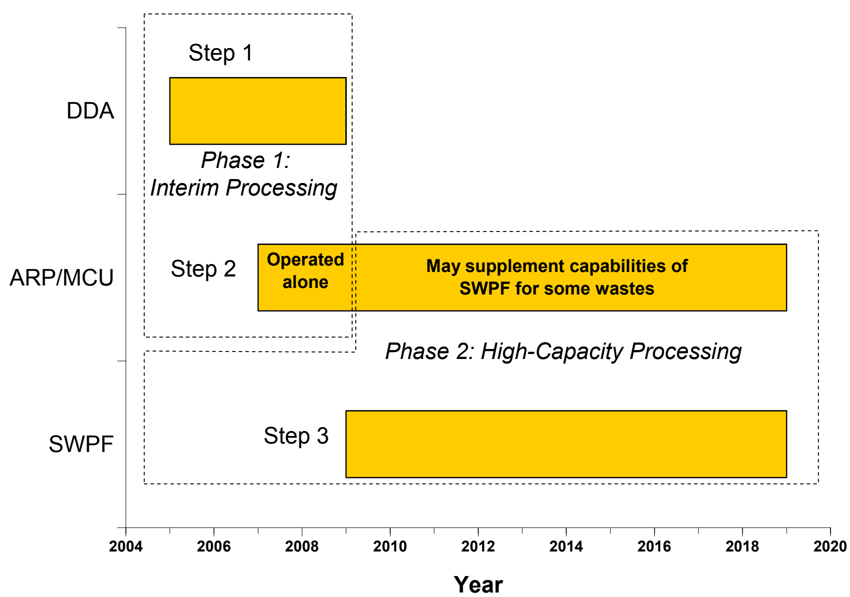


FIGURE 6 Time line for salt waste processing at the Savannah River Site as described by DOE (two-phase, three-step approach).

The high-capacity chemical processing facility, called the Salt Waste Processing Facility, is scheduled to be available in 2009 and could be supplemented by the ARP, if needed. DOE's current plan for such retrieval and processing is shown in Figures 7 and 8 (DOE, 2005a).

The first low-capacity process, the DDA process (Step 1, Figure 6), selectively retrieves salt waste that has relatively low concentrations of cesium. The process begins with removing the overlying supernate, draining the interstitial liquid from the saltcake (DOE estimates that this step will be 50 percent effective), and storing the liquid for later processing. Liquids are then added to the tank to dissolve the remaining saltcake and insoluble constituents are allowed to settle out.[42]

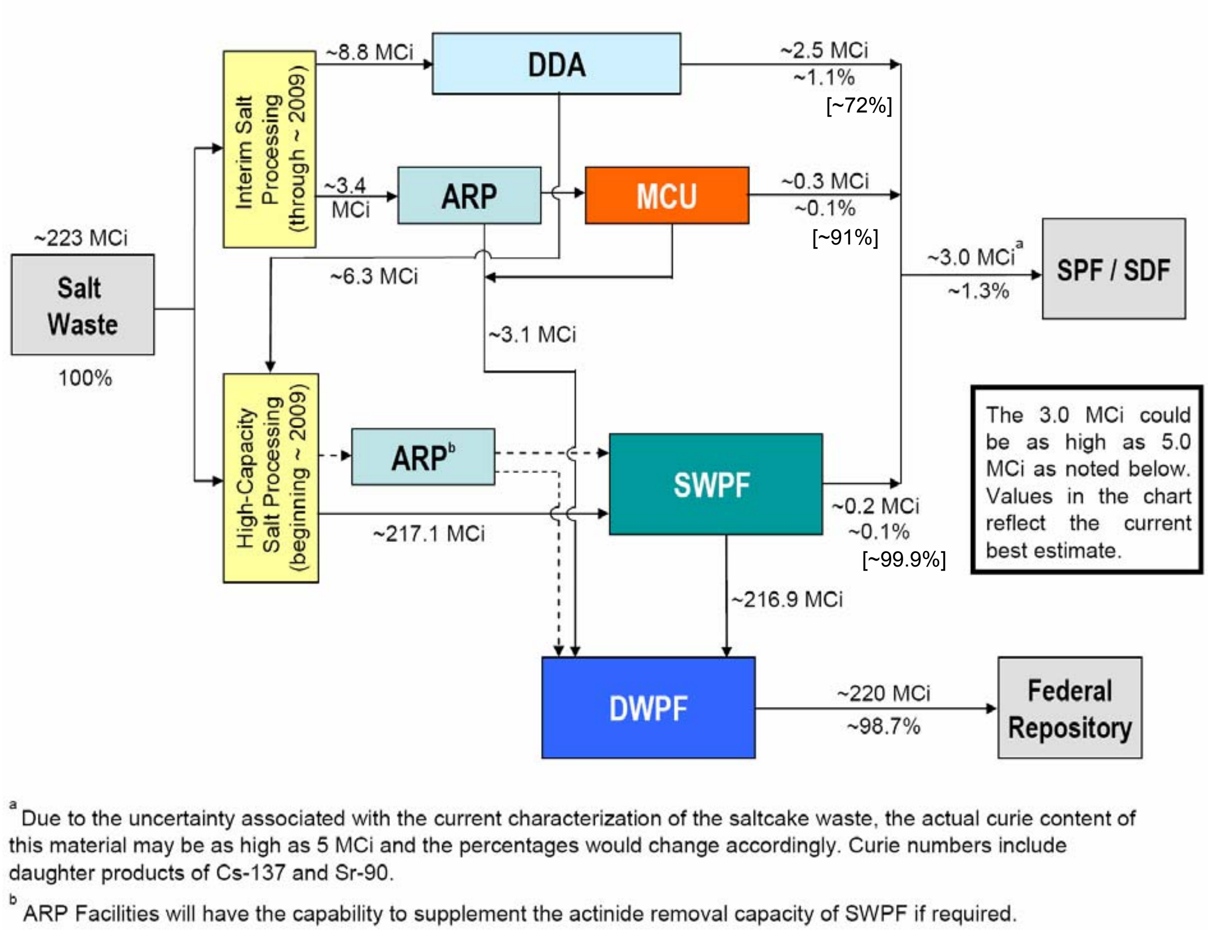


FIGURE 7 Radioactivity flows in DOE's salt waste processing plans. Percentages in brackets are the radioactivity separation efficiencies of the processes. NOTES: DDA = Deliquification, Dissolution, and Adjustment; ARP = Actinide Removal Process; MCU = Modular Caustic-Side Solvent Extraction Unit; SWPF = Salt Waste Processing Facility; DWPF = Defense Waste Processing Facility; SPF = Saltstone Production Facility; SDF = Saltstone Disposal Facility. SOURCE: Adapted from DOE (2005a).

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[42] As noted previously, the insoluble component contains actinides and strontium. The radionuclide removal effectiveness of this settling process is not known, although DOE describes it as removing a significant portion of the radionuclides.

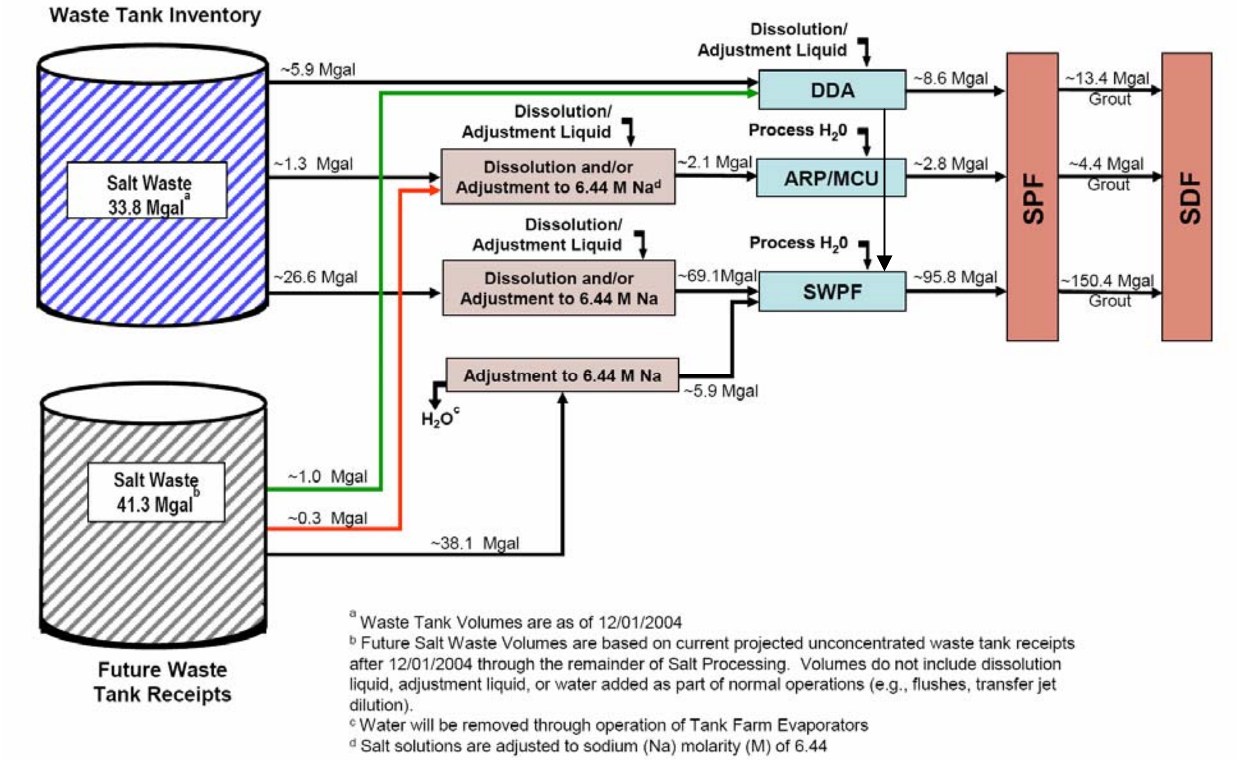


FIGURE 8 Volume flows in DOE's salt waste processing plans. NOTES: 1 Mgal = approximately 3,800 $m^3$. DDA = Deliquification, Dissolution, and Adjustment; ARP = Actinide Removal Process; MCU = Modular Caustic-Side Solvent Extraction Unit; SWPF = Salt Waste Processing Facility; SPF = Saltstone Production Facility; SDF = Saltstone Disposal Facility. SOURCE: Adapted from DOE (2005a)

Finally, after adjusting the sodium concentration in dissolved salt waste, DOE sends this waste to the Saltstone Production Facility for immobilization in the Saltstone Vaults. Thus, the DDA process uses physical rather than chemical means to accomplish cesium separation. A discussion of the effectiveness of the DDA removal process compared to the ARP/MCU and the SWPF follows (see Finding and Recommendation 2). The physical separation method used in DDA cannot achieve degrees of separation similar to those in the chemical processes used in the other facilities, described below. DDA is scheduled to operate from October 2005 until approximately 2009.

In the second low-capacity process (Step 2, Figure 6), DOE plans to apply two chemical processes in sequence: an actinide removal process (ARP) and a modular caustic-side solvent extraction unit (MCU). In the ARP, monosodium titanate is added to a tank to sorb strontium and the actinides. The monosodium titanate is recovered by filtration. The MCU will use a solvent extraction process to recover cesium from the salt waste. The ARP/MCU processing facility will have a smaller throughput than the other two processes and is designed to operate on its own for two years and, then in conjunction with the high-capacity facility thereafter, if needed. The recovered products from both ARP and MCU will be sent to the DWPF to be incorporated into glass logs, and the processed salt waste will be incorporated into saltstone. ARP/MCU is scheduled to begin operation in 2007 and could run until the end of the waste processing campaign (projected to be 2019).

The high-capacity processing will apply the actinide and cesium removal processes described above on a larger scale and in facilities designed for a much greater salt waste throughput, the Salt Waste Processing Facility. The ARP may continue to be used for additional recovery of strontium and actinides from selected wastes. Recovered products will be sent the DWPF to be incorporated into glass logs, and the processed salt waste will be incorporated into saltstone. This larger-volume treatment phase is scheduled to operate from 2009 until the salt waste processing is completed in approximately 2019.

The approach shown in Figure 6, using different processes at different times, was conceived for two reasons: (1) to allow DOE to continue tank remediation and operation of the DWPF during the time required to construct and permit the SWPF and (2) to free up tank space to support site operations and batch preparation for the SWPF (Hintze, 2005; Spears, 2005).

Table 3 presents DOE's estimates of the amounts of salt waste processed, saltstone produced, and concentrations of radionuclides relative to concentration limits for Class C waste given in Title 10, Part 61.55 of the Code of Federal Regulations (10 CFR 61.55; DOE, 2005a). The concentration limits in 10 CFR 61.55 define the maximum concentrations generally acceptable for near-surface disposal in a disposal facility meeting the other requirements of the regulation.

DOE plans to send what it has identified as the least radioactive salt wastes from the tanks through the DDA process. Yet because of the limited cesium separation achieved by DDA, the saltstone from this process is still expected to contain cesium concentrations that are two orders of magnitude (i.e., a factor of 100) higher than the waste from the chemical processes to be used in SWPF. Although DDA generates only 8 percent of the volume of the low-activity waste to be generated during salt waste processing, its waste contains 80-90 percent of the total radioactivity that is projected to be sent to the Saltstone Disposal Vaults.[43]

No separations process is perfect, and using processes that are tailored to the demands imposed by the characteristics of the wastes is, in principle, consistent with the recommendations of a previous National Academies report (NRC, 2000a). The earlier report found that given the varied nature of the wastes in the tank farms, DOE need not use the same radionuclide separations process for all of the wastes, and some of the least contaminated wastes may be suitable for disposal without separations.

Deciding how much effort to expend in both retrieving wastes from tanks and avoiding sending radionuclides to saltstone requires balancing technical factors, such as long-term risks to the public and occupational exposures, as well as nontechnical factors, such as costs and stakeholder views. From a technical perspective, to have an impact on long-term risks the separations must reduce concentrations of particular radionuclides. Both the low-activity stream and the residual waste in the tanks are to be grouted and disposed on site, either in the tanks or in the saltstone facility. If the separations processes are ineffective at removing radionuclides from the salt waste and instead leave them for on-site disposal as saltstone, aggressive efforts to retrieve tank heels may not reduce the overall long-term risks. An overall risk assessment comparing the risk of release from the residual radionuclides in the grouted tanks to those of release from saltstone is an essential tool to evaluate the trade-off of immobilizing radionuclides in the tanks or in the saltstone. Such a risk assessment was not available to the committee when it prepared this report.

[43] DOE estimates that 2.5 MCi of radioactivity from the DDA process and 0.5 MCi from the other processes will be sent to saltstone (DOE 2005a). DOE also notes that the total could be as high as 5 MCi. The 90 percent figure presumes that the uncertainty in total radioactivity derives from uncertainties about how much cesium would be removed by the DDA process.

TABLE 3 Estimated Saltstone Volume and Radionuclide Contents for Salt Waste Processing

| Saltstone Contents | Salt Waste Processing Phase | | |
|---|---|---|---|
| | DDA | ARP/MCU | ARP/SWPF |
| Contained volume of liquid salt waste, thousands of $m^3$ | 31 | 10 | 348 |
| Volume of saltstone, thousands of $m^3$ | 49 | 16 | 546 |
| **Radionuclide** | **Radionuclide Concentration in Saltstone $Ci/m^3$ (Fraction of Class C Limit)** | | |
| Carbon-14 | 0.00009 (0.001%) | 0.00003 (0.0003%) | 0.00003 (0.0003%) |
| Technetium-99 | 0.002 (0.06%) | 0.00004 (0.001%) | 0.00004 (0.002%) |
| Iodine-129 | 0.00001 (0.02%) | 0.000006 (0.008%) | 0.00003 (0.04%) |
| Alpha-emitting transuranic nuclides with a half-life greater than 5 years[a] | 64 nCi/g (64%) | 8 nCi/g (8%) | <10 nCi/g (<10%) |
| Plutonium-241 | 19 nCi/g (0.5%) | 10 nCi/g (0.3%) | 8 nCi/g (0.2%) |
| Curium-242 | 0.005 nCi/g (0.00003%) | 0.005 nCi/g (0.00003%) | 0.005 nCi/g (0.00003%) |
| Nickel-63 | 0.00008 (0.00001%) | 0.00003 (0.000004%) | 0.00003 (0.000004%) |
| Strontium-90 | 3 (0.04%) | 0.0002 (0.000003%) | 0.0002 (0.000003%) |
| Cesium-137 | 27 (0.6%) | 9 (0.2%) | 0.01 (0.0002%) |

[a] Primarily plutonium-238 but also includes other isotopes of plutonium, neptunium-237, americium-241 and -243, and curium-244. NOTES: DDA = Deliquification, Dissolution, and Adjustment; ARP = Actinide Removal Process; MCU = Modular Caustic-Side Solvent Extraction Unit; SWPF = Salt Waste Processing Facility. SOURCE: Adapted from DOE (2005a)

## Immobilization

After DOE has completed its separation of radionuclides, the inherent radiological hazards of the low-activity waste and the waste left in tanks will not be reduced further. Thus, all that can be done to reduce the *risks* posed by the material is to limit the potential exposures of humans and the environment. For the high- and low-activity wastes, DOE plans to solidify the material itself (in glass and grout, respectively), with the high-activity waste planned for disposal in a deep geologic repository off-site and the low-activity waste planned for disposal on-site in the Saltstone Vaults. For the tanks and their residual waste, DOE plans to fill the tanks with cementitious materials as described in Section I.

Site personnel have explained that in previous tank grouting, an engineered grout (Smart Grout) was placed by tremie[44] on top of the tank heel. [45] The engineered grout was designed to provide near- and long-term reducing capabilities to maintain the radionuclides and toxic heavy metals in their least mobile chemical forms (i.e., low-oxidation state or reduced form); to minimize the flow of water through the material (and the consequent leaching of radionuclides and metals from the grout); and to be pumped through grout lines into the tank and flow in the tank without segregation.

There is effectively no mixing of the grout with the insoluble tank heel due to the nature of tremie placement and the differences in density and viscosity between the Smart Grout and the tank heel. However, in Tanks 17 and 20 a series of tremie placements was made around the circumference of the tank to lay down the first grout layer and contain the tank residues rather than displace them toward the walls. Documents indicate that the small areas of incomplete grout coverage were at the intersections of different tremie deposits (USNRC, 1997). The engineered grout covered the fixed insoluble waste particles (containing primarily the actinides and strontium) and displaced the liquids. The liquids, which contain most of the technetium, other soluble radionuclides, and some suspended insoluble particles, were largely displaced to the top of the grout. They were absorbed by a second layer of dry grout placed on top to provide further immobilization of the waste. An improved version of a "controlled low-strength material" was then added above to provide structural stability. Finally, a third layer of a higher-strength grout material was used to fill the voids around the risers and to act as an intruder barrier. Plans for grouting tanks for future closures are still evolving as DOE learns from previous closures and factors in other considerations.

DOE’s estimates of grout behavior over time do not assume that the waste is mixed in the grout, but they do assume that the grout maintains its structural integrity[46] for 1,000 years and its chemical integrity[47] for 10,000 years. Despite the considerable amount of work performed by DOE contractors, the committee received only conceptual bases for evaluating how long the grout might last. Although requested, little quantitative (experimental or other) basis for the 1,000-year and 10,000-year assumptions was provided to the committee. The committee is aware of a qualitative analysis of the tank waste grout from 1992 (Lokken et al., 1992). Langton and co-authors describe the different needs and challenges for waste tanks at each DOE site, tank fill materials placement requirements,

[44] A tremie is a pipe used to convey and deposit grout or concrete rather than simply pouring the material from a height.

[45] Generally after pouring grout, excess water, called “bleed water,” floats to the surface of the grout. The Smart Grout formulation includes silica fume, which effectively eliminates bleed water.

[46] Structural integrity refers to the mechanical properties of the tank fill material. Structural integrity is needed to support the weight of the filled tank and the overburden.

[47] The tank fill materials are selected to be chemically basic and chemically reducing. Chemical integrity means that the grout maintains its basic and reducing conditions.

leaching and durability properties, and technology needs to demonstrate tank fill physical and leaching properties (Langton et al., 2001). The committee is aware of only one recent experimental study on the leach properties of grout with respect to technetium-99 (Harbour et al., 2004). The committee believes that the short- and long-term performance of Smart Grout warrant further research to bridge a knowledge gap (see Recommendation 4).

### Minimize Public and Occupational Hazards

Some occupational hazards are unavoidable: working with radioactive waste is potentially hazardous. Workers incur exposures during any operations that open the risers, including sampling, inserting equipment for cleaning, and inspecting the tanks. DOE reports that collecting and analyzing a single salt waste sample results in 2 person-millisieverts (200 person-millirem) of worker dose. DOE tries to keep workers' exposure below 5 millisieverts per person per year at most of its sites.[48] Exposures to radiation and other worker hazards are incurred in any waste management option to some degree. In selecting among options, there often are trade-offs between reduction of near-term committed dose incurred by workers and reduction of long-term risks to human health and the environment.

### Minimize Residual Hazards to Minimize Long-Term Maintenance

What long-term monitoring, maintenance, and controls are required at a site is determined in large part by the magnitude, duration, and type of hazard that remains. The hazards that are left on-site are determined by the effectiveness of the tank waste removal operations and radionuclide separation operations described above. Reducing reliance on the use of long-term monitoring, maintenance, and control could help DOE select performance requirements for these operations.

A previous National Academies study (NRC, 2005) found that recovery of every last gram of high-level waste from the tanks is technically impractical and unnecessary. At this committee's April 2005 meeting, DOE reported that the estimated effort involved in dismantling and removing a tank would take five years and cost about $100 million. DOE has argued that it is impractical to dismantle and remove tanks because of the exposures incurred by workers from radioactive residues and because of the overall prohibitive costs of exhuming such large structures. If a tank were very clean, little, if any, reduction in long-term risk would be achieved by removing the tank, its cooling coils, and any other waste material stored in it.

If the impetus for removing a tank were that substantial waste remained after attempts at heel removal, and removing the tank afforded greater access for further waste retrieval, the worker exposures entailed would probably be very high. Although highly radioactive waste recovered from a tank could be immobilized for disposal in a repository, exhumed tank pieces and much of the waste from the tank likely would simply be reburied in

[48] The regulatory dose limit for an individual worker is 50 millisieverts per year, but DOE has established the DOE control level of 10 millisieverts per year and recommends that facilities adopt a 5-millisievert-per-year administrative control level (DOE, 2004). The average annual background dose in the United States is about 3 millisieverts (NCRP, 1987); the estimates of all other radiation doses, including medical, are about 0.6 millisieverts for a total average dose to the US population of 3.6 millisieverts per year. The National Council on Radiation Protection and Measurements is revisiting the estimates of the total annual average doses in light of the increased use of medical radiation.

another waste facility on-site. The committee has seen no formal analysis of DOE's claims about the difficulty of tank removal.

The federal government plans to continue operations at portions of the Savannah River Site indefinitely. DOE assumes that the Savannah River Site will remain under federal government ownership within its current boundaries in perpetuity. Even if operations at the site are discontinued, South Carolina DHEC staff explained to committee staff that the federal government would have to maintain institutional controls at the General Separations Area (including the tank farms; see Appendix E for a map) because of extensive contamination from the seepage basins and other contaminant sources in the area (SCDHEC, 2005). DOE intends to restrict the area around the facilities where tank waste will remain on-site, namely the F- and H-Tank Farms and the Z-area saltstone storage facility, from residential use for 10,000 years.[49]

DOE's assumptions of institutional control at the site have been translated into assumptions about future human activity and, thus, future exposures. Previous National Academies studies have pointed out the pitfalls of such assumptions (NRC, 2000b, 2003, 2005), noting the likelihood of failure of institutional controls over the long term, even in a location such as the Savannah River Site, which has a continuing national security mission. It is, therefore, prudent to plan for such failures and to assess their consequences. The committee will address this topic further in its final report.

Based on USNRC guidance, active institutional controls that prevent inadvertent human intrusion are assumed to endure for 100 years. DOE has considered in its facility performance assessments[50] the possibility that after this time an inadvertent intruder could construct a residence on top of one of the storage facilities (DOE, 2005; Ross, 2005).[51] According to recent DOE analyses (DOE, 2002a, Table C.4.1-4), radiological doses from drinking water from the water-table aquifer 1 meter from the H-Tank Farm facility boundary (after the tanks are grouted, but without an engineered cap) are expected to peak at 1 sievert per year (100 rem per year) 175 years following tank farm closure.[52] (Figure E.3 shows the water table and the main flow directions of the groundwater.) The same analyses report that the maximum drinking water dose from water taken from the seepline (where the groundwater meets the surface and where the performance objectives were applied, called the point of compliance) is 25 microsieverts per year (2.5 mrem per year) 455 years after tank farm closure (DOE, 2002a). Thus, failure to maintain groundwater controls in the tank farm area for a period stretching into centuries could expose an intruder who draws drinking water from a well to high dose rates.[53] Comparable estimates for the Saltstone Vaults were not part of the saltstone performance assessment.

The difference between the dose rates quoted above is dramatic. From this difference, it is clear that the point of compliance (i.e., the location at which compliance with the performance objectives is measured) may determine whether DOE can comply with the

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[49] The *High Level Waste Tank Closure, Final Environmental Impact Statement* (DOE, 2002a) also states that DOE intends to restrict the entire site from residential use. However, the draft environmental impact statement (DOE, 2000) considers that members of the public are residents who construct a dwelling within site boundaries.

[50] A performance assessment is the set of computer models of the behavior and impacts of the waste disposal system over time.

[51] This is consistent with 10 CFR 61.42, which requires reasonable protection of any individual inadvertently intruding into a disposal site at any time after active institutional controls are removed.

[52] This dose value can be compared to an average background dose of 3 millisieverts per year.

[53] The committee recognizes that the performance assessments DOE is preparing are undergoing review and change. Thus, the results of the analyses have been presented simply to illustrate that groundwater doses could be very high centuries after the facilities are closed. The committee respects the fact that such numbers might be modified in future performance assessments.

performance objectives. The point of compliance for the tanks was selected by DOE and the South Carolina DHEC for the tank closure assessments for Tanks 17 and 20.

Similarly, the exposure scenario is crucial to the calculated dose results. The U.S. Environmental Protection Agency (EPA) approach to protecting human health and the environment from such contaminants differs from that used by the USNRC. The EPA uses a lifetime cancer risk criterion to determine acceptable levels of residual soil contamination, whereas the USNRC and most states use an annual dose criterion. The two criteria cannot be compared in a meaningful way without also examining each agency's entire system for the protection of public health and the environment, including methods of site characterization, assumptions about future land use, and methods assessing dose and risk, as well as uncertainties in determining levels of residual contamination and uncertainties in dose and risk assessments (NCRP, 2004).

Selection of an intruder scenario and the point of compliance involve policy and technical choices. A number of different intruder scenarios and points of compliance have been used in performance assessments and accepted by regulatory authorities. However, good risk management practice requires that the intruder doses and the rest of the spectrum of risks and trade-offs associated with future scenarios be considered with other assumptions in the context of the entire decision-making process, not in isolation. The committee is exploring what it can say further on these matters in its final report.

# III

# Findings and Recommendations

## PATHS TOWARD SOLUTIONS TO TANK WASTE PROBLEMS

As noted in the introduction, the committee has focused on actions that tend to (1) reduce the waste left on-site and (2) increase DOE's understanding of factors that affect the near- and long-term risks associated with the waste. Before commenting on issues specific to the Savannah River Site, it is useful to summarize briefly the general philosophy and approach that the committee considers important given its mandate from the Congress.

The committee notes that the goal of management of tank wastes that are to be left on site is protection of public health and the environment. The committee endorses a risk-informed approach, as described in *Risk and Decisions About Disposition of Transuranic and High-Level Waste* (NRC, 2005). A risk-informed approach starts with risk but incorporates many other factors in a decision process that leads to the desired end states (goals). The performance objectives define those goals, and the performance assessments determine which courses of action will meet those objectives. There are well-defined procedures for setting performance objectives to meet an acceptable end state. Much of the concern and difficulty relating to cleanup of the tanks relates to choices among alternative end states that meet the minimum legal and regulatory requirements and are protective of public health and welfare. The alternatives may differ substantially in several dimensions, including the types of risks associated with the end state, information needed to evaluate risk, time until final cleanup goals are met, the risks through time prior to achieving the end state, costs, and a variety of other considerations such as cultural, social, and political, as well as local, regional, and national economic interests.

The challenge, therefore, is not in demonstrating that performance objectives can be met by a particular cleanup option, but in determining which cleanup options provide an appropriate balance of costs, protection of public health and the environment, and other relevant factors, including consideration of the steps necessary to achieve the selected end state.

The committee believes that the basis for choices could be made clearer, and a wider range of possibilities may become apparent, if DOE were to identify and assess cleanup as a sequence of decisions (see, e.g., NRC, 1996). Management, treatment, and eventual disposal of tank wastes at DOE sites involve a complex and interdependent set of decisions, characterized by uncertainties in the consequences of each decision element. Some parts of the sequence of decisions can be made without finalizing the entire sequence. A most fundamental element of sound decision making under uncertainty is to preserve options for action as long as possible, provided that waiting for information or resolution of uncertainties does not create greater offsetting risks to health and the environment or other costs. Actions that would eliminate important options should be delayed when possible because options have value.

By structuring the path toward a final end state as a sequence of decisions (e.g., a tank closure decision or a saltstone processing decision), one can start to separate the decisions into decisions that clearly should be taken as soon as possible and those that potentially may be delayed until important uncertainties can be reduced (allowing a better choice to be made) or until new options become available (e.g., through operational experience, research, and technological innovation) that may make the decision easier (reduced risk at lower cost) and better informed.

The committee's findings and recommendations address four major issues: (1) near-term and long-term risks; (2) tank space crisis; (3) Class C limits and performance objectives; and (4) research and development needs. The following findings and recommendations are based on information available to the committee at the time of writing this interim report and may be extended if new information becomes available at the time the final report is written.

## Near-Term Versus Long-Term Risks

**Finding 1a: By far the greatest reductions in near-term probability and quantity of radionuclide and hazardous chemical releases to the environment are achieved by bulk removal and immobilization of liquid, salt, and sludge from the noncompliant high-level waste tanks. The tank heels that remain after bulk removal contain a smaller quantity of waste that is less mobile and constitutes a much lower near-term probability of release.**

**Finding 1b: The Savannah River Site Federal Facility Agreement has schedules for waste removal from and closure of the noncompliant tanks. For some tanks, the tank-closure step immediately follows the waste-removal step, making them appear to be coupled. This coupling could limit the time available for tank-waste removal and consequently could determine how much waste can be removed to "the maximum extent practical." A decoupled schedule is already planned for a limited number of tanks, as shown in Appendix F. Decoupling allows the consideration of a wider set of options for removing and/or immobilizing residual waste (especially for tanks that have significant obstructions that complicate waste removal), which could reduce long-term risks.**

**Recommendation 1: DOE should decouple tank waste removal and tank closure actions on a case-by-case basis where there are indications that near-term (5-10 years) techniques could become available to remove tank heels more effectively, safely, or at a lower cost. In evaluating schedules for each tank, DOE should consider the risks from postponing tank closure compared with the risk reductions that could be achieved if the postponement improves heel removal. Although the committee believes that postponing tank closure need not extend the closure dates of the tank farms, DOE should work with the State of South Carolina to revise the schedule for closure of a limited number of the tanks that contain significant heels, if necessary.**

## Rationale

The bulk of the waste within the noncompliant tanks poses the greatest potential for environmental release in the near term, and if released into the environment it constitutes an essentially irretrievable source term of untreated hazardous material into the future. Therefore, most of the reduction in risk from such releases is achieved by bulk removal of these wastes. Removal of sludge in the heel, which contains most of the strontium salts (i.e., medium-lived radioactivity) and most of the insoluble actinides (i.e., long-lived radioactivity), will also reduce risks although it is more difficult to achieve. The committee agrees with DOE's and South Carolina's overall approach to tank waste removal at the Savannah River Site: bulk removal and immobilization of the waste is the highest priority to reduce the probability of release of radioactive materials to the environment in the near term. The noncompliant tanks, about half of which have a history of leakage, demand attention first but most of the tanks are beyond their design lifetimes.

Residual waste left in the tanks poses a lower near-term risk because it is less mobile and, as such, has less potential for environmental release, and there is less of it to constitute a potential source term. However, wastes left in tanks for longer terms may result in increased risks due to aging and corrosion of the tanks, and the greater likelihood of extreme natural events with time.

The milestones in the Federal Facility Agreement have been negotiated among DOE, the state, and EPA and are based on policy decisions; from a technical perspective, the schedule that the milestones imposes make tank waste removal and tank closure schedules appear "coupled" (i.e., one following the other as soon as possible) for some tanks. The disadvantage of closing tanks as soon as waste removal actions cease is that it forecloses near-term options to remove additional waste and/or to use improved immobilizing materials to fill the tank. Filling a tank with grout is essentially an irreversible action, although it is always conceivable to open a tank and excavate the grout if absolutely necessary.

DOE should decouple cleanup and closure schedules, keep as many options open as practical for a limited period of time (i.e., 5-10 years), and regularly assess technology developments and alternatives to reduce long-term risks presented by the tank heels (radioactive source term). In some cases, such as tanks with large obstructions where retrieving all of the heel is particularly problematic, DOE should make additional investments in research and development to enhance tank waste removal (reducing the source term), to improve residual waste immobilization (stabilizing the source term), or to reduce the ingress of water once the tanks are closed (protect the source term); see Recommendation 4. A similar recommendation was made in a previous National Academies report for DOE's Environmental Management Science Program (NRC, 2001).

A qualitative assessment by DOE of the issues associated with aged and abandoned underground structures and vessels includes the potential for roof and side wall collapse; filling with water from runoff (bathtub effect); and internal seepage which can lead to overflowing, leaking, or leaching, and buoyancy (Langton et al., 2001). However, the committee is not advocating abandoning the empty tanks on-site and has seen no quantitative assessment of the risks of postponing tank grouting. According to DOE, the tanks are not in near-term danger of collapsing after bulk waste retrieval;[54] indeed the structural support provided by the tank fill is not likely to be needed until DOE is ready for

[54] It is the committee's understanding that the geometry of the tanks is inherently stable (i.e., resistant to collapse). The emptied tanks, therefore, need not be filled until immediately prior to closure of the entire tank farm and placement of the engineered cap (if used).

ultimate closure of the tank farm. In most cases, postponing closure of tanks that contain substantial amounts of residual waste for several years would appear to have essentially no effect on near- or long-term risk.

In some cases, tank closure need not be delayed, such as in tanks that have small heels (i.e., as small as those in Tanks 16, 17, and 20) and/or low concentrations of radionuclides or if there are risks specific to the tank that require closure as soon as waste removal is completed. Conversely, delaying closure may be warranted for tanks with large heels or high concentrations of radionuclides. This approach need not necessarily affect the final closure dates of the tank farms, which will occur later than 2022, the milestone for closure of the noncompliant tanks. If new technologies become available in the near future (i.e., 5-10 years), it may be possible to clean up and/or close tanks faster (possibly leaving less waste behind), thus meeting the final milestone for closing the tank farms.

There are specific advantages in delaying closure of the most challenging tanks. DOE needs time to gather operational experience for tanks with cooling coils and other major obstructions. DOE obtained good results in retrieving waste from Tanks 17 and 20, leaving behind very little residual waste. Tanks 18 and 19, which have undergone waste removal, are estimated to have an order of magnitude more radioactivity than Tanks 17 and 20, but the greater challenges lie ahead. DOE started its tank waste removal and closure campaign with Type IV tanks, which are simpler to work with because of the absence of cooling coils. This approach makes sense with respect to retrieval technology, because it allows DOE to learn from the simpler tanks before tackling the more complex ones. Tanks with coils may present an additional challenge because they are likely to have solids encrusted on the walls, bottoms, and the coils themselves.

DOE has developed operational experience on in-tank activities, such as sampling, slurrying, pumping, removing waste heels with water jets (sluicing), and operating other remotely controlled equipment. In some cases, DOE may need more time than is allowed by the FFA closure milestone to apply what it has learned, test, identify any new challenges, and evaluate new technologies to maximize the removal of waste and stabilize residual waste in the more difficult tanks (see also Recommendation 4).

The other advantage of decoupling tank waste removal and closure is that it would allow DOE the opportunity to enhance the effectiveness of tank closure. As previously noted, the long-term performance of the tank fill materials, especially Smart Grout, has not been adequately established. To lend confidence to the assumptions used in the performance assessment, a delay in tank closure would give DOE more time to evaluate grout formulation and techniques further and to conduct studies of projected long-term performance by laboratory and field testing of tank fill materials (see Recommendation 4).

The committee recognizes that there are also drawbacks to delaying tank closure. The State of South Carolina told the committee that the state wants to see progress on closing out the tanks and does not favor a “piecemeal approach” to waste cleanup, decoupling bulk removal from tank closure (SCDHEC, 2005). It has been argued that unless previously agreed to milestones for tank closure continue to be met, progress will stall. Moreover, once equipment is in place for tank waste removal (e.g., the superstructure for in-tank operations), it is convenient to proceed to use the same equipment for closure, rather than moving it to another tank and re-equipping the first tank when it is ready for closure.

The committee does not advocate decoupling the removal and closure schedule based only on the future possibility of discovering better technologies for cleanup and closure, without identifiable prospects. Rather, the idea is to develop or adapt specific technologies that are at least in the applied research stage and to research a narrow set of questions that, if answered, could enhance tank heel removal and closure effectiveness. In Recommendation 4, the committee suggests three promising topics that warrant further research and development efforts to achieve these two objectives.

A reason for decoupling schedules concerns what is practical. The tank wastes must be dealt with and Congress has provided a means to do so. One element of Congress' mechanism concerns removal of highly radioactive materials to the maximum extent practical. Ideally, all radioactive materials would be removed; in practice, waste cleanup decisions account for risks, costs, benefits, the likelihood of improvements, and other policy considerations. The committee is concerned that what is practical is being defined, in some cases, by an agreed upon schedule or what meets the performance objectives, not accounting for the ALARA requirement. The committee is also concerned that the cleanup not extend indefinitely into the future. Therefore, the committee has selected a time frame that is in reasonable accord with the overall schedule for tank farm closure. If substantially improved waste removal and closure can be achieved with no or little effect on the overall tank farm closure schedule, it would seem prudent to do so.

Finally, as DOE considers delaying closure for some tanks, it has to evaluate advantages and disadvantages from both a risk and a cost perspective. If DOE can relax other constraints on tank waste removal, such as the tank space problem, then delaying tank closure could free up funds planned for closure activities, and those funds could be devoted to enhancing waste removal, waste processing, and confidence in the near- and long-term performance of the waste immobilization and tank fill materials. Similarly, research and development require funds, but could, if successful, result in lower costs and increased safety overall (see Finding and Recommendation 4).

## Tank Space Crisis

**Finding 2a: The lack of compliant tank space does appear to be a major problem because of continuing waste inputs and the anticipated future needs for space to support site operations and tank cleanup. As presently operated, sludge waste processing results in a net addition of waste to the compliant tanks. Salt waste processing will also require storage volume in compliant tanks for batch preparation and other operations.**

**Finding 2b: DOE plans to use the deliquification, dissolution, and adjustment process to free up space in compliant tanks. While DOE analyses so far suggest that the wastes from this process would meet the performance objectives in 10 CFR 61, it achieves less radionuclide separation than other planned processes. While waste from the DDA process represents only 8 percent of the volume of low-activity waste to be generated during salt waste processing, it contains 80-90 percent of the radioactivity that is projected to be sent to the Saltstone Disposal Vaults.**

**Recommendation 2: DOE and other involved parties should consider options other than DDA to alleviate the impending crisis in usable storage in compliant tanks. Options include actions that (1) reduce waste inputs to the tanks, such as redirecting the DWPF recycle stream for disposition in the Saltstone Facility; and (2) actions that free up usable volume in compliant tanks, such as using noncompliant tanks not known to have leaked for emergency storage volume.**

### Rationale

As noted previously, compliant tank space is scarce and DOE often makes multiple transfers among tanks to ensure that there is sufficient operating space in specific tanks, such as tanks that are connected to an evaporator. As the compliant tank space diminishes, the needed transfers become more complex, even to the point of making transfers between the tank farms. Further, unless currently obligated compliant tank space is freed up, there will come a point when the tanks cannot accommodate more waste. DOE has indicated that without increasing the available compliant tank space, it faces a decision in the next year about whether and how to reduce waste additions.

As noted in Section II, the DNFSB has raised concerns about tank space problems and the increased risks of accidents and worker exposures incurred as a result of the additional waste transfers that are required as space becomes more scarce (DNFSB, 2004). The committee shares these concerns and believes they deserve serious attention: DOE needs options to address this problem, even if new inputs are slowed, as recommended above.

DOE plans to address the tank space problem in the near term by implementing the interim salt waste DDA process. The DDA process would alleviate some of the space problem. However, during the short time it will be in operation DDA would process less than 10 percent of the salt waste and would leave behind at least five times as much radioactivity in the saltstone compared to the ARP/MCU and the high-capacity processes that will treat the other 90 percent of the salt waste. Because grouting the LLW is an irreversible action, the decision to send the DDA waste stream directly to saltstone permanently commits a substantial amount of radioactivity to the site. In other words, although the DDA process would free up tank space, this tank space is attained at the cost of a large increase in radioactivity left on-site, compared to processing the waste through the planned chemical processing facilities (ARP/MCU and SWPF). Even these higher levels of radioactivity, primarily from cesium, may not cause projected doses from the Saltstone Vaults to exceed dose limits, although, as noted earlier, details underlying a performance assessment for DDA saltstone were not available for committee examination. However, the separation achieved with DDA raises the question: Does this process remove radionuclides to the maximum extent practical?

Table 4 compares the efficacies of salt waste treatment processes. The table shows that DDA is significantly less effective than ARP/MCU and the SWPF in removing radioactivity from salt waste. DOE indicated that up to 5 MCi of radioactivity could be sent to saltstone depending on the uncertainties in the characterization of the saltcake; if this were to be the case, the contribution of radioactivity sent to saltstone from DDA alone could increase to 4.5 MCi, which represents almost 90 percent of the total amount of radioactivity sent to saltstone from all three salt waste processes.

Neither the model that generated the detailed inventory of the waste constituents nor the saltstone waste acceptance criteria[55] were available to the committee for review. The committee, therefore, can neither endorse nor recommend changes to a phased salt waste processing approach that includes the DDA without this additional information.

One committee concern is what will happen with salt waste processing if the SWPF or the interim chemical processing cannot be brought into operation on schedule. The committee did not review the engineering readiness of the salt waste processing, but the schedule to bring the facilities on-line (ARP/MCU by 2007 and the high-capacity SWPF by 2009) and operating to specifications (i.e., processing waste at the expected throughput and meeting the waste acceptance criteria) is ambitious.

[55] Waste acceptance criteria take into account performance objectives and broader considerations, such as waste "processibility" (i.e., compatibility of waste and secondary products with the chemical and physical processes prior to disposal) and other site-specific requirements.

TABLE 4 Projected Efficacy of Salt Waste Treatment Facilities

| | DDA | ARP/MCU | SWPF |
|---|---|---|---|
| Date expected to be in operation | 2005 | 2007 | 2009 |
| Date expected to cease operations | 2009 | 2009 | 2019 |
| Volume to be processed, million gallons | 6.9 | 2.1 | 75 |
| Volume to be sent to saltstone, million gallons | 8.6 | 2.8 | 95.8 |
| Radioactivity to be removed, MCi[a] | 8.8 | 3.4 | 217.1 |
| Radioactivity to be sent to saltstone, MCi | 2.5 | 0.3 | 0.2 |
| Projected radioactivity removed, % | 71.6 | 91.1 | 99.9 |
| Projected share of radioactivity in the saltstone, % | 83.3 | 10 | 6.7 |

[a] DOE indicated that due to the uncertainty associated with the current characterization of the saltcake waste, the actual radioactivity of the material going to saltstone may be as high as 5 MCi. Other uncertainties associated with radioactivity values and the time lines have not been determined. Values in curies include contributions from the daughter products of cesium-137 and strontium-90.

Based on DOE's prior experience with developing and initiating operations at major waste processing facilities,[56] it is prudent to plan for the possibility that salt waste will not be removed from the tanks at the planned pace. In other words, DOE needs a contingency plan for tank space. More generally, the committee cautions that in a schedule-driven system there is the danger that wastes could be sent through the process that is currently available rather than the one that is most suited to the wastes. The committee recognizes, of course, that there are other considerations (e.g., safety, risk, and cost) involved in such decisions. The committee here offers some suggestions to reduce waste inputs to tanks and to free up compliant tank space.

### *Reducing Waste Inputs*

(1) *Reduction in DWPF recycle stream volume*. As previously noted, a major source of new waste inputs to the tanks is from the DWPF recycle stream, which is a low-activity, high-volume waste stream. According to information provided by DOE (Fellinger and Bibler, 2004), the main contributor to radioactivity in this recycle stream is condensate from the melter off-gas (i.e., vapors and gases produced during melter operations). This off-gas contains a small amount of solids entrained in the steam produced when the waste slurry is evaporated in the melter. DOE's analyses indicate that both the nonradioactive and the radioactive compositions of samples taken from the off-gas condensate tank, and subsequently the recycle concentrate tank, which collects all DWPF recycle stream, reflect the composition of the waste sludge that is being vitrified. According to the same analyses, the total radioactivity in the recycle stream amounts to about 0.001 Ci/liter with about two thirds of the radioactivity coming from cesium-137 and one third from alpha-emitting

[56] Several Government Accountability Office reports have commented on the challenges of bringing online and operating large-scale waste processing facilities (GAO, 1997a, 1997b, 1999, 2003, 2004).

isotopes. The DWPF recycle stream is therefore essentially a very dilute solution that carries traces of the original waste sent to the DWPF.

Installing an evaporator at the DWPF to reduce the volume of the recycle stream would reduce waste inputs to the tanks. However, as noted before, DOE indicated that the earliest an evaporator could be brought on-line is 2010. While an evaporator would not now be able to alleviate the near-term tank space crisis without an expedited schedule, such an option should be investigated for longer-term waste management operations.

Other longer-term options for consideration include the installation and use of temporary holding tanks as part of the sludge washing and DWPF recycle handling to reduce the waste generation from those operations or a change in operations of the DWPF.

(2) *Redirecting the DWPF recycle stream*. The DWPF recycle waste stream could be grouted and sent directly to the saltstone facility. As noted above, DOE indicated that this stream is a low-activity waste stream and therefore could be disposed on-site as saltstone. DOE is currently sending the DWPF recycle stream to the tank farm because of future potential use in waste processing (e.g., batch preparation); however, this waste stream currently does not appear to be used for any purpose and the near-term benefits of more tank space may outweigh the long-term detriment of introducing additional water into the system.

### *Freeing Up Existing Compliant Tank Space*

(1) DOE holds the equivalent volume of one empty tank in compliant tank space in reserve for emergencies. Holding such a reserve is sensible, but it is not clear that the space has to be in a compliant tank. Several Type IV tanks have no history of leakage, and some could provide emergency reserve. This would free up the equivalent of a full compliant tank. According to DOE and the South Carolina Department of Health and Environmental Control, DOE may store waste in noncompliant tanks if the waste is kept below the height of any historical or anticipated leak.

Given that virtually all of the usable tanks are filled to capacity with very limited free working volume, the system is vulnerable to mishaps and perhaps to leaks, overflows, and possibly even tank or line failures with potential extensive releases to the environment. Therefore, it seems prudent to proceed apace to obtain the working volume to deal with unexpected circumstances while refining waste treatment processes for the long term (i.e., 10-20 years or more).

## Class C Limits and Performance Objectives

**Finding 3: The future site-specific risks posed by wastes disposed of on-site is the primary issue of concern in this study. Such risks are determined by the radionuclide and chemical quantities and concentrations, their conditioning, their interactions with the environment, and their bioavailability, not by the relationship of radionuclide concentrations to generic limits such as those for Class C low-level waste. The National Defense Authorization Act Section 3116 requires the use of the performance objectives in 10 CFR 61 to limit and minimize these risks.**

**Recommendation 3: When deciding what wastes may be disposed of on-site, DOE and other involved parties should ensure that discussions focus on how radionuclide and chemical quantities and concentrations, their conditioning, their interactions with the environment, and their bioavailability affect site-specific risk.**

## Rationale

The Class C limits are not a criterion for the acceptability of on-site disposal of tank wastes from reprocessing of spent nuclear fuel under the present law, but are sometimes discussed as if they were. In Section 3116 of the Ronald Reagan National Defense Authorization Act of 2005 (NDAA), Congress established criteria for determining that some waste from spent fuel reprocessing is not high-level waste and may be disposed of on-site at the Savannah River Site and the Idaho National Engineering and Environmental Laboratory. Congress implicitly divided the non-HLW destined for on-site disposal into two subclasses, depending on the concentrations of radionuclides in the waste in relation to Class C concentration limits in 10 CFR 61.55 (see Table 5). Therefore, at the Savannah River Site and the Idaho National Engineering and Environmental Laboratory (but not at Hanford), there are essentially three categories of reprocessing waste: HLW, non-HLW Class C or less and non-HLW greater than Class C, as shown in Table 5. The recent promulgation of the NDAA adds further complexity to the regulatory framework for tank waste at the Savannah River Site in that the “consultative” role of the U.S. Nuclear Regulatory Commission has not been defined in the NDAA and is now being applied for the first time.

TABLE 5 Management Standards for Wastes Stored in HLW Tanks at the Savannah River Site and the Idaho National Laboratory

| HLW | Non-HLW Class C or Less | Non-HLW Greater than Class C |
|---|---|---|
| Default classification of all highly radioactive wastes from reprocessing of spent nuclear fuel | DOE, in consultation with the USNRC, may decide that the wastes do not require deep geologic disposal | DOE, in consultation with the USNRC, may decide that the wastes do not require deep geologic disposal |
| | High-activity radionuclides removed to the maximum extent practical | High-activity radionuclides removed to the maximum extent practical |
| | Disposal must meet performance objectives of 10 CFR 61, subject to USNRC monitoring and reporting to congressional committees | Disposal must meet performance objectives of 10 CFR 61, subject to USNRC monitoring and reporting to congressional committees |
| | Disposal must be approved by host state | Disposal must be approved by host state |
| | | DOE consults with USNRC on disposal plans |
| Must be disposed of in deep geologic repository | Need not be disposed of in deep geologic repository | DOE develops disposal plan in consultation with USNRC |

NOTE: Standards established in Section 3116 of the Ronald Reagan National Defense Authorization Act of 2005.

DOE and the Nuclear Regulatory Commission are now testing this process through the Salt Waste Process Determination (DOE, 2005a).

The present study focuses on non-HLW, although the committee is encouraged to consider as much of the issue as is necessary to make meaningful recommendations. The committee draws several conclusions from the legal structure in Table 5:

1. The non-HLW categories potentially apply to the reprocessing wastes planned for land disposal at the Savannah River Site, including tanks, tank heels, and saltstone in vaults.
2. Whether a particular non-HLW meets or exceeds Class C criteria is relevant to its disposition only procedurally regarding USNRC roles in that DOE must consult with the USNRC on its disposal plans. The USNRC has a consultation and monitoring role in both of the non-HLW categories, but it has no decision-making role in either.
3. Congress has mandated that the substantive disposal standards for non-HLW be the following:

- Removal of highly radioactive radionuclides "to the maximum extent practical."
- Compliance with the performance objectives of Subpart C of 10 CFR 61. The performance objectives focus on

    i. ensuring that the dose to the public meets specific requirements and is as low as reasonably achieved (ALARA) below this level;
    ii. protection of inadvertent intruders;
    iii. ensuring that the occupational dose meets specific requirements and is ALARA below this level; and
    iv. ensuring long-term stability of the disposal site including elimination of the need for active maintenance to the extent practicable.

- Disposal pursuant to a state-approved closure plan or state-issued permit.

4. Risk to human health and the environment is not an explicit criterion in disposal decisions, though the performance objectives are proxies for human health risk to the extent that dose limits and ALARA are representative of this goal.

In sum, within this regulatory structure, whether a particular waste stream meets or exceeds the definition of Class C makes little difference in terms of what is really at issue here—compliance with performance objectives and the protection of human health and the environment. This conclusion underlies Recommendation 3.

Class C limits were not designed to be applied for legacy waste at DOE sites. These concentration limits for waste were developed for a diverse commercial sector to establish limits on what is generally (not site specifically) acceptable for near-surface disposal, based in part on assumptions about the overall set of wastes destined for disposal. It was never envisioned that one might have a large, near-surface disposal facility filled to capacity with waste at or near the Class C limit. Indeed, if the Class C limits alone were the criteria for acceptance of waste in the Saltstone Disposal Vaults, all of the cesium-137 in the high-level waste tanks at the Savannah River Site could potentially go into the saltstone.

Congress recognized the importance of the performance objectives for evaluating site-specific near-surface disposal of waste in Section 3116 of the NDAA by explicitly including these objectives as the basis for management standards to be applied to waste in high-level waste tanks at the Savannah River Site and Idaho. Note, too, that the USNRC eliminated comparisons to Class C concentration limits in favor of a site-specific, performance-based approach for the West Valley Demonstration Project (USNRC, 2002; Vietti-Cook, 2000).

Rather than Class C limits, site-specific risks (as calculated in performance assessments) are the bases for determining whether the facility meets the performance objectives in the regulations. Risks depend on radionuclide quantities and concentrations, their conditioning, and their interactions with the environment. It is possible that some Class C wastes may not be acceptable for near-surface disposal at a particular site and that some greater-than-Class C wastes may be acceptable for near-surface disposal at a another site as exceptions to the generic concentration limits. At the Savannah River Site, DOE proposes on-site disposal of certain wastes in known facilities (e.g., Saltstone Vaults, existing tanks). As a consequence, the relevant criterion concerning the maximum concentration of radionuclides acceptable for such disposal is whether performance objectives are met for those specific locations, which is supposed to be reflected in the "waste acceptance criteria" for each disposal facility. The allowable concentrations may be higher or lower than the Class C limits, but they would likely be based on relevant data, models, and assumptions rather than generic calculations. Risk evaluations must be done using a properly constituted "performance assessment" and associated uncertainty analysis for the specific situation at hand. A previous National Academies report (NRC, 2005) provides extensive guidance on how such risk assessments should be performed.

Concerning the related issue of radionuclide concentration averaging, the committee draws similar conclusions to those described above. The actual distribution of radionuclides within the waste form and the waste form's ability to immobilize the radionuclides affect risk. The performance assessment used to assess risks must use the actual distributions or conservative simplifications of those distributions. Concentration averaging that is used only to calculate radionuclide concentrations for comparison to the Class C limit is not relevant to risk. Such averaging will not be required for saltstone, the composition of which should be well known and is essentially homogeneous over large volumes. This way of thinking about concentration averaging is in agreement with the U.S. Nuclear Regulatory Commission's guidance on these issues (Knapp, 1995).

## Research and Development Needs

**Finding 4: Focused research and development could help DOE reduce the amount, improve the immobilization, and test some of the assumptions used in performance assessment of tank waste to be disposed of at the Savannah River Site. These actions could reduce the risks to humans and the environment and improve confidence in DOE's risk estimates. These research and development activities could also increase DOE's ability to demonstrate compliance with the performance objectives in 10 CFR 61.**

**Recommendation 4: DOE should fund research and development efforts focused on providing deployable results within 5-10 years on the following topics: (1) in-tank and downstream processing consequences of chemical tank-cleaning options, (2) technologies to assist in tank-waste removal, including robotic devices, and (3) studies of the projected near- and long-term performance of tank-fill materials such as grout.**

### Rationale

To reduce long-term risks at the site and test the assumptions in the performance assessment, the committee recommends that DOE carry out focused research and development activities to improve capabilities for tank waste removal and closure. This recommendation implies that certain tanks should not be closed immediately after cleanup, as stated in Recommendation 1. The committee is not advocating delaying closure of certain tanks to perform long-term research and development activities: efforts should be limited to promising technologies that are at a near-deployment stage (i.e., they could provide deployable results within 5 to 10 years, in time to be implemented during the tank closure process). All noncompliant tanks are scheduled to be closed by 2022. A technology developed in the next 5-10 years could be deployed in time to address the most challenging tanks (i.e., those with cooling coils).

Although the committee is lacking critical information to determine whether DOE's management and closure plans will comply with the dose limits in the performance objectives, the committee believes that a focused research and development program aimed at reducing the amounts of waste left in the tanks or improving its immobilization may increase confidence in DOE's plans or cause DOE to revise some of the assumptions used in the performance assessment. Validating assumptions and improving DOE's knowledge base could increase its ability to comply with the performance objectives. Moreover, these research and development activities could support the development of contingency approaches to address unanticipated difficulties in baseline processes.

These research and development activities would be carried out either in parallel with the current baseline approach to tank waste removal and closure or until a specific technology becomes ready to be deployed. These technologies will likely require pilot-scale tests with tank mockups and with surrogate heels to test their effectiveness before full-scale deployment.

The committee believes that there are at least three critical topics warranting further research and development efforts.[57] These topics represent the greatest technological challenges (i.e., waste retrieval and tank cleanup) and knowledge gaps (i.e., Smart Grout long-term performance). Research and development activities to address these topics are discussed below.

*In-Tank and Downstream Consequences of Existing and Advanced Chemical Cleaning Options*

As noted previously, DOE has demonstrated the efficacy of oxalic acid for the chemical cleaning of waste tanks but also uncovered potential drawbacks associated with criticality safety and downstream processing. DOE's concerns about criticality issues are linked to the potential for selective removal of a neutron poison (e.g., iron hydroxide) from a phase containing significant quantities of fissile isotopes.[58] DOE provided no indication that calculations have been carried out to substantiate these concerns. Oxalic acid may also interfere with downstream processing for further separation or immobilization of radionuclides. For example, foaming of organic chemicals could occur depending upon a number of conditions including chemical concentration, temperature, and mixing.

Two paths can be explored: (1) research and development of cleaning agents other than oxalic acid that would not interfere with sludge or salt waste processes; or (2) research and development on ways to both predict and eliminate criticality concerns and downstream problems if oxalic acid is used as the cleaning agent. Examples of research to address downstream problems from oxalic acid could include destruction of oxalic acid and metal

[57] Other topics may be added in the final report, as the committee gathers further information.

[58] Fissile isotopes have a high probability of undergoing nuclear fission when struck by neutrons and, in the right quantities and configurations, can sustain a nuclear chain reaction.

oxalates via ozone oxidation, chemical oxidation, and electrochemical oxidation (Patello et al., 1999; Nash et al., 2003). Savannah River Site personnel indicated that they are in communication with other national laboratories, DOE sites, and with Russian experts on tank cleaning technologies, particularly on chemical cleaning.

The chemical species formed by radioactive elements have been identified as key parameters in understanding their dissolution and solution behavior in tank waste (Garnov et al., 2003; Nash et al., 2002). Over the past 30 years, significant advances have been made in metal-specific complexation and ligand design which exploit metal ion speciation in producing selective complexes. A number of these advances are based on biomimetic studies that evaluate specific metal ion-ligand interactions in natural systems (Raymond, 1990; Durbin et al., 1989). While metal-ligand interactions are primarily understood in the solution phase, ligands produced by bacteria (siderophores) will solubilize iron oxides, dissolve oxides of uranium and plutonium, and can be exploited in developing metal-specific reactions for solid phases (Brainard et al., 1992). These metal-specific ligand approaches have been used for the selective removal of radionuclides from the human body (see for example, Gorden et al., 2003). This same selective ligand approach has been applied to the area of radionuclide removal from tank waste (see, for example Nash et al., 2000). To date, these advances have not impacted the site's tank waste removal operations but in the future they might offer cost-effective options for removing both solution and solid phase radionuclides from the tanks.

*Technologies to Assist in Tank Waste Removal, Including Robotic Devices*

Numerous technologies for retrieving residual high-activity waste from tanks at DOE sites have been developed to varying extents. The technologies mostly include tethered devices that may be either remotely controlled or robotic (i.e., programmable) and that maneuver along the bottom of a tank, as well as end-effectors deployed on the end of a mechanical arm. Such technologies are typically designed to gather, retrieve, and/or characterize relatively small amounts of residual waste remaining in the tank after bulk retrieval has been completed.

Some devices have been deployed in the harsh environment represented by tanks containing high-activity wastes (Vesco et al., 2000; DOE, 2001d). However, the instances in which these devices have been deployed in tanks are relatively few and the devices have been tethered and not programmable or autonomous. Such devices and enhancements thereof appear to be suitable for the many DOE tanks that do not have internal structures such as cooling coils.

Looking forward, DOE faces the need to retrieve waste from many large tanks containing cooling coils and other obstructions, especially at SRS. The baseline bulk retrieval approach consists of using water jets from the riser locations to spray material off the internal tank structures onto the bottom of the tank, consolidating it by sluicing, and pumping it from the tank. The potential limitations of bulk retrieval techniques are clear when one notes that the tanks containing a 'jungle' of cooling coils are 25 to 28 meters (75 to 85 feet) in diameter and up to 10 meters (30 feet) in height. The efficacy of bulk retrieval in tanks with coils is uncertain: good cleaning of tank surfaces appears to have been achieved in zones beneath the risers but the amount of residual waste remaining in the 'dead zones' between risers and in the tank periphery is unknown. However, the use of remotely controlled and robotic devices to retrieve residual tank waste also faces challenges as a result of the jungle of piping and other obstructions that severely limit the size and mobility of retrieval devices. According to the committee's experts, no device—robotic or otherwise—is ready to be deployed in such tanks to recover residual waste. A few devices seem promising but require time for development and testing (see Sidebar 2), and significant investments.

In general, since the 1970's, robotic technology advances have paralleled the progress of the microprocessor, though with a lag of some years. The continued increase of processing power and speed has allowed robotic devices to make major advances in speed, precision, cost effectiveness, scope of applications and most critically, reliability. This is especially true in industrial applications. More exotic applications such as space, service, military and security robotics have also seen impressive gains commensurate with the funding level invested in development. Because the challenge of DOE tank waste cleanup is unique and the opportunities for deployment have been few due to the pace of the tank waste cleanup program, development and deployment of robotic devices for this purpose has only been attempted by a few teams. DOE's previous work and experience on retrieval systems for residual wastes (e.g., the Fluidic Pulse Mixing and Retrieval System, the Modified Light Duty Utility Arm [Thompson et al., 1997; Magleby et al., 2002], previously cited deployments) is a worthwhile first step in a necessary continuing investigation. Robotic technologies will continue to advance and may accomplish in the future what is not possible today.

The committee is planning to learn more about DOE's research and development efforts on technologies for retrieving residual tank waste and may write more in the final report. In the interim, research and development investments in residual waste retrieval technologies suitable for tanks containing cooling coils or other obstructions appears prudent.

### *Near-Term and Long-Term Performance Studies for Tank Fill Material*

As previously mentioned, DOE's assumptions about the long-term performance of the tank fill materials, especially Smart Grout, have not been verified with empirical tests or

**SIDEBAR 2 USE OF TEST BEDS FOR THE STUDY OF RETRIEVAL TECHNIQUES**

Waste retrieval (bulk or heel) has not yet occurred in most tanks at the Savannah River Site. As noted in Section II, many of the tanks contain internal features such as cooling coils or other debris that promise to impede waste retrieval. In these situations, new technology or adaptations of existing technology may be desired or required. Adapting an existing retrieval technology or deploying a new retrieval technology in a radioactive environment can cost millions of dollars and failures can cost even more. Thus, it is technically prudent and cost-efficient to test retrieval technologies in nonradioactive test facilities (test beds) before attempting to deploy them. The usual approach to ensuring that a radioactive waste process will work consists of two steps: tests with the actual material on the laboratory scale to ensure that the process fundamentals are understood (e.g., sludge dissolution, pumpability), and tests with nonradioactive simulants on large or full scale to prove the design and the equipment (velocities, mass transfer).[a]

DOE has operated such a test bed at the TNX facility at the Savannah River Site, but it is not clear that this test bed will be available in the future. The committee believes that a nonradioactive test bed for retrieval technologies that can be adapted to simulate a variety of tank situations (i.e., recalcitrant heels, cooling coils, and debris) should be maintained. The Pump Test Tank is a partial Type IV tank mockup at the mostly decommissioned TNX facility, used for testing and equipment before deployment, and similar test beds at other sites, are candidates for this role. The committee will further address the need for experimental retrieval facilities in its final report.

[a] Lab scale tests and tests with simulants did not reveal the difficulties that emerged when DOE used the in-tank precipitation process to remove cesium from waste in Tank 48. That process, however, is rather different in nature than the type of waste removal and tank cleanup technologies that the committee describes here.

even documented analytic reasoning. To lend confidence to the assumptions used in the performance assessment, DOE should further evaluate grout formulation and techniques and conduct studies of the near- and long-term performance of the grout by laboratory and field testing of tank fill materials.

Experts at Savannah River (Dr. C. Langton and Mr. T. Caldwell) stated that based on tests they have concluded that there is effectively no mixing of grout with the insoluble tank heel, but the liquid is effectively absorbed by the grout or the dry cementitious materials deposited on top of the grout. Accordingly, DOE's ongoing performance assessment does not take credit for mixing of the grout and heel but, as noted previously, assumes that the grout maintains its structural integrity for 1,000 years and its physicochemical integrity for 10,000 years. The basis for the 1,000-year assumption is taken from an earlier analysis done for the E-Area Vaults Performance Assessment (Martin Marietta Energy Systems et al., 1994). It appears that these assumptions have not been validated adequately either by literature review or by laboratory or field experiments. Moreover, despite requests, DOE has not presented evidence of long-term performance tests or modeling on grout to support these durability assumptions; therefore, the committee cannot assess the 1,000- and 10,000-year assumptions of physical and chemical durability of the Smart Grout.

Although the committee acknowledges that a short research program (5 to 10 years) will not remove all uncertainties about the long-term performance of fill materials, such as cemented grout, research aimed at understanding the long-term performance of these materials in simulated tank field conditions and an assessment of projected service lifetime would provide a valuable insight to DOE's assumptions. The concrete-durability research conducted by the Atomic Energy of Canada Limited for its near-surface disposal facility indicated that service life predictions can be made with some level of confidence from a 5- to 10-year laboratory test program.

For example, DOE's performance assessment takes credit for the tank fill materials, designed with objectives such as resistance to water infiltration and inadvertent intrusion for 1,000 years, as part of an engineered barrier system. The committee suggests conducting research and development activities to test these assumptions.

Moreover, to lend confidence to the assumptions of the long-term integrity and durability of Smart Grout DOE should conduct laboratory and field research activities. Such activities could include high-temperature leach tests; grout-waste mixing tests; and tests to verify the effectiveness of the grout's chemical properties on key radionuclides and hazardous metals, as well as the evolution of these properties with time. More basic research activities that could be performed in the same time frame include identifying and evaluating oxidation pathways and kinetics mechanisms for grout degradation. Some of these activities could also be conducted in parallel with saltstone to compare retention capabilities for the mobile radionuclides, such as technetium-99. Many of these research and development needs were identified by Westinghouse Savannah River Company at the committee's meetings; the committee is not aware of any active research on tank fill materials performance for the Savannah River Site. Ongoing research on building materials, mainly for civil engineering purposes, could also provide a valuable insights for applications involving waste immobilization. The USNRC is cosponsoring research at the National Institute for Standards and Technologies on degradation mechanisms, mixing formulations, durability, and modeling of cementitious materials (Garboczi et al., 2005).

Research and development on alternative grout placement technologies, such as jet grouting, to improve the degree of mixing of waste with grout could also yield results that are deployable in 5 to 10 years. Research and development work on jet grouting is already in progress at the Los Alamos National Laboratory (AEATES, 2004).

An additional topic for research and development for which the committee does not yet have a recommendation concerns the environmental effects of the Saltstone Disposal

Vaults, in light of the 3 to 5 MCi that DOE plans to there. Similarly, a study of the interaction of the tank fill material with the environment is warranted to determine the long-term impacts of waste residuals in the tanks. An updated, albeit partial, environmental impact statement for the Saltstone Vaults was provided to the committee. The environmental impact statement for all tank closures is not yet available (see Appendix B).

# IV

# Future Plans for the Study

The committee's full task is to review and evaluate DOE's plans to manage radioactive waste streams from reprocessed spent fuel that:

(1) exceed the concentration limits for Class C low-level waste as set out in Section 61.55 of Title 10, Code of Federal Regulations;
(2) DOE plans to dispose of on the sites specified below rather than in a repository for spent nuclear fuel and high-level waste; and
(3) are stored in tanks at the Savannah River Site, South Carolina; Idaho National Engineering and Environmental Laboratory, Idaho; and the Hanford Reservation, Washington.

Congress asked the National Academies to assess the following:

a) DOE's knowledge of the physical, chemical, and radiological characteristics of the waste in the tanks;
b) actions that DOE should consider to ensure that management plans comply with the performance objectives for land disposal facilities;
c) DOE's monitoring plans to verify compliance with the aforementioned performance objectives;
d) existing technology alternatives for waste management;
e) technology gaps for waste retrieval and management; and
f) any other matters that the committee considers appropriate and directly related to the subject matter of the study.

For its interim report, the committee was charged to examine whether DOE's plans to manage its radioactive waste streams at the Savannah River Site will comply with the performance objectives of 10 CFR 61.

Compliance with the performance objectives depends upon the amount of radioactive material left onsite, the manner in which it is immobilized, its interaction with the environment and its interaction with ecological and human receptors. As noted above, some critical data, analyses and plans were not available when this report was written: the performance assessment for closed tanks; plans for residual waste characterization; plans for tank annuli and tank-system piping; support for assumptions, estimated levels of conservatisms, and sensitivity analyses for performance assessment calculations; and long-term monitoring plans are examples of the missing information. In this interim report, the committee has fulfilled the charge to the extent possible by focusing mainly on the amount of waste left in the tanks and in the Saltstone Vaults at the Savannah River Site. The committee has made findings and recommendations on four major issues:

(1) near-term and long-term risks in the context of tank waste removal and the schedule for tank closure;
(2) the tank space crisis and options to alleviate the crisis;
(3) the roles of the Class C limits and the performance objectives in determining whether on-site disposal is acceptable; and
(4) research and development needs, particularly in-tank and downstream processing consequences of chemical cleaning options, technologies to assist in tank waste removal, including robotic devices, and studies of the projected near- and long-term performance of tank fill materials, such as grout.

The committee is still examining the interactions of the tanks and the saltstone with the surrounding environment; the role of environmental monitoring; the role of the point of compliance in meeting the performance objectives; and the role of modeling in the performance assessment. These topics are relevant to all three sites and will be addressed in the final report, along with the rest of the statement of task. For a substantive analysis, the information described above will be needed at all sites. In addition, because the wastes and the site conditions differ, the topics investigated in this report will also be examined at the Hanford and Idaho sites. These investigations will have an impact on the committee's views on the Savannah River Site. Hanford will likely offer the committee the greatest challenge because it is the oldest site, has many tanks that have leaked, and has the most complicated wastes because of the various management practices and several chemical processes that generated the wastes, including the earliest processing technologies. The committee may also extend the comments on the Savannah River Site found in this report, as additional information on this site becomes available during the period of this study.

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# Appendix A

# Statement of Task and Performance Objectives

## STATEMENT OF TASK

The objective of this study is to review and evaluate the Department of Energy's (DOE's) plans to manage certain radioactive waste streams stored at its sites as identified below.

The waste streams to be addressed in this study are the streams of waste from reprocessed spent nuclear fuel that:

1) exceed the concentration limits for Class C low-level waste as set out in Section 61.55 of Title 10, Code of Federal Regulations;
2) the Department plans to dispose of on the sites specified below rather than in a repository for spent nuclear fuel and high-level waste; and
3) are stored in tanks at the following sites:
   (A) Savannah River Site, South Carolina.
   (B) Idaho National Engineering and Environmental Laboratory, Idaho.
   (C) Hanford Reservation, Washington.

This study shall evaluate:

1. the state of the Department's understanding of the physical, chemical, and radiological characteristics of the waste referred to above, including an assessment of data uncertainties;
2. any actions additional to those contained in current plans that the Department should consider to ensure that its plans to manage its radioactive waste streams will comply with the performance objectives of Part 61 of Title 10, Code of Federal Regulations;
3. the adequacy of the Department's plans for monitoring disposal sites and the surrounding environment to verify compliance with those performance objectives;
4. existing technology alternatives to the current management plan for the waste streams mentioned above and, for each such alternative, an assessment of the cost, consequences for worker safety, and long-term consequences for environmental and human health;
5. any technology gaps that exist to effect improved efficiency in removal and treatment of waste from the tanks at the Hanford, Savannah River, and Idaho sites; and
6. any other matters that the committee considers appropriate and directly related to the subject matter of the study.

The committee may develop recommendations it considers appropriate and directly related to the subject matter of the study, including:

1. improvements to the scientific and technical basis for managing the waste covered by the study, including the identification of technology alternatives and mitigation of technology gaps; and
2. the best means of monitoring any on-site disposal sites from the waste streams referred to above to include soil, groundwater, and surface water monitoring.

## TITLE 10—ENERGY
## CHAPTER I—NUCLEAR REGULATORY COMMISSION

## PART 61: LICENSING REQUIREMENTS FOR LAND DISPOSAL OF RADIOACTIVE WASTE

### Subpart C: Performance Objectives

Sec. 61.40 General requirement.

Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in Sec. 61.41 through 61.44.

Sec. 61.41 Protection of the general population from releases of radioactivity.

Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

Sec. 61.42 Protection of individuals from inadvertent intrusion.

Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.

Sec. 61.43 Protection of individuals during operations.

Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in part 20 of this chapter, except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by Sec. 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable.

Sec. 61.44 Stability of the disposal site after closure.

The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.

# Appendix B

# Information-Gathering Meetings

Below is a list of presentations received by the committee during its information-gathering meetings, which were open to the public and included opportunities for public comment. Following the list of presentations, the committee lists the most important documents it received during the information-gathering phase for the interim report (March to June 2005) and the documents that were not available during this phase.

## INFORMATION-GATHERING MEETINGS

### Meeting 1: March 7-8, 2005, Washington, D.C.

*Background on Congressional Request to Do the Study,* Congressman John Spratt, D., South Carolina, member House Armed Services Committee and ranking member House Budget Committee, and Mike Lieberman, Legislative Assistant to Congressman John Spratt

*Environmental Management, Keeping Our Commitments: Proven to Deliver,* Paul Golan, Principal Deputy Assistant Secretary for Environmental Management, U.S. Department of Energy (DOE-EM)

*Department of Energy Tank Wastes,* Ken Picha, Engineer, DOE-EM

*NRC's (U.S. Nuclear Regulatory Commission's) Role in Waste Determinations*, Larry Camper, Director, Division of Waste Management and Environmental Protection, Office of Nuclear Materials Safety and Safeguards

*NRC's Previous WIR (Waste Incidental to Reprocessing) Reviews,* Scott Flanders, Deputy Director, Division of Waste Management and Environmental Protection

*States' Perspectives,* Mike Wilson, Nuclear Waste Program, Washington State Department of Ecology, and Kathleen Trever, Manager, Idaho National Laboratory Oversight Program

*Environmental Public Interest Group,* Tom Cochran and Geoff Fettus, Natural Resources Defense Council

### Meeting 2: April 13-15, 2005, Savannah River Site (SRS), Augusta, Ga

*Tour of F Tank Farm, H Tank Farm, Saltstone Facility, and Pump Test Tank at TNX*

*Characteristics and Understanding of SRS Tank Farm Waste,* Scott Reboul and Pete Hill, Westinghouse Savannah River Company (WSRC)

*Tank Waste Removal Processes,* Doug Hintze, Director, Waste Disposition Programs Division, U.S. Department of Energy Savannah River Operations Office (DOE-SR)

*Savannah River Site Removed Waste Treatment Overview,* Terrel J. Spears, Director, Salt Processing Division, DOE-SR

*Savannah River Site Meeting Performance Objectives for On-site Disposition of Tank Waste,* Sherri Ross, Engineer, Programs Division, DOE-SR

*Savannah River Site Concentration Averaging, Challenges, and Factors of Safety for On-site Disposition of Tank Waste,* Sherri Ross, Engineer, Programs Division, DOE-SR

*Monitoring Activities,* James Heffner, WSRC

*NRC's Previous SRS WIR Review,* Anna Bradford, Senior Project Manager, Division of Waste Management and Environmental Protection, Office of Nuclear Material Safety and Safeguards, USNRC

*NRC's Technical Review of Tank Closure at SRS*, David Esh, Senior Systems Performance Analyst, Division of Waste Management and Environmental Protection, Office of Nuclear Material Safety and Safeguards, USNRC

*South Carolina Department of Health and Environmental Control (SCDHEC*), David Wilson and Shelly Sherrit, SCDHEC

*Waste Removal and Treatment Technology,* Tom Caldwell, Program Integration and Technology, Closure Business Unit, WSRC

*Strontium-Actinide Separations,* David T. Hobbs, Advisory Scientist, Waste Treatment Technology, Savannah River National Laboratory (SRNL)

*Waste Treatment Technology for On-site Dispositioned Streams: Caustic-Side Solvent Extraction*, Harry D. Harmon, Development Manager, Tank Focus Area Salt Processing Project Research and Development Program, Pacific Northwest National Laboratory

*Tank Closure Grouts,* Christine A. Langton, Advisory Scientist, SRNL

*Waste Disposition Heel Removal,* Noel F. Chapman, Engineering Manager, Tank Closure Projects, WSRC

**Meeting 3: May 5-6, 2005, SRS, Augusta, Ga**

*High-level Waste System Analysis,* Mark Mahoney, Program Integration and Technology, Closure Business Unit, WSRC

*Tank Space Overview,* Mark Mahoney, Program Integration and Technology, Closure Business Unit, WSRC

*Safety Case,* Doug Hintze, Director, Waste Disposition Programs Division, DOE-SR

*Removal of Heels—Bases for Decisions and Methods of Testing,* Tom Caldwell, DOE-SR

*Monitoring Activities*, James Heffner and Daniel Wells, WSRC

*Performance Assessment Results in Waste Determination,* Elmer Wilhite, James Cook, SRNL

*Grout Waste Form—Mixing, Encapsulation, Durability, and Performance,* Christine A. Langton, SRNL, and Tom Caldwell, DOE-SR

*SRS Waste Tank Sampling Programs,* Peter J. Hill, Scott H. Reboul, and Bruce A. Martin, WSRC

*Salt Waste Processing Facility (SWPF) Project Line Item 05-D-405, Project Status Review,* Terrel J. Spears, Federal Project Director, Salt Processing Division, DOE-SR

# MATERIAL AVAILABLE TO THE COMMITTEE

The committee received more than 175 documents in the March-June 2005 period. Through the presentations listed above, DOE provided a wealth of information. However, most of this information was qualitative. For example, DOE presented a "discussion" of the performance assessment for the saltstone (Cook and Wilhite, 2005), rather than the actual performance assessment, which is not yet publicly available. The same applies to a qualitative discussion of the tank farm monitoring plans (Heffner and Wells, 2005). The committee did have some quantitative analyses available, such as the following:

- Draft salt waste determination and supporting documentation (DOE, 2005a)
- Performance assessment for Saltstone Vaults (Martin Marietta Energy Systems et al., 1994)
- Performance assessment for the closure of Tanks 17 and 20 (DOE, 1997a, 1997b)
- Environmental impact statement for tank waste closure (DOE, 2000)
- U.S. Nuclear Regulatory Commission tank closure determination for Tanks 17 and 20 (USNRC, 2000)

DOE also made available to the committee a large number of technical reports on salt waste processing, bulk waste retrieval, heel removal, residual waste characterization, tank cleaning, and tank filling and closure.

Most of the documents listed above were published before the new salt waste processing approach was proposed at the Savannah River Site in February 2005. Because of the significant differences in the new approach (e.g., significantly higher concentrations of cesium to be sent to saltstone with the deliquification, dissolution, and adjustment process, see Finding and Recommendation 2; and on-site disposal of waste from Tank 48, see Section II), the available information needs to be updated. Below are examples of information that the committee did not have and that it deems necessary to the fulfillment of its task.

## Examples of Committee's Information Gaps

The following are examples of pieces of information that the committee needs to determine whether DOE's tank waste management plans slated for on-site disposal meet the performance objectives in Title 10 Part 61 of the Code of the Federal Regulations. This list is not meant to be exhaustive.

- Supplemental performance assessment calculations for the saltstone facility addressing the changes introduced with the Section 3116 salt waste determination and sensitivity studies.
- Response of disposal systems to extreme events (fires, floods).
- Performance assessments and environmental impact statement for tank farm closure (except tanks 17 and 20).
- Plans for annulus cleaning.
- Plans for deactivation and decommissioning of the piping within the tank farms-Plans for residual waste characterization.
- Revised Waste Acceptance Criteria for the saltstone vaults addressing the changes introduced with the Section 3116 salt waste determination-Support for

assumptions, estimate of levels of conservatisms, and sensitivity analyses for any calculation related to public health.

- Long-term monitoring plans.
- Estimates of worker doses for various steps and options for salt waste processing.
- Relative risks of various options for salt waste processing.
- Effectiveness of separations processes (i.e., efficiency in radionuclide removal) for the new salt waste processing approach.
- Risk assessment determining acceptable radionuclide concentrations (and/or inventories) and distributions that take into account measured and/or projected radionuclide concentrations, spatial variability of the concentrations, and attendant uncertainties (see Finding and Recommendation 3).

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# Appendix C

# Biographical Sketches of Committee Members

FRANK L. PARKER (NAE), *Chair*, is a distinguished professor of civil and environmental engineering at Vanderbilt University. Dr. Parker's research interests include hazardous chemical and radioactive waste disposal policy, risk analysis of hazardous and radioactive waste disposal, as well as thermal pollution, and water resources engineering. He served in the U.S. Army in a variety of engineering positions and worked for the U.S. Bureau of Reclamation and the Rockland Light and Power Company as a civil and water resources engineer. After graduating from Harvard, Dr. Parker worked for a consulting hydraulic engineering firm and then went to the Oak Ridge National Laboratory, where he became head of Radioactive Waste Disposal Research. He also served as head of Radioactive Waste Disposal Research for the International Atomic Energy Agency. In recent years, he has focused on radioactive and hazardous chemical waste problems, with increasing attention to the policy questions associated with these problems at both the national and the international level. Dr. Parker was elected to the National Academy of Engineering in 1988 for world leadership in the development of basic information required for the safe disposal of high-level radioactive wastes. Dr. Parker has served on several National Academies' committees and boards, including the Board on Radioactive Waste Management, which he chaired from 1984 to 1991.

HADI ABU-AKEEL (NAE) is president of AMTENG Corp., an independent consulting firm. Dr. Abu-Akeel recently retired from FANUC Robotics NA, Inc., an industrial robotics firm, where he was senior vice president and chief engineer. His main areas of expertise include optimization of robot design including trade-offs of performance, cost, manufacturability, application requirements, and user friendliness; utilization of robotic devices to overcome manufacturing productivity challenges and provide cost-effective manufacturing process alternatives; development and application of microsensors for intelligent robots, robotic assist devices, autonomous robots, and remote presence; and risk assessment, safety, and safeguarding of robot applications. In 1997 he was elected to the National Academy of Engineering for contributions to the design, control, and implementation of industrial robots. Since then, he has served as a member of the National Academies' Panel for Manufacturing Engineering and the Mechanical Engineering Peer Committee.

JOHN S. APPLEGATE is associate dean for Academic Affairs and Walter W. Foskett Professor of Law at the Indiana University School of Law—Bloomington. He teaches and writes about environmental law, regulation of hazardous substances, risk, environmental remediation, and the U.S. Department of Energy. Mr. Applegate co-chaired the long-term stewardship and accelerated cleanup subcommittees of the Department of Energy's Environmental Management Advisory Board. He was previously the James B. Helmer, Jr., Professor of Law at the University of Cincinnati College of Law and chaired the Fernald Citizens Advisory Board. He has served as a visiting professor at Vanderbilt University Law School, a judicial clerk to the United States Court of Appeals for the Federal Circuit, and an attorney in private practice. He is the author or coauthor of more than 20 articles and the author or editor of books on risk and environmental law.

HOWIE CHOSET is an associate professor of mechanical engineering and robotics at Carnegie Mellon University where he conducts research in motion planning and design of serpentine mechanisms, coverage path planning for de-mining and painting, mobile robot sensor-based exploration of unknown spaces, and education with robotics. In 1997, the National Science Foundation awarded Dr. Choset its career award to develop motion planning strategies for arbitrarily shaped objects. In 1999, the Office of Naval Research started supporting Dr. Choset through its Young Investigator Program to develop strategies to search for land and sea mines. Recently, the Massachusetts Institute of Technology Review elected Dr. Choset as one of its top 100 innovators in the world under 35. Dr. Choset directs the undergraduate robotics minor at Carnegie Mellon and teaches an overview course on robotics that uses a series of custom-developed Lego labs to complement the course work. Finally, Dr. Choset is a member of an urban search and rescue response team using robots with the Center for Robot Assisted Search and Rescue.

PAUL P. CRAIG is professor of engineering emeritus at the University of California, Davis, and a member of the university's Graduate Group in Ecology. Dr. Craig has expertise in energy policy issues associated with energy system responses to global environmental change. He is a member of the Sierra Club's National Global Warming and Energy Committee and served as chair of the committee from 2000 to 2003. Dr. Craig was a member of the U.S. Nuclear Waste Technical Review Board from 1997 to 2004, assessing the science and engineering supporting the characterization of the Yucca Mountain site for a potential nuclear waste repository. Dr. Craig has more than 21 years of teaching experience and has authored or coauthored more than 100 refereed publications. Dr. Craig has held positions at Los Alamos National Laboratory, Brookhaven National Laboratory, and the National Science Foundation. He became director of the University of California Council on Energy Resources in 1975 and professor of engineering at the University of California, Davis, in 1977 earning emeritus standing in 1994. He was a member of the National Academies' Board on Radioactive Waste Management from 1993 to 1997.

ALLEN G. CROFF retired from Oak Ridge National Laboratory (ORNL) in 2003. While employed at ORNL, Mr. Croff was involved in technical studies and program development focused on waste management and nuclear fuel cycles. Mr. Croff chaired a committee of the National Council on Radiation Protection and Measurements that produced the 2002 report *Risk-Based Classification of Radioactive and Hazardous Chemical Wastes*; he also chaired the Nuclear Energy Agency's Nuclear Development Committee for a decade. Mr. Croff is currently vice-chairman of the U.S. Nuclear Regulatory Commission's Advisory Committee on Nuclear Waste and is a member of the Nuclear Energy Research Advisory Committee. Mr. Croff is currently serving on the National Academies' Nuclear and Radiation Studies Board and has worked on numerous National Academies' committees.

PATRICIA J. CULLIGAN is a professor of civil engineering and engineering mechanics at Columbia University. Her research focuses on applying geoengineering principles to understand and control the migration of contaminants from waste disposal sites. In particular, she studies the behavior of miscible contaminants and nonaqueous-phase liquids in soil and fractured rock and the effectiveness of in situ remediation strategies for the cleanup of waste sites. Her research interests also include the design of land-based disposal sites for waste materials. Dr. Culligan has received numerous awards including the Arthur C. Smith Award for Undergraduate Service (1999) and the National Science Foundation CAREER Award (1999). She is the author or coauthor of more than 50 journal articles, book chapters, and refereed conference papers.

KEN CZERWINSKI is an associate professor in the Chemistry Department at the University of Nevada, Las Vegas, and director of the radiochemistry Ph.D. program. His expertise is in actinide chemistry focusing on understanding, evaluating, and predicting the chemical forms of actinide elements in differing conditions, with research efforts in speciation of actinides in the environment, actinide separations in the nuclear fuel cycle, and actinide chemical forms in solids. Dr. Czerwinski has been an associate professor in the Nuclear Engineering Department at the Massachusetts Institute of Technology and an associate research scientist for the Institut für Radiochemie Technische Universität München. He has been accorded the Presidential Early Career Award in Science and Engineering.

RACHEL J. DETWILER is senior engineer at Braun Intertec Corporation in Minneapolis, Minnesota. Her areas of expertise are construction forensics, construction troubleshooting, concrete durability, transport properties, microstructure, and test methods for concrete and cement-based materials. Dr. Detwiler served in an advisory role for the initial development of a formulation of grout for the stabilization of radioactive and hazardous waste in underground storage tanks at the Savannah River Site until 1996. She has served as a principal engineer at Construction Technology Laboratories; an assistant professor at the University of Toronto; a postdoctoral research fellow at Norges Tekniske Høgskole, Trondheim, Norway; and a design and materials engineer with ABAM Engineers, Inc. She is a member of the American Society for Testing and Materials and a fellow of the American Concrete Institute, where she has served as chair of Committee 227 on Radioactive and Hazardous Waste Management and as a member of Committee 234 on Silica Fume in Concrete. She has received a Norges Teknisk-Naturvitenskapelige Forskninsgråd Fellowship and the Carlson-Polivka Fellowship, and has published more than 50 technical papers related to concrete microscopy, durability, and testing.

EDWIN E. HERRICKS is professor of environmental biology in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign. His areas of expertise include aquatic ecology and stream ecosystem and watershed management, and he has broad experience in the identification, assessment, and restoration of the adverse effects of man's activities on streams, rivers, lakes, and their watersheds. His current research has focused on the development of methods to restore stream habitat, manage wildlife on and around airports, manage stormwater runoff, and develop ecohydrology and ecohydraulics methods. Dr. Herricks has recently served on National Research Council panels dealing with endangered species and the Platte River and evaluation of the U.S. Army Corps of Engineers project process. He has written numerous articles and papers on the broad theme of improving engineering design and environmental decision making. He is a member of the Urban Water Resources Research Council of the American Society of Civil Engineers and is chairman of a task group on receiving system effects from urban runoff.

TISSA H. ILLANGASEKARE is the AMAX distinguished chair of environmental sciences and engineering and a professor of civil engineering at the Colorado School of Mines (CSM). He is also the director of the Center for the Experimental Study of Subsurface Environmental

Processes (CESEP) located at CSM. His expertise is in mathematical and numerical modeling of flow and transport in porous and fractured media, unsaturated and saturated zone processes, surface-subsurface interaction, snow hydrology, multiphase flow, aquifer remediation, and physical modeling of flow and transport in laboratory test tanks. He is a registered professional engineer and a fellow of the American Geophysical Union. He is the hydrology editor of *Earth Science Review* and serves on the editorial boards of *Water Resource Research*, *Journal of Hydrology, Journal of Contaminant Hydrology,* and *Vadose Zone Journal.*

MILTON LEVENSON (NAE) is nationally recognized for his ability to apply creative new insights to major engineering challenges in the nuclear industry and for his organizational and leadership skills. Currently an independent consultant, Mr. Levenson is a chemical engineer with more than 50 years of experience in nuclear energy and related fields. His technical experience includes work related to nuclear safety, fuel cycle, water reactors, advanced reactors, and remote control. His professional experience includes research and operations positions at the Oak Ridge National Laboratory, the Argonne National Laboratory, EPRI (formerly the Electric Power Research Institute), and Bechtel. He was elected to the National Academy of Engineering in 1976. Mr. Levenson is a fellow and past president of the American Nuclear Society, a fellow of the American Institute of Chemical Engineers, and a recipient of the American Institute of Chemical Engineers' Robert E. Wilson Award in Nuclear Chemical Engineering. He is the author of more than 150 publications and presentations and holds three U.S. patents. Mr. Levenson also is a member of the National Academies' Nuclear and Radiation Studies Board and has served on several National Academies' committees.

PAUL A. LOCKE is a visiting scholar in the Department of Environmental Health Sciences at the John Hopkins Bloomberg School of Public Health. Dr. Locke has worked extensively on environmental health and policy issues, including radiation protection and radioactive waste disposal, indoor air quality, alternatives to animal testing, and risk assessment. Dr. Locke currently serves on the U.S. Environmental Protection Agency's Clean Air Act Advisory Committee, is a member of the National Academies' Nuclear and Radiation Studies Board, and is a councilor of the National Council on Radiation Protection and Measurements. He is also a member of the editorial board of *Risk Analysis: An International Journal*, and is a past councilor of the Society for Risk Analysis. Dr. Locke is a lawyer licensed to practice before the bars of the District of Columbia and the United States Supreme Court.

MICHAEL H. MOBLEY is a private consultant on regulatory radiation-related issues, particularly in the area of commercial low-level waste processing. He is a retired director of the Tennessee Division of Radiological Health and has worked in every aspect of the division's Radiation Control Program. He has represented the State of Tennessee since 1984 as a commissioner for the Southeast Low-Level Radioactive Waste Management Compact Commission. Mr. Mobley is a past chairperson of the Conference of Radiation Control Program Directors, Inc. (CRCPD), has served as that organization's treasurer, and has served on numerous committees and working groups for the CRCPD. He served on the Federal Facilities Committee, which was given the charge by the CRCPD to develop and coordinate information regarding federal facility radiological impact issues. Mr. Mobley received the Gerald S. Parker Award in 1996 for his significant contributions to radiation protection and to the CRCPD. In 2000 he was awarded life member status to the CRCPD (one of four awarded in 35 years). Mr. Mobley has also served as the state liaison officer for Tennessee to the U.S. Nuclear Regulatory Commission.

DIANNE R. NIELSON is the executive director of the Utah Department of Environmental Quality. Her current responsibilities include regulating the Envirocare commercial low-level waste facility and the White Mesa and Ticaboo Uranium Mills, and maintaining state primacy for implementing federal programs. Dr. Nielson is a member of the American Association of Petroleum Geologists and a fellow of the Geological Society of America. She has served as a member of the National Academies' Board on Earth Sciences and Resources and on several National Academies' committees. In addition to her expertise in geology, Dr. Nielson also brings a state perspective to the committee.

KEN E. PHILIPOSE is a project manager with the Decommissioning and Waste Management Business Unit at Chalk River Nuclear Laboratories of Atomic Energy of Canada Limited. His current responsibilities include research and development on the storage of cement-grouted fissile high-level liquid waste (in particular molybdenum-99) and decommissioning planning of large, buried carbon steel tanks containing heels of high-level waste. Mr. Philipose has more than 30 years of experience in durable concrete development studies and applications, waste management and decommissioning, design coordination, and project management of nuclear structures and facilities. Mr. Philipose has participated in several international studies concerning material research and development and has authored or coauthored several publications.

ALFRED P. SATTELBERGER is a senior laboratory fellow and former director of the Chemistry Division, Office of Science Programs, and the Science and Technology Base Program Office at Los Alamos National Laboratory (LANL). Dr. Sattelberger's research interests include actinide coordination, organometallic chemistry, technetium chemistry, and metal-metal multiple bonding. He was elected a fellow of the American Association for the Advancement of Science in 2002 in recognition of his scientific contributions to early transition metal and f-element chemistry. Prior to his appointment at LANL in 1984, Dr. Sattelberger held a faculty appointment in the Chemistry Department at the University of Michigan. He is the immediate past chair of the Inorganic Chemistry Division of the American Chemical Society and serves on the board of directors for the Inorganic Syntheses Corporation and on the editorial advisory board of the *Journal of Coordination Chemistry*. He served as a member the 1996 general inorganic chemistry Environmental Management Science Program merit review panel. He has also served as a member of several National Academies' committees examining radioactive waste management issues at the U.S. Department of Energy.

ANNE E. SMITH is an expert in integrated assessment of environmental and energy problems, specializing in risk management, decision analysis, benefit-cost analysis, and economic modeling. She has applied these techniques to issues such as contaminated site management, nuclear waste management, global climate change, air quality, and food safety. Dr. Smith has experience in assessing societal values for risk changes or environmental benefits. She has developed and reviewed decision support tools for risk-based ranking of contaminated sites and for making risk trade-offs in selecting remediation alternatives. Dr. Smith is a vice president of CRA International in Washington, D.C. Previously, she was a vice president of Decision Focus Incorporated and an economist with the U.S. Environmental Protection Agency. She has served on several National Academies' committees examining issues involving risk management within the U.S. Department of Energy's Environmental Management Program.

J. LESLIE SMITH is the Cominco Chair in Minerals and the Environment at the University of British Columbia in Vancouver. His expertise is in the areas of subsurface hydrology and contaminant transport processes. His current research interests include transport processes in fractured rock masses, hydrologic processes in unsaturated waste rock piles, hydrogeological decision analysis and risk assessment, inverse modeling, and radionuclide transport in watersheds near the Chernobyl Nuclear Power Plant in the Ukraine. Dr. Smith has served on several National Academies' committees, including the Committee for a Review of the Hanford Site's Environmental Remediation Science and Technology Plan and the Committee to Review Specific Scientific and Technical Safety Issues Related to the Ward Valley, California, Low Level Radioactive Waste Site.

DONALD W. STEEPLES is currently the Dean A. McGee Distinguished Professor of Applied Geophysics, Department of Geology, at the University of Kansas and president of Great Plains Geophysical, Inc. Previously, he held positions at the Kansas Geological Survey. Dr. Steeples is involved in the development and application of noninvasive geophysical techniques, specifically, shallow seismic reflection methods applied to environmental and groundwater problems. Dr. Steeples also chairs the geoscience reviews of the Laboratory Director's Advisory Board at the Idaho National Laboratory. He has published more than 100 articles on the application of geophysical methods and is currently an editorial referee for more than 20 scholarly journals. Dr. Steeples has served on several National Academies' committees, including one on noninvasive techniques for characterization of the shallow subsurface for environmental engineering applications.

# Appendix D

# Acronyms

| | |
|---|---|
| ALARA | As Low As Reasonably Achievable |
| ARP | Actinide Removal Process |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CFR | Code of Federal Regulations |
| DDA | Deliquification, Dissolution, and Adjustment |
| DHEC | South Carolina Department of Health and Environmental Control |
| DNFSB | Defense Nuclear Facilities Safety Board |
| DOE | Department of Energy |
| DWPF | Defense Waste Processing Facility |
| EPA | Environmental Protection Agency |
| HLW | High-Level Waste |
| INL | Idaho National Laboratory |
| LLW | Low-Level Waste |
| MCi | Million curies |
| MCU | Modular Caustic-Side Solvent Extraction Unit |
| NDAA | Ronald Reagan National Defense Authorization Act of 2005 |
| NRC | National Research Council |
| RCRA | Resource Conservation and Recovery Act |

| | |
|---|---|
| SDF | Saltstone Disposal Facility |
| SPF | Saltstone Processing Facility |
| SRS | Savannah River Site |
| SWPF | Salt Waste Processing Facility |
| USNRC | U.S. Nuclear Regulatory Commission |
| WIR | Waste Incidental to Reprocessing |
| WSRC | Westinghouse Savannah River Company |

# Appendix E

## Maps of the Savannah River Site

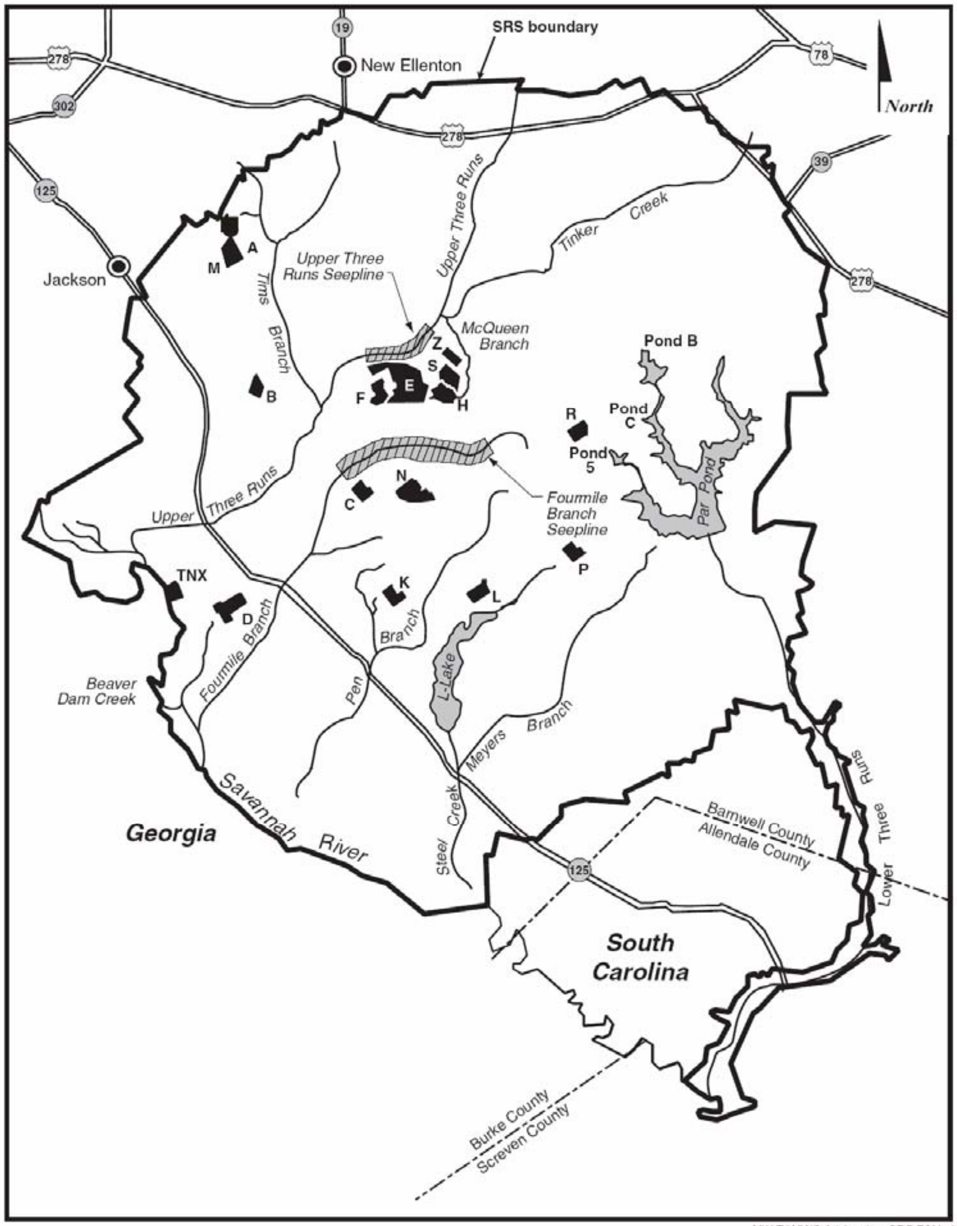


FIGURE E-1 Map of the Savannah River Site. The area labeled F is the location of the F Canyon and F Tank Farm. E-Area includes low-level waste disposal units. H-Area is the location of the H Canyon and H Tank Farm. S-Area is the Defense Waste Processing Facility . Z-Area is the location of the Saltstone Production Facility and Saltstone Vault SOURCE: DOE (2002).

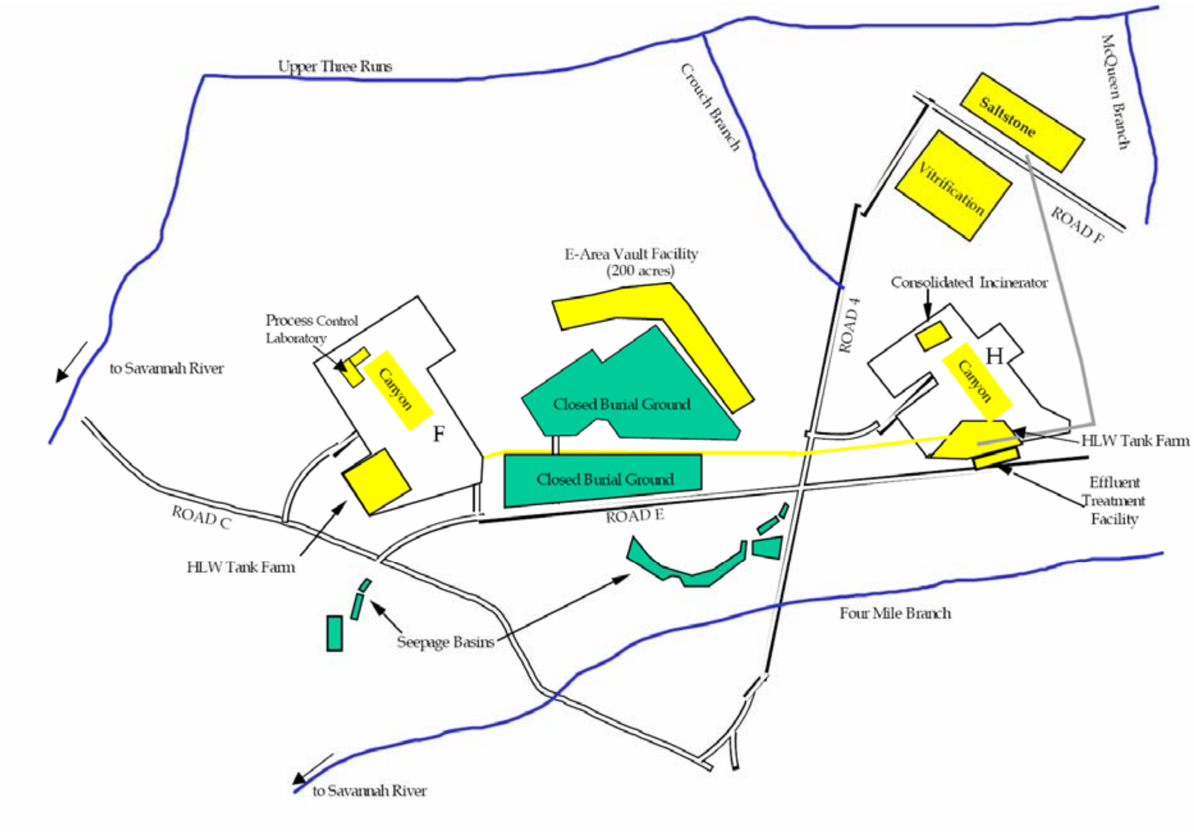


FIGURE E-2 Map of the General Separations Area at the Savannah River Site
SOURCE: Cook (2002).

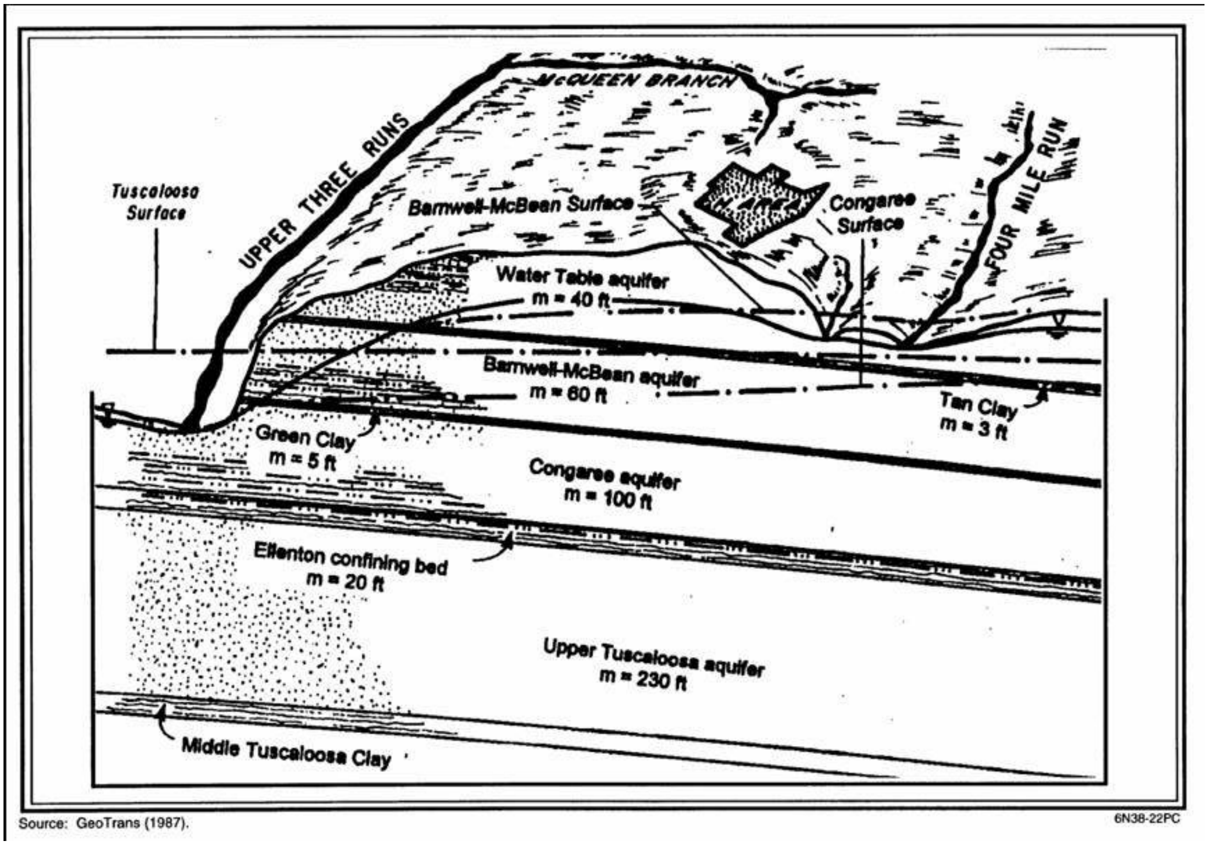


FIGURE E-3 Hydrologic units in the General Separations Area. SOURCE: DOE (1997).

## References

Cook, J.R. 2002. Comprehensive Environmental Management System Approach: The Right Tool For Stewardship. WSRC-MS-2002-00651. Aiken, S.C.: Westinghouse Savannah River Site Company.

U.S. Department of Energy (DOE). 1997. Industrial Waste Water Closure Module for the High-Level Waste Tank 17 System. Revision 2. August 26. Construction Permit Number: 17,424-IW. Aiken, S.C.: Department of Energy Savannah River Operations Office.

DOE. 2002. High-Level Waste Tank Closure, Final Environmental Impact Statement. DOE/EIS-0303. May. Aiken, S.C.: Department of Energy Savannah River Operations Office.

# Appendix F

# Federal Facility Agreement Waste Removal Schedule

The Savannah River Site Federal Facility Agreement (FFA) requires the U.S. Department of Energy to submit to the U.S. Environmental Protection Agency and the South Carolina Department of Environmental Control an annual report containing, among other items, the schedule for the removal of high-level waste from noncompliant tanks (i.e., those that do not have a full secondary containment). These are Tanks 1 through 24. Figure F-1 shows the latest removal schedule, as of September 2004 (DOE, 2005).

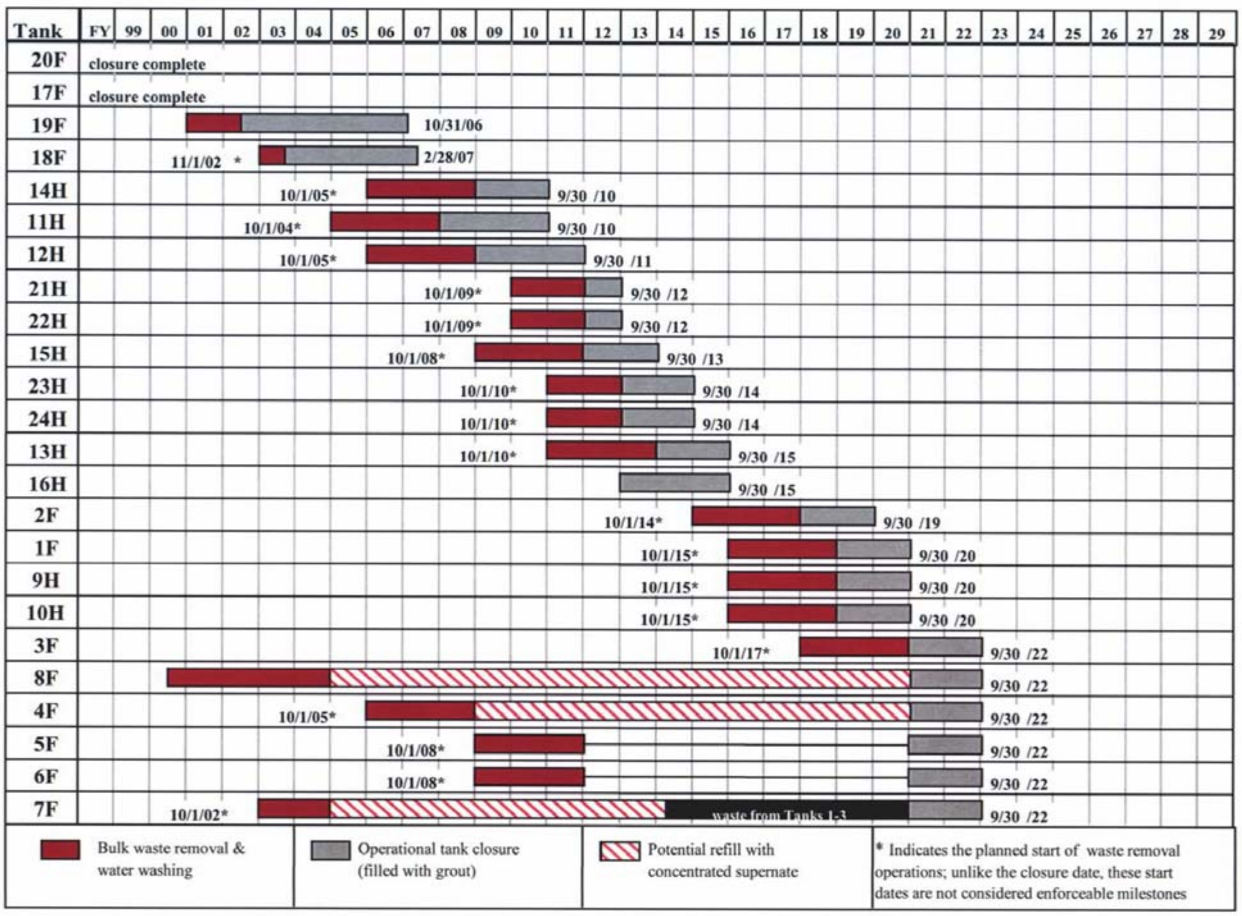


FIGURE F1 Federal Facility Agreement waste removal schedule, revision 2, as of September 2004. SOURCE: DOE (2005).

## Reference

U.S. Department of Energy (DOE). 2005. F/H Area High Level Waste Tank Status Report for CY2004. CBU-ENG-2005-00005. Aiken, S.C.