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Containing the Cold War Mess:

Restructuring the Environmental Management of the U.S. Nuclear Weapons Complex

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Preface

More than half a century of nuclear weapons production in the United States has created a host of daunting, costly, and complicated environmental and waste management problems. The environmental, safety, and health problems posed by the U.S. nuclear weapons complex range from emptying million-gallon tanks that contain highly radioactive waste to decontaminating process vessels that were used to separate plutonium to deciding what to do with polluted aquifers and contaminated soils. The current Department of Energy (DOE) best estimate for partial environmental restoration and waste management and disposal is $227 billion over a 75-year period. Previous estimates have varied a great deal from about $100 billion to $1 trillion.

The problem of environmental remediation and waste management of the nuclear weapons complex is so big and diverse that it is impossible to study it in all its important aspects with the limited resources of a small non-governmental organization like the Institute for Energy and Environmental Research (IEER). So we have chosen to look at it by doing case studies of three rather different problems, each important in its own way. We have also relied on extensive previous work done by IEER in other studies. Finally, we have been able to use some important documents that have been produced by the DOE itself in the last few years as a part of our overall evaluation.

The three case studies that we have done are:

- The problem of improperly buried waste and highly contaminated soil, both containing high levels of transuranic radionuclides like plutonium. We examined this problem at five sites that are seriously affected: Hanford, the Savannah River site, Los Alamos National Laboratory, the Idaho National Engineering and Environmental Laboratory, and the Oak Ridge Reservation.
- The high-level waste tanks at the Hanford Site in Washington State, which contain most of the volume of high-level radioactive waste in the nuclear weapons complex and are also the most difficult from a stablization point of view.
- The radium- and thorium-contaminated wastes at the Fernald, Ohio site, which are in many ways characteristic of mill tailings that constitute the largest volume of solid radioactive waste.

Our case studies cover a wide range of problems, but also omit some important issues. Notably, we have not looked in detail at the decommissioning of highly-contaminated equipment and buildings. We have also not examined the problem of remediating contaminated groundwater whose volume is far greater than contaminated soil or solid radioactive waste. There are other problems that we do not cover explicitly in this report, but for which we rely on other studies that we have done as the basis for our general

findings and recommendations. Specifically, we rely on previous work on the following issues:

- Management of irradiated fuel and target rods: material that contains plutonium and highly radioactive fission products. Two major previous IEER reports deal with this issue: *Risky Relapse into Reprocessing*, (Sachs, 1996) and *To Reprocess or Not to Reprocess: The PUREX Question* (Saleska and Makhijani, 1990).
- Long-term management of radioactive waste: *High-level Dollars, Low Level Sense* (Makhijani and Saleska, 1992) as well as various articles in *Science for Democratic Action*, notably the May 1997 issue (volume 6, number 1). Articles from this issue are reproduced in Appendix B.
- High-level waste management in general: *Plutonium: Deadly Gold of the Nuclear Age* (IPPNW and IEER, 1992) and *Deadly Crop in the Tank Farm* (Makhijani, Alvarez, and Blackwelder, 1986).

We have also relied on previous work we have done in studying and providing comments on the official attempts to develop clean-up and waste management standards. Finally, as discussed in Chapter 1, we have relied on several DOE efforts, such as the Baseline Environmental Management Reports, and plutonium and uranium vulnerability studies, that have yielded new data and insights. Together these DOE efforts constitute perhaps the most important accomplishment of the Environmental Management program so far because they have helped to identify the scope of most problems. But other DOE efforts, notably the Waste Management Programmatic Environmental Impact Statement, are costly, wasted efforts that have neither promoted understanding of the problems nor their resolution.

In point of fact, part of the specific impulse to do the present report came from the failure of the Waste Management Programmatic EIS to address the most serious issues in the nuclear weapons complex. In keeping with its poor public participation record, DOE chose to ignore comments on the implementation plan that the very framework of the Programmatic EIS was so flawed that it could not possibly yield meaningful results. Yet the DOE spent tens of millions of dollars on this essentially useless study. Moreover, the DOE has reneged on its legal commitment made in 1989 to produce a Programmatic Environmental Impact Statement on environmental restoration of the nuclear weapons complex. A lawsuit has been filed by numerous environmental groups to compel DOE to fulfill this commitment.

This IEER report cannot possibly fill the huge gap left by DOE's failures to do proper programmatic environmental impact statements in these two areas. But we hope that the case studies as well as our recommendations for restructuring the environmental management of the nuclear weapons complex will help reshape DOE's remediation and waste management programs. They need to be drastically restructured so that scarce taxpayer dollars are actually spent on the resolution of urgent problems and on laying the foundation for addressing difficult long-term waste management issues. The limitation of

resources of a public interest organization coupled with the immense complexity of the mess in the nuclear weapons complex means that our recommendations here are an outline for a new direction.

Some remarks on terminology are needed.

We generally use the term "environmental remediation" in place of the more usual term "clean-up" in this report. (The exception is when we discuss "clean-up" standards, a term used by the EPA as shorthand for decommissioning and remediation.) Since there is no practical way to get rid of the radioactivity, it is necessary to reduce risk by moving and treating contaminated areas and facilities and then managing the resultant wastes carefully. Thus, remediation and overall risk reduction is also tied to waste management and we emphasize this by using the terms environmental remediation and waste management or environmental management for short. Only when these two aspects are considered, planned and implemented together will there be any real assurance that a long-term risk reduction will actually be achieved .

A note on the term "vitrification" is also needed. Literally, the term simply means glassification, or the process of making glass. As used in the context of waste management, it first referred to a blending of high-level radioactive wastes containing fission products with carefully controlled glass composition. This kind of vitrification technology has been tested since the 1960s and there is considerable experience with it worldwide, though US experience is far more limited. In the 1990s, the term vitrification has also been applied to the process of mixing plutonium in a carefully controlled composition of glass, with or without other radioactive materials, such as fission products, or with other actinides, such as thorium.

However, the term vitrification is also being applied to the process of making a variety of materials, such as contaminated soils, into glassy materials. This last use of the term vitrification is rather unfortunate, because it gives the impression that the process is well understood and that the glass composition is controlled, as it is in the other uses of the term. This is not the case. As we show in the Fernald case study, and as has been demonstrated in other attempts to turn miscellaneous waste into a glassy material, the technical challenges of such vitrification can be very great if the soil or other waste contains materials problematic for glass formation. Finally, we note that categorizing the vitrification of Hanford waste is more difficult, since the composition of Hanford waste is more complex and diverse than the high-level wastes for which there is considerable vitrification experience.

Finally, we use DOE to refer either to the Department of Energy and its contractors or just the Department of Energy itself, depending on the context. When we discuss implementation of projects, for example, we implicitly mean the Department of Energy's contractors.

The report is organized as follows. Main findings and recommendations are presented first, followed by findings for the case studies. Chapter One outlines the scope of the environmental legacy of the nuclear weapons complex, including a summary of the status of DOE's Environmental Management program. Chapters Two, Three, and Four present the case studies that form the main part of the report. Chapter Five presents some recommendations for a restructuring of DOE's environmental management program. In this chapter, we also present a summary of our recommendations for the case studies. Two Appendices, one on clean-up standards and one on suggestions for a new waste classification system, discuss crucial issues that need to be integrated into a restructured environmental management program.

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Finally, those acknowledged here do not necessarily endorse the findings, conclusions, or recommendations of the study, the responsibility of which lies solely with the authors. We also, of course, take full responsibility for any errors.

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Summary of Main Findings and Recommendations [1]

More than half-a-century of nuclear weapons production in the United States has created tens of millions of cubic meters of long-lived radioactive waste, decommissioning problems associated with thousands of contaminated facilities, and environmental problems involving contaminated land and water. Throughout the Cold War, the culture that pervaded the nuclear weapons complex put the production of nuclear weapons first and muddled along on other issues, including management of radioactive waste, leaving the consequences to be dealt with later. Caroll Wilson, the first general manager of the Atomic Energy Commission (AEC), noted in retrospect that:

> Chemists and chemical engineers were not interested in dealing with waste. It was not glamorous; there were no careers; it was messy; nobody got brownie points for caring about nuclear waste. The Atomic Energy Commission neglected the problem....The central point is that there was no real interest or profit in dealing with the back end of the fuel cycle.[2]

The production of 70,000 nuclear warheads and bombs would have resulted in a problem of environmental remediation and waste management in any case. But the neglect and mismanagement of radioactive and toxic wastes has created problems that are far more costly than they might have been; some appear to be intractable with current technology. Figure 1 (see Chapter One) shows the approximate locations of sites with major nuclear weapons research, production, and testing facilities.

The Department of Energy (DOE), a Cabinet-level department that is a successor to the Atomic Energy Commission (AEC), is responsible for nuclear weapons production. It manages the nuclear weapons complex. Much of this complex is now shut, since large-scale production of nuclear weapons has ceased. But some production capacity is still in place, some weapons are still being modified and built, obsolete warheads are being dismantled, and extensive laboratory testing facilities are being built and operated that will generate still more wastes and future remediation problems.

DOE is also responsible for the management of the wastes arising from past nuclear weapons production and for environmental remediation and decommissioning activities. Finally, it is charged with developing a deep geologic repository for high-level radioactive wastes from military plutonium production and for spent (or irradiated) fuel from commercial nuclear power plants. Currently the only site being investigated for this purpose is Yucca Mountain, Nevada, on land claimed by the Western Shoshone people. DOE is developing another deep geologic repository, the Waste Isolation Pilot Plant, for

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[1] Chapter Five presents a discussion of our main recommendations and recommendations for the case studies.

[2] Wilson, 1979.

some of the waste containing high concentrations of plutonium and other transuranic elements.[3]

In 1989, as the Cold War ended, DOE started a new effort that was aimed explicitly at remediating the contamination of the nuclear weapons complex. A new division of DOE, called Environmental Restoration and Waste Management (later shortened to Environmental Management) was created. Its annual budget has been in the $5 billion to $6 billion range since that time. A high level of expenditure is expected to continue for many years -- the total cost for the program is estimated by DOE to be $227 billion (in 1996 dollars).

We have chosen to look at the problem of environmental remediation and waste management of the nuclear weapons complex by doing case studies of three rather different problems, each important in its own way. We have also relied on extensive previous work done by IEER in other studies. Finally, we have been able to use some important documents that have been produced by the DOE itself in the last few years as a part of our overall evaluation.

Main Findings

1. Nuclear weapons production and associated activities have created tens of millions of cubic meters of dangerous wastes and roughly two billion cubic meters of contaminated soil and water.

DOE is responsible for managing some 36 million cubic meters (well over one billion cubic feet) of radioactive and hazardous wastes in a wide array of forms and storage configurations. These wastes are classified in six major categories: high-level, transuranic, low-level, mixed low-level, uranium and thorium byproduct material, and hazardous waste. DOE manages 5,000 excess facilities, many of them seriously contaminated, and will be responsible for some 15,000 more as operational facilities are shut down. Weapons production and associated activities have contaminated 79 million cubic meters of soil and almost 2 billion cubic meters of groundwater. Additionally, DOE manages an estimated 820 million kilograms of miscellaneous materials, including 585 million kilograms of depleted uranium, mostly in the form of uranium hexafluoride.

2. Since 1989, DOE has made considerable progress in characterizing many of the crucial problems of environmental remediation and waste management in the nuclear weapons complex, but much remains to be done.

In 1989 there was only a broad picture of the scope of environmental problems in the DOE weapons complex. Since that time a number of studies and research efforts have

[3] Transuranic elements are so called because they have atomic numbers higher than that for uranium, which is the last element in the periodic table that occurs in nature in significant quantities. The atomic number of uranium is 92.

resulted in a much more detailed characterization of the problem. These efforts include the plutonium and uranium "vulnerability" studies, two baseline environmental management reports, and reports on materials in inventory. The efforts of the Technical Advisory Panel on the Hanford tanks, for instance, resulted in a far clearer understanding of the risks of fires and explosions and in remediation measures for one tank identified as the most serious risk.

Yet much remains to be done, partly because the problem of characterization is vast in scope and partly because DOE's priorities are inappropriate. For instance, DOE has not devoted sufficient efforts to characterizing buried transuranic wastes which pose serious threats to water resources at several sites.

3. DOE is proceeding with the most expensive environmental program in history without national remediation standards to govern and guide the process.

After having agreed to cooperate with the Environmental Protection Agency (EPA) in developing residual radioactivity standards and regulations to govern decommissioning, DOE asked the EPA to stop work on them and the EPA has agreed. DOE's rationale that site-by-site guidelines would be more appropriate is highly misleading because national standards need not dictate how to assess factors specific to each site, but would provide rules that limit risk to present and future generations from remediation and waste disposal activities.

DOE is now proceeding in an ad hoc way that all but guarantees large discrepancies in protection between sites. For instance, the levels of residual plutonium suggested for the Rocky Flats site "buffer zone" -- 651 picocuries per gram of plutonium-239/240 -- exceed by almost 40 times the levels DOE agreed to for Rongelap and Johnston Atolls in the Pacific, where atmospheric nuclear tests were conducted in the 1950s. Preventing activities in the "buffer zone" over a period anywhere near the 24,000 year half-life of plutonium-239 will be essentially impossible. Activities such as farming and residential development in such highly-contaminated areas would be very undesirable.

4. Despite about $40 billion dollars in expenditures since 1989, DOE does not have a sound direction, plan, priorities, or implementation strategy for dealing with the remediation and waste management problems. Institutional factors are the single most crucial element in DOE's failure to achieve a sound direction.

DOE's resistance to national remediation standards is only one obstacle to a sound plan. While the technical obstacles to are immense, and many have yet to be overcome, we believe that institutional problems are the underlying reason for many of the problems that are evident in our case studies. The principal institutional problems that we have identified are:

- attachment to Cold War technologies related to weapons research, development, testing, and production
- a tendency toward "monumentalism" -- that is, rushing into big projects without proper preparatory scientific and engineering work (this tendency perhaps derives from a desire to maximize the flow of funds into the weapons complex)
- a lack of sound internal scientific and technical peer review that actually matters in decision-making or in approval and implementation of large projects, and a corresponding tendency to ignore inconvenient extra-departmental advice
- a tendency to approve large budget increases for contractors without thorough engineering-based reviews of the problems that led to the budget changes
- a failure to learn lessons from past mistakes
- an attachment to the Yucca Mountain and Waste Isolation Pilot Project (WIPP) repository programs out of institutional, legal, political, and financial inertia even though these are compromising a much larger effort to remediate the weapons complex, manage long-lived highly-radioactive wastes, and develop a scientifically sound repository program
- a lack of independent regulation of DOE's nuclear activities.

The last problem will be remedied somewhat as DOE comes under the purview of the Nuclear Regulatory Commission (NRC) over the next decade. However, most of the decisions with long-term environmental impact will have been taken well before that time. Many will fall short of the requirements of independent regulatory oversight. For instance, even DOE's waste classification is more lax than that of NRC. It allows large quantities of fission products to be present in transuranic waste without a corresponding reduction in maximum transuranic content, as NRC rules require. But NRC regulations for Greater than Class C waste (the category corresponding to DOE's TRU waste) are not being taken into account in DOE decision-making.

5. The U.S. waste classification system is an unsound basis for implementing waste management or environmental remediation decisions.

As we illustrate in the TRU waste and Hanford case studies, and as is discussed in more detail in Appendix B, the U.S. radioactive waste classification system is not scientifically sound. It permits the disposal of long-lived radioactivity in shallow land burial and is not systematically based on the longevity or hazard of the waste.

6. DOE is not holding contractors sufficiently accountable for project mismanagement and poor technical decisions.

In two of the three case studies, we document a history of poor technical judgements and managerial decisions and inadequate oversight of complex and important projects. Yet, so far as we have been able to determine, DOE has allowed huge cost increases without adequate, detailed, engineering reviews of their basis. In the Hanford high-level waste case study, we did not examine budgetary issues.

7. A number of problems cannot be satisfactorily solved with presently available technology. Sound research and development and careful project planning will be needed over a long period.

There are many examples of problems whose solutions will require a strong, sustained commitment of resources. Foremost among the long-term problems is the lack of adequate engineered barriers to contain highly radioactive wastes should they be disposed of in a repository. An example of a short- and medium-term problem is the lack of technologies to empty the Hanford tanks safely or to process the waste into forms that will be suitable for long-term management.

Main Recommendations

Overall, we find that the prospects of DOE's Environmental Management program succeeding are poor.

Almost a decade after the fall of the Berlin Wall, the determination to hold on to Cold War levels of spending for military purposes and for sloppy "clean-up" and waste management practices has not changed. Despite much progress in characterization of the environmental management problem, in openness about past misdeeds, and even modest progress in a couple of areas of waste management (such as partial operation of high-level waste vitrification at the Savannah River Site), we found a lack of institutional commitment within DOE to real clean-up and to learning lessons from success and failure.

DOE needs to openly acknowledge the long-term legacy of environmental problems in the nuclear weapons complex so that quick-fix, short-term "solutions" are not the focus of its program. Such "solutions" to waste management in the past have made today's environmental problems all the more overwhelming. DOE must also abandon the inclination to let institutional controls take the place of remediation and waste management. It needs to lay the foundation for addressing long-term issues by promoting

sound scientific approaches to problems, instituting credible mechanisms for public participation, and developing necessary technologies.

The most important single reform that is needed is institutional. DOE can make internal reforms at once. It should:

- create both a internal and technical and financial project review structure for large projects
- create a standing advisory committee, under the Federal Advisory committee Act, to review projects from early stages through implementation both as regards their technical aspects and the reasonableness of budgets from an engineering standpoint. The majority of members on this committee should be free of conflicts of interest in regard to contracting with DOE or its contractors.
- reinstate the practice of issuing annual Baseline Environmental Management Reports, and make them more complete by including all sites, whether closed or operational.

Such internal reforms are unlikely to solve the entrenched problems that we have discussed above. We recommend that President Clinton appoint a commission, under the Federal Advisory Committee Act, on Institutional Reform of Environmental Remediation and Waste Management. The commission should hold hearings around the country and make definitive recommendations within a six- to twelve-month period.

The following alternatives could be considered in reforming the environmental management program of DOE:

1. The Environmental Protection Agency could be given the authority to carry out the remediation, with regulation by the Nuclear Regulatory Commission. This suffers from the disadvantage that it is the option most likely to result in a wholesale transfer of existing management structure to the new system with only a change of nameplates.

2. The affected states and Indian tribes could be given the authority and the money to remediate the weapons complex in their states, under national clean-up standards enforced the Environmental Protection Agency, and mandatory guidelines for public participation. While there are clear advantages to this approach there are also many weaknesses. The states may not have the staffing and expertise to carry do the job, nor the experience to oversee it. Moreover, politics at the state level may be even more vulnerable than federal-level politics to the influence of contracting corporations with deep pockets.

3. A public corporation, operating under strict public accountability and openness rules, could be created for the purpose of doing and/or subcontracting environmental remediation. In order to prevent the reform from being an exercise in a change of nameplates, a majority of the Board of

Directors and top management of the corporation could be appointed by the governors of the affected states, with the rest being appointed by the President of the United States.

Whatever the reform chosen, general technical principles will need to be adopted and reforms implemented to restructure the environmental management program. We mention some of them here. More detail is provided in Chapter 5. The government should:

1. *Create a new, rational, environmentally-protective system of radioactive waste classification* according to longevity and specific activity, so that comparable hazards are managed comparably.
2. *Coordinate waste management and environmental remediation* and make reduction of short-term risks compatible with minimizing long-term risks.
3. *Approach remediation with independently enforced, national, health-based clean-up and waste management standards,* including specific provisions to protect groundwater resources and mandatory guidelines to keep doses as low as reasonably achievable (ALARA) both for workers and for off-site populations. The ALARA guideline for releasing sites for unrestricted use should be to remediate to background levels, if reasonable, or else to keep doses to under 2 millirem per year (which is the British ALARA guideline).
4. *Suspend the politically expedient Yucca Mountain and WIPP repository programs and put in place a scientifically sound program of long-term high-level waste management*, including repository research, sub-seabed disposal research, and research on materials to contain radioactivity that are analogous to natural materials that can last for millions of years. (See Appendix B for more details on IEER's waste management recommendations.)
5. *Provide funds and technical support to communities that have residual contamination* so that they can monitor the environment and keep themselves informed. Such funds are needed to protect communities against future known risks and also against risks due to inadequate characterization or present incomplete understanding of risks. The size of the fund should depend on the size and character of the residual radioactive and non-radioactive hazardous contamination of land, remaining structures, surface waters, river beds, and groundwater, as well as the total amount of radioactivity and non-radioactive hazardous material left in disposal areas on site.
6. *Manage non-radioactive toxic components of wastes in ways that do not seriously compromise management of radioactive components.*
7. *Stabilize waste so as to greatly reduce or eliminate the most serious environmental and health threats* and store it on-site while sound long-term management strategies are developed.
8. *Provide the states, Indian tribes, and the public (with special emphasis on the affected communities and workers) with timely information* so that they can participate effectively in decision-making.

Findings from the Case Studies

Transuranic Waste Management

1. A large volume of transuranic waste has been disposed of by shallow land burial at a number of sites in the DOE complex. This waste has contaminated surrounding soil as well as groundwater aquifers beneath disposal areas.

Beginning in 1970, sites were required to keep transuranic-contaminated wastes in retrievable storage. Transuranic wastes were defined as containing greater than 10 nanocuries per gram of transuranic elements with half-lives greater than 20 years. The lower limit was later raised to 100 nanocuries per gram. This requirement was imposed by the Atomic Energy Commission (AEC), a predecessor to the Department of Energy, and was designed to end the practice of shallow land burial of such wastes. These wastes pose special threats because of their long half-lives and because alpha radioactivity is more damaging per unit energy than gamma or beta radioactivity. Transuranic radionuclides with half-lives greater than 20 years include plutonium-238, plutonium-239, neptunium-237, and americium-241.

DOE now classifies transuranic waste as "buried" and "retrievably stored," generally using 1970 as the distinction between the two. "Buried" wastes were generally disposed of before 1970 in shallow land burial. Most, but unfortunately not all, TRU wastes were retrievably stored after that date.

There is a considerable body of information that indicates that a much larger volume of transuranic waste is in shallow land burial than in retrievable storage. For instance, estimates in DOE's 1997 *Linking Legacies* report indicate that there is roughly twice as much buried TRU waste as retrievably stored TRU waste.

Because of often shoddy burial practices, such as disposal of plutonium-contaminated waste in cardboard boxes, serious environmental problems exist at several sites. Contamination of surrounding soil and underlying groundwater aquifers due to the migration of transuranic and other contaminants in the burial areas has been documented at most sites.

2. Contrary to its stated policy to give a high priority to projects for managing and eliminating "urgent risks,"[4] DOE is putting most of its TRU waste management money into the area that is least urgent – retrievably stored TRU waste. It has put a low priority on buried TRU waste, TRU contaminated soil, and the aquifers they are threatening. Thus, DOE's practice on TRU waste is the opposite of its precept.

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[4] The Environmental Management program (DOE 1996j) actually states it as follows "Goal 1: Eliminate and manage urgent risks." See also DOE, 1997c, page 2-2.

The focus on sending retrievably stored waste to the Waste Isolation Pilot Plant (WIPP) in New Mexico is contrary to the policy of putting the highest priority on eliminating urgent risks. Of all TRU waste, the retrievably stored waste poses the least short- and medium-term risks, since they are generally monitored and stored in covered facilities, or are in the process of being placed as such. New TRU wastes are being placed into such facilities.

By contrast, buried waste has already contaminated soil and groundwater and will continue to do so. This waste threatens many vital water resources including the Snake River Plan Aquifer, the Columbia River, and the Tuscaloosa Aquifer beneath the Savannah River Site.

The high priority given to WIPP, which is part of a flawed repository program, is largely due to politically-expedient promises made to states during the Cold War that enabled DOE to continue focusing on weapons production.

3. Official data on the volume, mass, and radioactivity of buried transuranic waste and transuranic soil are inconsistent and contradictory. There does not appear to be any scientific basis on which data are entered and changed from one year to the next, and one document to the next.

Volumes of wastes listed as buried TRU wastes in the DOE's Integrated Data Base Reports vary inexplicably from year to year. Moreover, these data are inconsistent with data reported in other documents. For instance at Los Alamos, there are two quite different estimates of the amount of plutonium in the waste -- one of 610 kilograms published by DOE headquarters and the other of 1375 kilograms published by the site. The enormous difference of 765 kilograms is unexplained so far as we are aware.

Such discrepancies in the data do not appear to have any explanation. Changes in numbers from one year to the next are made without reference to previously published data. The DOE's $31 million dollar Waste Management Programmatic Environmental Impact Statement, released in May 1997, does not even mention buried TRU waste at any site except for the Idaho Lab, much less analyze its environmental impacts.

The only study of actual records that has been done (for buried TRU waste at the Idaho Lab) estimated that the transuranic radioactivity was nine to twelve times higher than previously estimated and contained three times as much mass of transuranic radionuclides. Despite this startling finding, DOE has done little or nothing to try to arrive at better estimates of buried TRU waste quantities at other sites, or to reassess its strategy for managing these wastes.

4. DOE definitions and management practices for TRU waste have varied from site to site and from year to year. This has led to considerable confusion in the design and implementation of TRU waste management programs.

Prior to 1970, wastes that are now called TRU wastes were buried as "low-level" waste in a variety of containers, including cardboard boxes and plastic bags. In 1970, wastes containing more than 10 nanocuries per gram of long-lived TRU radionuclides were classified as TRU waste. The AEC ordered them to be stored retrievably. In 1984, DOE increased minimum radioactivity limit for TRU radionuclides from 10 to 100 nanocuries per gram.

To further complicate the picture, some sites had their own definitions of TRU waste prior to 1970 that did not match subsequent AEC or DOE definitions. Some other sites ignored the 1970 AEC rule and continued to bury or otherwise dispose of TRU wastes for some time after 1970. For example, between 1982 and 1984, Oak Ridge TRU wastes were mixed with cement and pumped into deep rock formations (called "hydrofracture"), a practice that has contaminated groundwater. Finally, some of the wastes that were classified as "retrievably stored" were in fact improperly managed and have now been designated as "buried waste."

These circumlocutions in regulations and practice accompanied by a lack of enforcement have created a very difficult practical situation because the various TRU waste categories are now actually mixed up in burial areas.

5. One of the most egregious prior TRU waste management practices was the burning of 370,000 gallons of plutonium-containing organic solvents at the Savannah River Site in open pans with smoky fires during the 1950s and 1960s. The site has closed several underground tanks once used for storage of these solvents by filling them with concrete, and is planning for closure of the rest.

About half a million gallons of plutonium-contaminated spent solvent consisting of kerosene and tributyl phosphate was generated at the Savannah River Site. Of this, 370,000 gallons were burned in open, smoky fires over about two decades. In 1975, five years after the requirement for retrievable storage of TRU waste, the site reported that 150,000 gallons of spent solvent were kept in a couple dozen tanks. The transuranic content, according to site figures, appeared to be on the order of 150 nanocuries per gram. The site now reports that about 40,000 gallons are stored in new tanks, but there is no clear account of the balance of 110,000 gallons. Some may have been burned in an incinerator during the late 1970s or early 1980s.

Some of the tanks that were once used to store this solvent have been emptied by spraying water in the tanks and pumping out the liquids. Several tanks have been "closed" -- that is, filled up with cement and left in place in the New Burial Ground at the site. This is an inappropriate way to decommission tanks. The final radionuclide content of these tanks was not estimated before closure. The site is now in the process of characterizing the residual spent solvent in twenty-two tanks in the Old Burial Ground, and planning for "closure" of these tanks as well.

6. Rapid migration of transuranic elements from the soil into the groundwater has been documented at several sites. This evidence challenges long-held assumptions about the immobility of transuranic elements in the environment. This radionuclide migration is threatening groundwater and, in some cases, surface water resources.

Studies at Oak Ridge have found "significant and rapid" transport of curium-244, a transuranic element. At the Idaho Lab, americium-241, another transuranic element, has been detected in the Snake River Plain Aquifer 580 feet below the burial areas. Measurements in wells at the Nevada Test Site have provided evidence that plutonium can and does bind to small ("colloidal") particles that may then travel "significant distances in the saturated zone." Measurements of the soil beneath the high-level waste tanks at the Hanford site show that plutonium has migrated a "surprisingly far distance" and was measured as deep as 100 feet at levels significant relative to its health and safety risk.

This real-world experience challenges the assumptions that have been used to justify the acceptability of leaving transuranic wastes in shallow land burial. But DOE has yet to revise its models to reflect this real-world experience.

7. DOE has no comprehensive plan for dealing with buried transuranic wastes and transuranic contaminated soil. The few attempts to deal with buried transuranic wastes have been inadequate, misguided, and mostly have met with failure.

Rather than develop a comprehensive plan that would begin with careful characterization of the problem and thorough technology development, DOE has wasted much of the small amount of resources devoted to the buried TRU waste problem. It has been pursuing in-situ vitrification, an inappropriate and inadequate technology. Its Pit 9 project was an ill-advised experiment in "privatization" that led to huge cost increases, disputes, and delays and has come at the expense of actually making progress on reducing the risks posed by buried waste.

8. Separate management of "buried" and "retrievably stored" transuranic wastes gives rise to illogical outcomes and perverse incentives.

The separate management of waste according to whether they were generated before or after 1970 has created a predisposition toward leaving pre-1970 buried waste in-place. Since the pre- and post-1970 wastes are of similar composition, it is irrational to spend huge resources treating and disposing of one category (the retrievably stored wastes) while giving low priority to the rest.

The separated management has given rise to uncoordinated and wasteful projects. For instance, DOE has been planning the Advanced Mixed Waste Treatment Facility for treating retrievably stored wastes at the Idaho lab, but did not consider using this same facility for treating the buried wastes that would be recovered from Pit 9. Another division of DOE has pursued an entirely different facility to treat those wastes.

Hanford High-Level Tank Waste Management: Findings

1. The Hanford high-level radioactive tanks are the single most complicated and expensive component in the Environmental Management program of the U.S. nuclear weapons complex.

An estimated 206,000 cubic meters (54 million gallons) of high-level radioactive waste, mostly from the reprocessing of irradiated nuclear fuel to extract plutonium, are stored in 177 large underground tanks at the Hanford site.[5] These wastes constitute about 60 percent of the volume of high-level radioactive waste in the United States and contain an estimated 198 million curies of radioactivity as well as a complex mixture of toxic and potentially explosive chemicals and heavy metals.

High-level waste sites constitute some of the most expensive projects in DOE's Environmental Management program. However, even among these multi-billion dollar projects, the Hanford high-level waste stands out. In addition to the problems faced in other high-level waste projects, remediation of Hanford's high-level waste is complicated by the sheer volume of waste, mixtures of waste from dozens of processes, and deterioration of the tanks themselves.

Annual budgets since 1989 for managing the tanks have been as high $700 million, with a 1997 fiscal year budget of $320 million. Most of the money has so far been spent on operations and maintenance, safety, upgrades, and characterization of the wastes in the tanks. Even with this level of expenditures, however, legally mandated milestones are being missed.

The total cost for dealing with the waste in the tanks and the environmental contamination from high-level wastes discharged into the soil (intentionally and

[5] These include 149 "single shell" tanks, many of which have leaked, as well as 28 "double shell" tanks.

unintentionally) is unknown. Estimates for management and treatment of the waste in the tanks have ranged from $13 billion to over $30 billion. As with other large cost figures that we have examined, these are suspect. These costs estimates do not include treatment of the large volumes of contaminated soil, groundwater, residual waste in the tanks, nor dismantlement and disposal of the tanks themselves. Nor do they include the costs of disposing of the waste in a geologic repository.

2. Since 1989, DOE has made progress in characterizing the contents of the high-level waste tanks. However, despite huge expenditures, deadlines for characterization relating to safety issues have not been met.

During the 1990s -- after decades of neglect -- DOE finally made progress on the critical task of characterizing the contents of the Hanford tanks and identifying the scope of tasks relating to safe storage, retrieval, and treatment of the waste. This means that DOE finally has a logical framework set up within which it could prioritize remaining characterization needs. In principle, this would provide the basis for creating a sound management plan.

A 1993 recommendation by the Defense Nuclear Facility Safety Board called for completion of safety-related sampling for "watch list" tanks within 2 years and all others within one year after that. Almost four years later, only 27 of the 177 tanks have been sampled and undergone all required analyses. Twenty-five tanks have not been sampled, including six watchlist tanks.

3. DOE's plan to manage the Hanford tanks is seriously flawed, incomplete, and has incorrect priorities.

Despite successes in mitigating some serious safety issues, notably Tank SY-101, the plan for dealing with the tank wastes is seriously flawed. While some safety issues have been resolved, new ones have been noted. Important activities remain unfunded, despite their obvious need. Significant technical issues and uncertainties confront every aspect of the program. Only very preliminary steps have been taken toward integrating management of the waste in the tanks with environmental contamination in the soil and groundwater caused by leaks.

The current plan does not place appropriate emphasis on development of crucial technologies, characterization of key uncertainties, and initiation of small-scale investigations and projects. Rather, DOE is proceeding with very large scale efforts before the technical issues are even adequately defined. In attempting to transfer an ill-defined job to private entities (so-called "privatization"), DOE is prematurely limiting technological options and opening up the potential for prolonged legal tangles.

4. Moving waste from single shell tanks to double shell tanks solves some problems and raises new concerns.

DOE has been transferring waste from single shell tanks to double shell tanks in order to address the issues of leaks and, hence, worsening contamination of the vadose zone (the soil between the ground surface and the top of the water table). But it raises two new concerns. First, the pumping of liquids raises the possibility of higher tank temperatures, creating a risk that the waste might become hot enough to start a fire or explosion. Second, new problems may be created in the double shell tanks due to chemical reactions and/or transfer of more plutonium to the tanks.[6]

Finally, there is a concern that the process of pumping out of liquids may initiate new corrosion and hence the potential for more leaks from the single shell tanks since the pumping cannot remove all liquids (such as liquid in the pore spaces sludges or saltcake). Corrosion is suspected to occur at the liquid-air line in a tank. Therefore, changing the liquid level could create corrosion in new places. Despite the importance of the problem, DOE abandoned work on corrosion issues without resolving them. It has yet to resume addressing it though the concerns are recognized.

5. In October 1996, DOE declared the ferrocyanide safety issue closed. However, not all of the tanks that were once on the safety "watchlist" of tanks were sampled.

DOE began addressing the ferrocyanide safety issue by conducting laboratory tests. The tests showed that ferrocyanide can decompose over time. The sampling of nine of the tanks that were believed to contain the highest amounts of ferrocyanide led DOE to the conclusion that ferrocyanide has decomposed over the years, and is present in concentrations 10 to 40 times lower than those concentrations needed to create an explosion.

Although measurements were not directly made in the other ferrocyanide "watch list" tanks, in October 1996 the Department of Energy declared the issue resolved. The tanks that were not sampled were said to have received less ferrocyanide than the tanks that were sampled. The Defense Nuclear Facilities Safety Board and the Washington Department of Ecology have concurred. As a result, ferrocyanide is no longer part of DOE's priorities for characterization and sampling. However, because not all tanks were sampled, the potential exists that some of the ferrocyanide tanks could still present explosion risks, especially in light of the large uncertainties about the makeup of specific tanks and, as discussed above, in light of the transfer of liquids from single shell to double shell tanks.

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[6] That is, the plutonium currently in the single shell tanks.

6. DOE "closed" the criticality safety issue in March 1994, stating that there was a very small risk (an "incredible" risk) of accidental criticality in the tanks under present configurations. However, this statement was not based on conservative assumptions regarding the concentration of plutonium in the sludge (where almost all the plutonium resides).

Estimates of the amount of plutonium in the Hanford tanks range from 455 kilograms to 981 kilograms. The maximum sampled concentration of plutonium in the sludge at the bottom of the Hanford high-level waste tanks that has been reported, as of 1995, is 0.35 grams of plutonium per liter. The safety trigger point for criticality has been set by DOE at a concentration of 1 gram per liter. DOE has also stated that criticality safety is not assured above 2.6 grams per liter and depends on geometry and other factors. Given that the current level of sampling of the tanks is far from sufficient to determine the heterogeneities of radionuclide distribution, particularly in the non-uniform sludge layers, and that transfers of waste are occurring, we believe that the plutonium concentrations are too close to the criticality limit for the issue to have been closed.

7. While DOE is developing new technologies for removing wastes from the tanks, the only technology that has actually been used is "sluicing," which uses a large volume of water to mobilize the waste. Reliance on this technology could also create new leaks or re-open ones that may have become plugged over time by solid constituents in the waste.

Under the agreement that was signed by DOE, the State of Washington, and the U.S. Environmental Protection Agency (known as the Tri-Party Agreement), 99% percent of the waste is required to be removed from the high-level waste tanks. The 1996 Tank Waste Remediation System Environmental Impact Statement assumes that sluicing will be used to retrieve most waste in all 149 single shell tanks.

Emptying tank contents by sluicing could create many problems, including vastly increasing waste volumes and reopening sealed leaks. This technique appears to be especially inappropriate for the hardened portion of tank wastes, where the quantities of water necessary to dissolve and mobilize the waste may be hundreds of millions of gallons.

The appropriate technologies for removing 99 percent of the waste volume does not yet exist. The work that DOE is conducting on other retrieval technology options that would be less environmentally damaging is a crucial component of remediating the high-level waste tank farms at Hanford.

8. The 99 percent removal goal is arbitrary and environmentally unsound. The one percent of the waste volume in the high-level waste tanks will likely contain millions of curies of radioactivity.

The Tri-Party Agreement between the DOE, the EPA, and the State of Washington requires removal of 99 percent of the volume of high-level waste in the Hanford tanks. The goal of 99 percent is not related to mitigating short-term risks or to preventing long-term management problems. This will allow perhaps millions of curies to be left in the tanks. Adoption of the 99% goal has also allowed DOE to inappropriately leave the consideration of the final disposition of residual radioactivity in the tanks and the decommissioning of the tanks themselves to a future National Environmental Policy Act review.

9. The decision to separate tank waste into high-level waste and "low-level" waste is unsound because it will result in the shallow land disposal of millions of curies of long-lived radioactivity.

DOE's plan for the waste that it retrieves from the tanks involves separation into high-level and "low-level" waste streams. DOE proposes to dispose of the "low-level" waste, which are required to meet the Nuclear Regulatory Commission's definition of Class C waste, on-site in shallow land burial. However, disposal requirements for Class C "low-level" waste do not sufficiently protect human health and the environment, since Class C waste can contain significant amounts of long-lived radionuclides. The Hanford "low-level" waste is projected to contain tens of millions of curies of cesium-137 and strontium-90. It is entirely inappropriate to put such waste in shallow land burial, especially given the proximity to the Columbia River.

Other countries, such as Britain, France, and Sweden require wastes with far lower concentrations of radioactivity to be put in a deep geologic repository. Thus, Hanford's tank remediation program is not creating a protective solution to the problem of long-term high-level waste management, but may be laying the basis for a more costly remediation problem in the future.

DOE claims an economic incentive for reducing the amount of waste sent to a geologic repository. However, the cost estimates are too speculative to be the basis for a decision at this point. Indeed, we found significant differences in assumptions -- amounting to tens of billions of dollars -- in DOE estimates made within just 2 to 3 years of each other. Our own analysis shows that the costs of disposing of all Hanford tank waste as high-level waste may be much lower than DOE assumes in its Tank Waste Remediation System Environmental Impact Statement.

It is noteworthy that the planned volume of "low-level" waste is almost seventy percent larger than the entire volume of high-level waste today.

10. DOE is rushing into the vitrification option for Hanford high-level waste without sufficient consideration of the obstacles and without having learned from problems at other sites.

Hanford high-level wastes are chemically and physically very complex. The technologies to concentrate essentially all of the long-lived radionuclides (most importantly cesium-137, technetium-99, and transuranics) in the high-level waste stream are not yet adequately developed. The variety of waste will likely result in problems in pretreatment and in processing them into uniform glass forms acceptable for disposal. Such problems have arisen even with waste that is far less complex, notably at Savannah River Site, and also with waste in silos at the Fernald site. But DOE has not applied those lessons to its Hanford plans. Moreover, DOE is not pursuing other treatment technologies, such as calcination and ceramification that may be better suited than vitrification to near-term goals of reducing the risk of leaks and safety hazards, as well as long-term goals such as minimization of waste volume. Nor has it looked carefully enough at calcining (turning wastes into an oxide powder by heating) as an interim (rather than final) waste form.

11. The "privatization" program for treating the high level waste in the tanks is inappropriate, ill-conceived, and is unlikely to yield good results either on technical or economic grounds. DOE is attempting to turn a poorly-defined scope of work into a privatized operation.

In response to a contracting system that has not yielded desired performance, DOE is trying a new approach, known as "privatization." Under privatization, technical risk for the project is supposed to shift to the contractor, who operates under a fixed-price contract. Supposedly, the contractor would only be paid upon successful implementation of the project, when the "end product" is delivered. In the case of the high-level tank waste, the end product would be a stabilized waste form suitable for disposal.

DOE claims that this approach to contracting will drive down costs through competition and also bring in more industrial expertise. So far, results at Hanford are not promising. For example, only two contractors bid on two available contracts, a situation that cannot be called competitive. Despite DOE's earlier insistence that three to five bidders were needed to make the initiative a success, it is still going ahead with the "privatization." Additionally, DOE is paying for preliminary work such as initial design (these costs total $54 million for the two contractors). Also, one of the contracting teams has already asked for up-front money from DOE for further design and permitting.

It also appears that privatization is being used as an excuse for DOE to scale back research on the sludges and solids that will remain as the high-level waste stream. Only very small-scale tests have been performed on a limited number of the sludges in the Hanford tanks. "Washing" of these sludges is a key component of Hanford's plan to minimize the volume of vitrified high-level waste. The tests that have been done will need to be scaled up by many orders of magnitude. However, before having initiated this

work, DOE is handing over responsibility for the technical aspects of the project to the contractors.

Demonstrating a new type of contracting on the largest project in DOE's Environmental Management program, whose technical and scientific elements are not yet well-defined and have large uncertainties, is a sacrifice of common sense to dogma. It is very risky and is unlikely to lift the burden from the public purse. Numerous other concerns with this contracting approach have been raised. Our central point here is that this effort is not only unlikely to benefit the taxpayer, it is detracting from the pressing technical work that needs to be done to manage Hanford tanks and to put the wastes in them into safer forms. The risks of this approach for one-of-a-kind problems are already evident in the disputes and cost escalations in which the "fixed-price" contract for the Pit 9 project at the Idaho Lab is currently mired (discussed in the case study on TRU management).

12. Contamination of the soil, or vadose zone, as well as the groundwater beneath the tank farms pose serious problems. Yet, DOE has not developed a plan to address such contamination.[7]

DOE's primary focus has been on the waste it plans to retrieve from the tanks and not the residual waste, the tanks themselves, and the contaminated soil and groundwater. These issues are to be dealt with in the future, by a different decision-making process. However, they are inextricably linked.

In fact, the first credible investigation of the contamination resulting from leaky tanks -- performed at the SX tank farm in 1996 -- indicates that models used in Hanford's Groundwater Management Plan are based on faulty and inaccurate assumptions. Transport of contaminants from the tanks through the soil and into the groundwater seems to be far more rapid than previously acknowledged, indicating errors in long-held assumptions regarding mobility of radionuclides, especially plutonium, in the environment. Our findings in the case study on TRU waste indicate that such assumptions are being refuted by experience at other sites as well.

Hanford does have small efforts underway to integrate some of these issues, specifically, the Hanford Tanks Initiative and the Vadose Zone Characterization Project. These programs are an important step to creating a more holistic approach to the entire tank farm area.

13. Characterization of facilities used to support storage of waste in the 177 high-level tanks (such as pipes, junction boxes, valves, pumps, and auxiliary tanks) has taken a back seat to the characterization of the tanks themselves.

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[7] Hanford has some efforts at groundwater and vadose zone remediation in areas not immediately connected to the high-level waste in the tanks; in particular, it is pumping and treating groundwater contaminated with trichloroethylene in the 200 West tank farm. Our comments apply specifically to the vadose zone associated with the tank waste.

Extensive operations involving pumping of wastes into and out of the tanks as well as changes in the chemistry of the wastes being pumped through the piping and valving infrastructure have undoubtedly caused build up of a substantial amount of radionuclide contamination. There has not been a sufficient effort to characterize the extent of this problem.

A 1996 investigation by the Defense Nuclear Facilities Safety Board suggested that some auxiliary tanks, especially 45 inactive miscellaneous tanks, may be of serious concern. Some of the tanks contain tens of thousands of gallons of solid and liquid wastes. For a majority of the tanks, even an estimate of the volume of waste is reported as unknown. The radionuclide composition of these wastes is also largely unknown, or least not reported by DOE. This is the state of affairs after almost a decade of effort and many billions of dollars of expenditures on Hanford environmental management.

Radium- and Thorium-Contaminated Waste at Fernald

1. A modestly satisfactory program to vitrify waste contaminated with large amounts of radium-226 and thorium-230 contained in three large silos at Fernald has been severely compromised by avoidable problems including contractor incompetence (both technical and managerial) and lack of adequate DOE oversight. This project is a major part of what was to be a "flagship" for the Environmental Management program. It has so far been an utter failure by any reasonable set of criteria.

After two years of construction and pilot plant tests, the plan for the treatment of radium- and thorium-contaminated waste at Fernald by vitrification (the treatment selected in a Record of Decision) is in a shambles as a result of shortcomings by DOE and its contractor, Fluor Daniel Fernald.

Despite the fact that the silos waste were not fully characterized and a novel vitrification technology was being proposed, DOE and the contractor decided to "fast-track" the pilot plant project by proceeding with simultaneous design and construction. This led to significant problems. For example, the melter delivered by a subcontractor did not match the preliminary designs that Fluor Daniel Fernald had used in its construction of the rest of the pilot plant.

The technical failures at Fernald have been as bad as the managerial failures. Materials used in the melter, particularly molybdenum disilicide "bubbler tubes," were incompatible with the high-lead content of the waste. As a result, the melter was destroyed part-way through the first of two phases of pilot plant testing. This dramatic failure is of even greater concern because project personnel identified the exact issue that led to destruction of the melter during technical reviews, yet it was not resolved.

2. The Vitrification Pilot Plant experienced dramatic cost and schedule increases over the course of two years. DOE and Fluor Daniel Fernald are now projecting similar cost and schedule increases for the full-scale vitrification facility.

Contractor and DOE failures led to significant cost increases for the Vitrification Pilot Plant. The pilot plant effort was estimated to cost $15.8 million in February 1994. By June 1996, the cost estimate for completion of all Pilot Plant testing was $66 million -- a four-fold increase. Through November 1996, $50 million had been spent in the Pilot Plant effort. In December 1996, an accident destroyed the melter and rendered the pilot plant useless for future work. The accident occurred before completion of Phase I of the Pilot Plant and only involved non-radioactive simulants of the waste in the silos.

Had the melter not failed, the $66 million estimate in June 1996 would surely have been exceeded because Phase II of the testing was supposed to involve actual radioactive waste from the silos. The plant, as built, could not have handled radioactive materials without high levels of worker exposure. As a result, major modifications of the plant would have been necessary.

As costs mounted during design and construction of the Pilot Plant, DOE and Fluor Daniel Fernald began to revise their estimates for the full-scale vitrification facility. In January 1996, cost estimates for the whole project had more than tripled from $92 million to over $300 million. In April 1997, Fluor Daniel Fernald estimated the total cost to range between $376 and $563 million.[8] Additionally, the estimated completion (including decontamination and decommissioning) had slipped by nine years -- from 2002 to 2011.

3. Technical, managerial, and financial shortcomings early on in the Pilot Plant led to efforts to attempts to abandon the vitrification treatment selected in the Record of Decision. Changes from vitrification to cementation for all or part of the waste have been proposed even though there seems to be no established, essential technical obstacle to proceeding with a vitrification program for wastes in all three silos.

Roughly one year after the Record of Decision was signed, DOE and Fluor Daniel Fernald began investigating alternatives to proceeding with vitrification of the waste in an effort to make up for cost increases and schedule delays, for the most part caused by failures not related to or only indirectly related to vitrification as such. A study in January 1996 proposed cementation of all or part of the waste in the silos. These recommendations were made six months before the Pilot Plant even began operating. The study was motivated by a desire to reduce costs and did not consider the commitments made in the legally-binding Record of Decision. Nor, obviously, was it

[8] This estimate involved substitution of cementation for vitrification as the treatment method for Silo 3 waste.

able to consider the technical information generated by the Pilot Plant effort, which was still under construction at the time of the study.

Technical difficulties in vitrification to date have largely arisen from a decision to mix different kinds of waste. Early in the project, it was decided to pursue vitrification of a blend of waste from Silos 1 and 2 (which are similar to each other) with waste from Silo 3 (which are dissimilar from waste in Silos 1 and 2). The result was a waste mixture high in both sulfates and lead, two constituents that are extremely difficult to vitrify in combination. By the completion of Pilot Plant testing, it was decided to abandon mixing the dissimilar waste, and instead deal with waste in Silos 1 and 2 differently from that in Silo 3. It appears that this decision to separate treatment of the different wastes was a sound one, based on the present state of knowledge about waste composition.

However, DOE and Fluor Daniel Fernald may have prematurely abandoned vitrification of Silo 3 waste. They are pursuing cementation and other alternative treatments that could result in an increase in volume or a less durable waste form.

At the same time, DOE and Fluor Daniel Fernald are also examining alternatives to vitrification for the wastes in Silos 1 and 2. The waste in these silos pose the greatest concerns for worker and off-site doses due to releases of radon. Vitrification for this waste was chosen in the Record of Decision because it would reduce waste toxicity, waste volume, and radon releases. Alternative treatment technologies under consideration, including cementation, could be worse on all three counts.

These changes are being pursued in large part due to supposed cost savings, yet DOE has not made a proper comparison of the alternatives, nor has it adequately explained why treatment cost estimates have changed from those cited in the Record of Decision.

4. The Environmental Protection Agency has indicated that that DOE should proceed with an Amendment to the Record of Decision for Silos 1 and 2 waste prior to any thorough explanation for the dramatic cost increases. EPA has also indicated it may allow DOE to substitute an inferior treatment technology for Silo 3 waste, without amending the Record of Decision.

EPA has stated that because of the large cost increases estimated for vitrification of Silos 1 and 2 waste, an Amendment to the Record of Decision should be issued. However, cost estimates were generated by the same contractor that has mishandled the initial Pilot Plant effort, and the cost increases have not been evaluated by an independent entity.

EPA has also stated that DOE should prepare an Explanation of Significant Differences to the Record of Decision if it decides to change the treatment of Silo 3 waste from vitrification to an alternative such as cementation. An Explanation of Significant Differences is a less rigorous requirement than an Amendment to the Record of Decision, which may be too lenient given that changing the treatment may change long-term durability of the waste form.

Chapter One: Scope of the Environmental Management Problem in the Nuclear Weapons Complex

The U.S. nuclear weapons complex includes dozens of industrial facilities and research and development laboratories spread across the country. Over approximately 50 years of operations, an estimated $300 billion was spent on nuclear weapons research, production, and testing.[9] Seventy thousand nuclear warheads were produced and more than 1,000 nuclear tests were conducted. During this period, 100,000 or more people were typically employed in the nuclear weapons complex at any time.

While the roots of many of the environmental problems in the nuclear weapons complex can be traced back to the Manhattan Project (as for instance with much of the high level waste problem at Hanford), they became far more complex and widespread during the vast expansion of nuclear weapons production in the 1950s. In the first half of that decade, a new plutonium production complex was brought on line at the Savannah River Site in South Carolina, a large-scale plutonium component fabrication facility was set up at Rocky Flats near Denver, and an assembly line that could put together thousands of warheads per year was built at Pantex, near Amarillo, Texas. A factory for making uranium metal on an industrial scale to provide fuel and target elements for plutonium production reactors was set up near Cincinnati. Many other facilities were also built or expanded. By the mid-1950s, 3.4 percent of the country's industrial construction budget was attributable to the Atomic Energy Commission (AEC), and industrial production amounted to 4 percent of the total US.[10] The AEC was also the monopoly procurer of uranium until 1962 -- up until this point, uranium was mined from large numbers of small-scale mines and over two dozen uranium mills that refined the ore into "yellow cake" were opened.

As a result of all these activities, nuclear weapons production not only became a crucial part of U.S. Cold War policy, it was also transformed into one of the largest production enterprises in the country. Like many other large-scale heavy industries, nuclear weapons production and related activities used large quantities of toxic chemicals such as fluorine gas, nitric acid, carbon tetrachloride and other organic solvents, and toxic metals like chromium and lead. But one important difference was that the AEC factories also handled radioactive materials. Therefore the contamination problems found at nuclear weapons production sites typically include both non-radioactive and radioactive hazardous materials.

Eight main activities comprised the nuclear weapons complex; they are listed in Table 1. Expenditures on these nuclear weapons production, design, and related activities are continuing at the rate of several billion dollars a year, adding to the environmental legacy of the Cold War.

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[9] DOE, 1996e, page 2. Cost is in 1995 dollars.
[10] Teeple, 1955, Chapters V and VI.

Table 1: Major Production Activities in Nuclear Weapons Complex

Uranium Mining, Milling, and Refining	Mining and milling involve extracting uranium ore from the earth's crust and chemically processing it to prepare uranium concentrate, commonly called yellowcake. Refining involves chemical conversion to purified forms such as uranium hexafluoride and uranium metal.
Isotope Separation (Enrichment)	Enrichment involves separating uranium isotopes in natural uranium by concentrating U-235 in one stream ("enriched uranium") and uranium-238 in the other ("depleted uranium").
Fuel and Target Fabrication	Fuel and target fabrication includes the foundry, machine shop, sintering and other operations required to convert uranium into fuel elements used in plutonium and tritium production reactors.
Reactor Operations	Involves operation of reactors used to irradiate fuel and targets.
Chemical Separations (Reprocessing)	Reprocessing involves chemical dissolution of irradiated fuel and targets to separate out and concentrate nuclear materials, notably plutonium and uranium.
Weapons Component Fabrication	Fabrication of weapons components includes manufacturing, assembly, and inspection of specialized nuclear and non-nuclear components of weapons.
Weapons Operations	Weapons operations include the assembly, maintenance, and dismantlement of nuclear weapons.
Research, Development, and Testing	Includes research and development work on weapons at laboratories as well as 1,054 actual tests of nuclear explosives.

Source: DOE, 1997a, Chapter 2.

The Department of Energy (DOE), a successor agency to the AEC, is the Federal agency that presently controls the nuclear weapons complex. It owns some 2.3 million acres of land and 120 million square feet of buildings.[11] DOE manages some 5,000 excess facilities.[12] An additional 15,000 facilities are classified as operational, 5,000 of which may be declared as surplus in the next ten years. Figure 1 shows approximate locations of the main DOE weapons research, production, and testing facilities.

Weapons disassembly and assembly was also carried out as a part of nuclear weapons production. Such disassembly is now being carried out as part of post-Cold War programs to reduce the size of the U.S. nuclear weapons arsenal.

[11] DOE, 1996e, page 2.
[12] DOE, 1997a, page 97.

A. The Environmental Legacy of Production

Environmental and waste management problems are varied and include:

- Plutonium residues and other impure plutonium in dangerous contaminated forms
- Highly enriched uranium that is too contaminated to be processed into reactor fuel
- Buried radioactive wastes that cannot be easily retrieved
- Abandoned contaminated equipment
- Contaminated buildings and equipment such as glove boxes, processing tanks, pumps, piping, etc., that are no long needed but must be decommissioned and disposed of
- Uranium mine wastes and mine sites that have been abandoned without remediation
- Uranium mill tailings
- Wastes, such as metal beams, pipes, and rubble with varying degrees of contamination resulting from decommissioning buildings and other facilities
- Over half a million tons of depleted uranium in the form of uranium hexafluoride
- Non-radioactive toxic wastes, ranging from heavy metals to toxic organic compounds, such as spent solvents
- Stored radioactive wastes, some of which contain non-radioactive toxic materials, that need to be prepared for final disposal
- Vast quantities of contaminated groundwater and contaminated soil
- Contaminated river and stream beds

The amount of waste and environmental contamination resulting from nuclear production is staggering. Partial estimates of the volumes of waste and contaminated environmental media are listed in Table 2. In addition, almost three thousand facilities currently classified as surplus are contaminated by and contain radioactive, hazardous, and toxic materials; as DOE proceeds, several thousand more facilities will require decontamination and decommissioning.[13]

[13] DOE, 1996c, page 2-10.

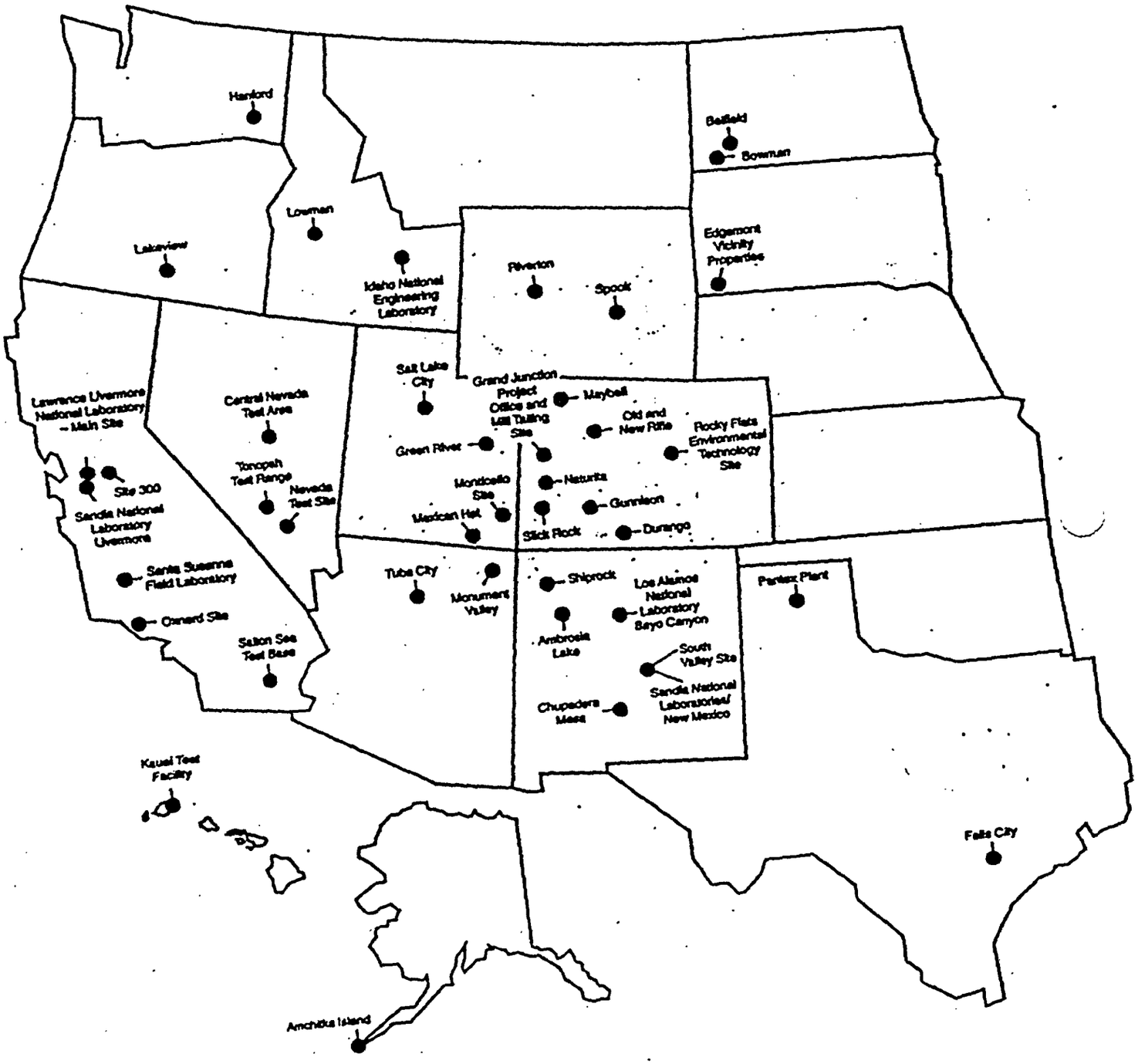
Table 2: Volumes of DOE Waste, Contaminated Soil, and Groundwater

Category	Volume, cubic meters[1]	Radioactivity, curies
Spent Nuclear Fuel [2]	1,280	Data not available
High-Level Waste (Reprocessing Waste)	380,000	960,000,000
Transuranic Waste	220,000	3,800,000
Low-Level Waste	3,300,000	50,000,000
Mixed Low-Level Waste (radioactive and hazardous)	146,000	2,400,000 (likely the upper bound)
Depleted Uranium Hexafluoride	120,000	200,000
"Byproduct" Material ("11e2 waste" - from processing of ore for uranium and thorium, analogous to mill tailings) [3]	32,000,000	27,000 (Ra-226 only)
Contaminated Soil	79,000,000	No estimates. Includes hazardous, radioactive, and mixed contamination.
Contaminated Groundwater	1,800,000,000	

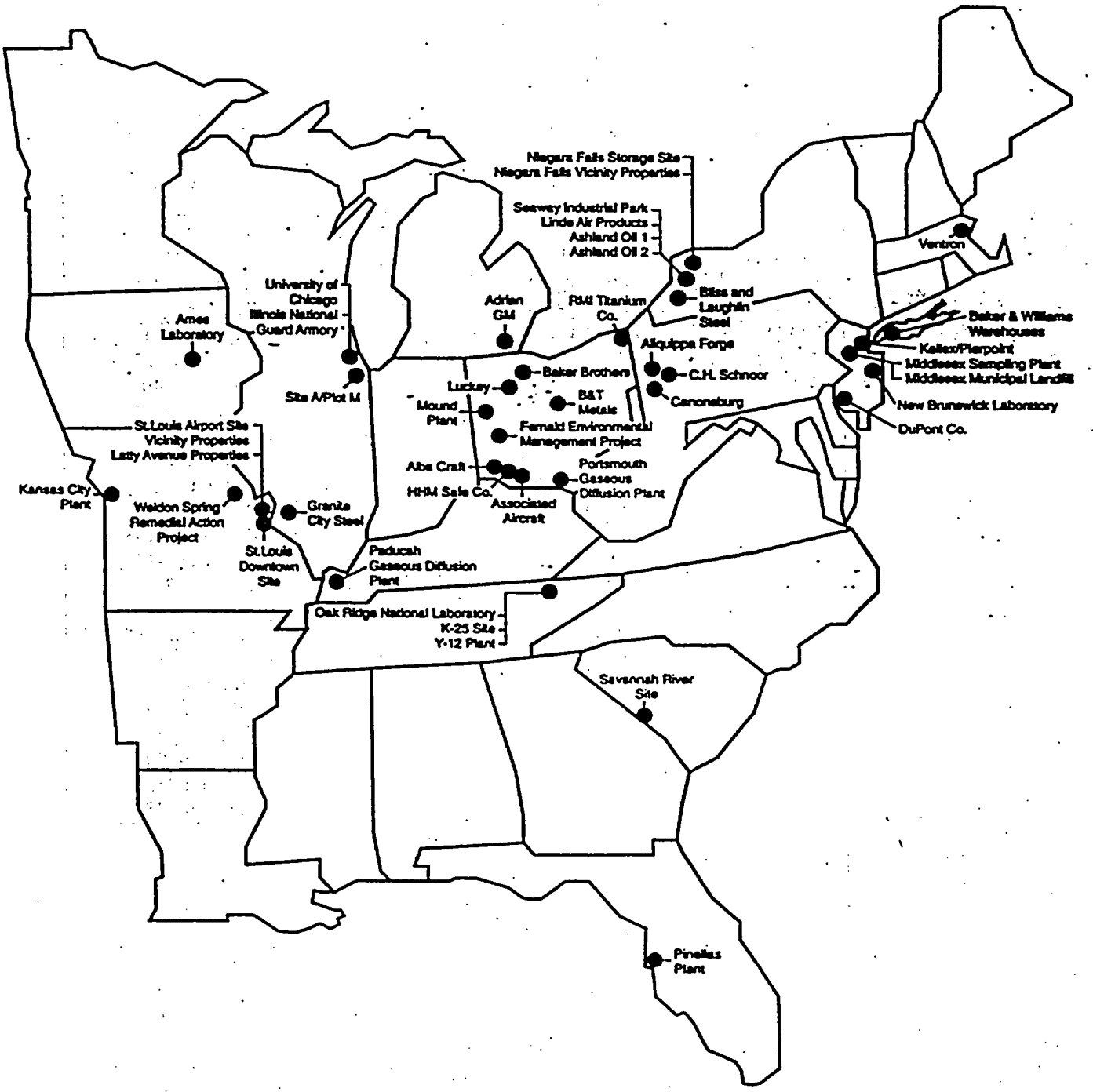
Sources: DOE, 1997a, Chapter 3, except for spent nuclear fuel volume, which is from IDB, 1996, and depleted uranium hexafluoride, which is from IEER, 1997b.
Note: Waste estimates do not include decontamination and decommissioning wastes or future wastes to be generated (for example, from the Stockpile Stewardship and Management Program -see below for a discussion). Wastes include those categorized as resulting from "weapons activities" as well as "non-weapons" activities. Non-weapons activities include the Naval Nuclear Propulsion Program as well as some research activities.
[1] One cubic meter is equal to 1000 liters, or approximately equal to 35 cubic feet or 264 gallons.
[2] In addition to 1,282 cubic meters of military spent nuclear fuel, there are 12,881 cubic meters of spent nuclear fuel from U.S. commercial power reactors containing an estimated 26,800 million curies of radioactivity.
[3] DOE does not provide a volume or radioactivity estimate for uranium mine waste, which, at least for uranium mill tailings, is comparable to tailings volume (IEER, 1997b).

A list of the radioactive and hazardous substances released to the environment at some of the main U.S. nuclear weapons facilities are listed in Table 3.

FIGURE 1: MAJOR U.S. SITES IN NUCLEAR WEAPONS PRODUCTION



Source: DOE, 1997a, pp. 18-19.



Note: Batelle Columbus Laboratory near Columbus, Ohio is missing from this map.

Table 3: Contaminants Found at Nuclear Weapons Complex Sites

Contaminant	Air	Soil	Surface Water	Groundwater
Radionuclides	Argon-41 Beryllium Carbon-14 Iodine-129 Krypton-85 Plutonium Plutonium-239 Radon Radon-222 Radon decay products Strontium-90 Technetium-99 Thoron Tritium Uranium Xenon-133	Americium-241 Antimony-125 Beryllium-7 Cadmium-109 Cesium-137 Cobalt-60 Curium-244 Europium-152 Europium-154 Europium-155 Iodine-129 Iodine-131 Plutonium-238 Plutonium-239 Plutonium-240 Radium-226 Radium-228 Radon-222 Rhodium-106 Ruthenium-106 Strontium-90 Thorium Tritium Uranium-232 Uranium-233 Uranium-234 Uranium-235 Uranium-238 Yttrium-90	Americium-241 Cesium-137 Cobalt-60 Curium-244 Iodine-129 Iodine-131 Plutonium Strontium-90 Tritium Uranium	Americium-241 Antimony-125 Barium-140 Beryllium-7 Cadmium-109 Cerium-141 Cesium-137 Cobalt-60 Curium-244 Europium-155 Iodine-129 Iodine-131 Iridium-192 Krypton Lanthanum-140 Neptunium-237 Potassium-40 Plutonium-238 Plutonium-239 Plutonium-240 Radium Rhodium-106 Ruthenium-103 Ruthenium-106 Sodium-22 Strontium-90 Technetium-99 Thorium-232 Tritium Uranium-232 Uranium-233 Uranium-234 Uranium-235 Uranium-238
Metals	Lead Mercury	Beryllium Cadmium Chromium Copper Lead Lithium Mercury Silver	Chromium Copper Lead Mercury Silver	Arsenic Barium Beryllium Cadmium Chromium Iron Lead Magnesium Manganese Mercury Molybdenum Nickel Selenium Sodium Thallium Zinc

Contaminant	Air	Soil	Surface Water	Groundwater
Inorganic compounds	Ammonia Hydrogen fluoride Nitrogen oxides	Aluminum hydroxide Aluminum persulfate Barium oxide Cyanide Ferric chloride Hydrochloric acid Hydrogen cyanide Lithium chloride Nitrates Nitric acid Sodium nitrate Sulfuric acid	Chlorine Cyanide Nitrates Sulfates	Aluminum hydroxide Aluminum persulfate Chlorides Cyanide Ferric chloride Fluorides Hydrochloric acid Lithium chloride Nitrates Nitric acid Sulfates
Volatile organic compounds	Acetylene Benzene Carbon tetrachloride Hydrochloric acid Hydrofluoric acid Perchloric acid Perchloroethylene 1,1,1-Trichloroethane Toluene	Acetone Benzene Carbon tetrachloride Chlorobenzene Chloroform Dichloromethane Dimethylformamide Ethyl acetate Methylene chloride Methyl ethyl ketone Methyl isobutyl ketone Perchloroethylene Tetrachloroethane Tetrahydrofuran Toluene Trichloroethane Trichloroethylene Xylenes	Perchloroethylene Tetrachloroethylene 1,1,1-Trichloroethane Trichloroethane Trichloroethylene	Acetone Benzene Carbon tetrachloride Chloroform 1,2-Dichloroethane 1,1-Dichloroethylene 1,2-Dichloroethylene Dichloromethane Dichlorophthalate Dimethylformamide Ethyl acetate Ethylbenzene Hexone Methylcyclohexane Methylene chloride Methyl ethyl ketone Methyl isobutyl ketone Napthalene Perchloroethylene Phthalates Tetrachloroethane Tetrachloroethylene Tetrahydrofuran Toluene 1,1,1-Trichloroethane Trichloroethane Trichloroethylene Xylene

Sources: Makhijani, Hu, and Yih, eds., 1995, pages 213-251, as well as some references cited in the case studies.

B. DOE's Environmental Management Program - A Brief Overview

DOE created the Office of Environmental Management in 1989 to deal with the legacy of nuclear production activities.[14] The environmental management program was initiated at a time when the Cold War was ending and the sorry state of disrepair of much of the nuclear weapons complex as well as the terrible environmental legacy of the Cold War years was coming to light. The Environmental Management program has consisted of waste management and custodial responsibilities for plants and equipment no longer required for nuclear weapons production, for environmental remediation, and for the development of technologies required for remediation. It is also responsible for the transuranic waste repository program, but not for the high-level waste repository program (which is run by the Office of Civilian Radioactive Waste Management).

Most of the $40 billion (1996 dollars) that has been spent to date on the Environmental Management program has been spent on custodial and waste management functions, not on environmental remediation. The entire remediation program is forecast to cost well over $200 billion.

According to the DOE, the Environmental Management program consists of four main activities:[15]

1. Nuclear Material and Facility Stabilization

When the decision was made to end the production of plutonium, a great deal of material was left in the production "pipeline" of the nuclear production complex. This material needs to be managed to prevent leaks, fires, explosions, theft, and radiation exposures. Many of the facilities housing these materials are over 40 years old and are deteriorating. The major materials and facilities are:.[16]

- 13 large nuclear reactors
- 41 radioactive processing facilities
- about 3,000 surplus buildings contaminated by and containing radioactive and hazardous materials
- 39 million liters (10.1 million gallons) of acids containing radioactive contaminants
- almost 3,000 metric tons of spent nuclear fuel
- several thousand kilograms of plutonium in various forms and locations
- 75 million curies of radioactive cesium and strontium
- a large variety of nuclear materials awaiting decisions on long-term storage and final disposition, such as depleted uranium.

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[14] It was known as the Office of Environmental Restoration and Waste Management when it was first created.

[15] From DOE, 1996e, pages 6-8.

[16] DOE, 1996c, pages 2-10 and 2-11. Note that this is DOE's list of major facilities and materials.

2. *Management of a tremendous quantity and variety of wastes*
As discussed above, production activities have generated a large volume and wide variety of wastes that need to be safely managed. Wastes will require treatment, storage, and disposal.

3. *Remediation of the environment*
This includes actions to deal with contaminated soil, contaminated surface and groundwater. Also included in "Environmental Restoration" is decommissioning of facilities such as reactor buildings and reprocessing canyons, which occurs after these facilities have been stabilized and deactivated. Wastes previously disposed of in shallow land burial may need to be dug up to prevent further contamination of the environment.

4. *Technology development*
A great number of environmental restoration and waste management problems currently have no feasible technological solutions. Other problems will require adaptation of industrial technologies to the special kinds of hazards posed by the various wastes. Still other problems will benefit from the development of new technologies that have the potential to greatly improve effectiveness and reduce costs. For these reasons, technology development is crucial to the long-term success of the Environmental Management program. It includes scientific research as well as development of new technologies.

DOE's Environmental Management program must comply with numerous federal, state, and local regulations, including:

- Atomic Energy Act
- Clean Air Act
- Clean Water Act
- Comprehensive Environmental Response, Compensation, and Liability Act
- Federal Facility Compliance Act
- Nuclear Waste Policy Act
- National Environmental Policy Act
- Resource Conservation and Recovery Act
- Safe Drinking Water Act
- Toxic Substances Control Act
- Uranium Mill Tailings Remediation and Control Act.

C. Problems in the Environmental Management Program

Despite some successes, discussed in part below, DOE's environmental management program confronts many basic problems:

- DOE is proceeding without national remediation or "low-level" waste management standards. Instead it is resorting to *ad hoc* approaches that will cause a wide variety of residual contamination at various sites. For instance, after active controls have lapsed at the Rocky Flats Plant, farming or residential development could occur on land having up to 651 picocuries per gram of plutonium-239/240. By comparison, the remediation standard for Johnston Atoll and Rongelap was about 40 times lower (see Chapter 2).
- DOE's priorities do not correspond systematically to urgent problems, as is demonstrated by its focus on transuranic waste that is relatively safely stored rather than the buried transuranic waste that is contaminating soil and groundwater.
- DOE is spending huge resources on Cold War technologies, notably reprocessing, under the guise of Environmental Management. For example, its own analysis shows that using the reprocessing plants at the Savannah River Site is the highest risk option for management of deteriorating irradiated fuel, even though that analysis omits one of the most serious risks -- that of increasing the probability of fires or explosions in waste tanks.[17]
- DOE is using shallow land burial to dispose of huge quantities of "low-level" waste, even though similar wastes in other countries would be managed for deep repository disposal (see Chapter 3).
- Despite years of talk about contracting reform intiatives, there appears to be tangible results that have prevented huge budget increases or increased contractor accountability. DOE's program of "privatization," its latest attempt at reform of contracting, is ill-advised and likely to produce more problems for the weapons complex, especially for its unprecedented remediation tasks (discussed in all three case studies).
- DOE continues to implement large projects without proper preliminary work, leading to costly failures and environmentally damaging delays, as demonstrated by every one of our case studies. We have called this seemingly endemic tendency "monumentalism" -- where projects and budgets are scaled up rapidly, whether the technology is ready or not. This tendency has prevailed even when there have been internal cautions or sound basic engineering indications that it would be unwise to proceed in this fashion.
- DOE's past waste management practices are at the center of the environmental management problems that DOE faces. (We have illustrated this problem in the TRU and Hanford tank case studies in this report.) Some of its present waste management approaches seem likely to create problems for the future. For instance, DOE plans to dispose of large quantities of long-lived radionuclides by shallow land burial.

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[17] Sachs, 1996.

- DOE seems unable to learn lessons from past failures in a consistent way or to transfer the lessons learned from one site to another. The manner in which it is proceeding with the Hanford tank program, for instance, indicates a failure to carefully take into account the problems encountered in a far less complex program at the Savannah River Site (see Chapter 3).

1. Programmatic Environmental Impact Statements for DOE Activities

In 1989, national and community-based environmental groups brought a lawsuit against DOE under the National Environmental Policy Act. Specifically, the groups argued that DOE needed to prepare a Programmatic Environmental Impact Statement (EIS) for it activities related to clean-up, waste management, and modernization of the nuclear weapons complex.

In 1990, the U.S. District Court in Washington, D.C., announced a stipulation stating that DOE had agreed to prepare a Programmatic EIS for Environmental Restoration and Waste Management and another for modernization of the weapons complex (also called "reconfiguration"), and publish Records of Decision for both.[18] DOE decided to prepare two separate EIS's, despite evident connections between the two areas that were pointed out in many comments prior to that decision.[19]

DOE's implementation of its commitments to prepare these two Programmatic EIS's has been incomplete on several counts, causing many of the same groups to file a new lawsuit aimed at forcing DOE to comply with the 1990 stipulation.[20] Two concerns are discussed below.

1. <u>In 1995, DOE abandoned the environmental restoration component of the Environmental Restoration and Waste Management Programmatic EIS.</u>

DOE's Waste Management program (referred to as "EM-30") and the Environmental Restoration program ("EM-40") are both responsible for managing large volumes of low-level, mixed low-level, and transuranic waste. Generally, the Waste Management program includes wastes that are already separated from the environment, such as high-level waste in tanks and transuranic waste stored in drums inside covered facilities. The Environmental Restoration program is responsible for dealing with contaminated soil and groundwater, decontaminating and decommissioning buildings and facilities, and digging up drums and boxes of waste.[21]

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[18] NRDC, 1990.

[19] Most importantly, the "modernization" of the weapons complex would involve production of new radioactive and hazardous wastes that would need to be managed along with existing wastes.

[20] McDiarmid and Finamore, 1997.

[21] DOE, 1997b, page B-2.

In the Waste Management Programmatic EIS, DOE states that "despite these differences, there is significant overlap between the two programs. They both address many of the same contaminants..."[22] As noted above, DOE agreed to a stipulation that it prepare a programmatic EIS that included both programs. However, DOE has abandoned the Environmental Restoration component, stating that

> The initial decisions DOE must make about environmental restoration are not programmatic or strategic, but specific to its individual sites. These decisions concern the uses to which each site will be put in the future. For the most part, a decision on how one site can or will be used in the future does not depend on how other sites in the complex will be used, but depends on such things as the degree of contamination, the applicable cleanup standards, the views of local residents and regulators, DOE's need for the site in the future, and the alternative uses that are feasible for the site. It would not be sensible to evaluate programmatic alternatives for future uses within the DOE complex, because the process of developing alternative uses and selecting among them will, for the most part, proceed at each site as part of cleanups taken pursuant to CERCLA [the Comprehensive Environmental Response, Compensation, and Liability Act] and RCRA [Resource Conservation and Recovery Act].[23]

DOE also stated that "some national perspective and public participation is needed" to address environmental restoration decisions. In the Waste Management Programmatic EIS, the only mechanism that DOE suggests is a "National Dialogue," which it does not define, either in terms of organization, scope, or influence.[24]

DOE's decision not to address Environmental Restoration wastes in the Programmatic EIS is a serious deficiency. This is because the vast majority of DOE's waste falls under the Environmental Restoration program. Table 4 shows that only a small fraction of the low-level, mixed-low level, and transuranic waste is currently under the Waste Management program -- roughly 1.5 million cubic meters out of 44 million cubic meters for low-level waste, 220,000 cubic meters out of 13 million cubic meters for mixed low-level waste, and 132,000 cubic meters out of 224,000 cubic meters for transuranic waste. DOE's approach in the Programmatic EIS, however, is to only provide analysis for a tiny fraction of the low-level and mixed low-level wastes, and about half of the transuranic waste.[25]

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[22] Ibid, page 1-40.
[23] Ibid, page 1-40 and 1-41.
[24] Ibid, page 1-44.
[25] As discussed below, the Waste Management Programmatic EIS does not report large volumes of transuranic waste, thus, it appears that less than half of the transuranic waste in the DOE complex is included in the EIS.

Table 4: Comparison of DOE Waste Volumes Reported in Waste Management Programmatic EIS

Type of Waste	Volume, cubic meters
Low-Level Waste	
Waste Management Program [a]	
Subtotal	*1,500,000*
Environmental Restoration Program	
Planned to be "removed" [b] and:	
• transferred to WM program for management and disposal	1,900,000
• managed and disposed of by ER program or commercial entities	9,600,000
Planned to be left in place	30,000,000
Plan not yet determined	1,900,000
Subtotal	*43,000,000*
Total, Waste Management plus Environmental Restoration Program	*44,500,000*
Mixed Low-Level Waste	
Waste Management Program [a]	
Subtotal	*220,000*
Environmental Restoration Program	
Planned to be "removed" [b] and:	200,000
• transferred to WM program for management and disposal	500,000
• managed and disposed of by ER program or commercial entities	5,800,000
Planned to be left in place	6,600,000
Plan not yet determined	*13,000,000*
Subtotal	
Total, Waste Management plus Environmental Restoration Program	*13,220,000*
Transuranic Waste	
Waste Management Program [a]	
Subtotal	*132,000*
Environmental Restoration Program	
Planned to be "removed" [b] and:	
• transferred to WM program for management and disposal	80,000
• managed and disposed of by ER program	39
Planned to be left in place	8,500
Plan not yet determined	3,100
Subtotal	*91,600*
Total, Waste Management plus Environmental Restoration Program	*223,600*

Source: DOE, 1997b, pages B-8 through B-10 and B-19.

[a] The volume of waste under the Waste Management program includes waste to be generated over the next 20 years. The Waste Management Programmatic EIS (page 1-37) states that there are currently 67,500 cubic meters of low-level waste, 82,000 cubic meters of mixed low-level level waste, and 67,700 cubic meters of transuranic waste currently in the Waste Management program.

[b] For example, wastes that will be removed from shallow land dumps or from facilities being decontaminated and decommissioned. DOE refers to removing these wastes as an "*ex situ* response."

Leaving aside the issue of the large volumes of waste DOE plans to leave in place and the waste for which DOE has not developed plans, there is still a large volume of waste that DOE plans to remove from the ground or from facilities that are being decontaminated and decommissioned; as shown in Table 4, the totals amount to 11.5 million cubic meters of low-level waste, 700,000 cubic meters of mixed low-level waste, and 80,000 cubic meters of transuranic waste. Since DOE already plans to manage and dispose of this "removed" waste, its argument about site-specific decisions is irrelevant here. DOE will need to manage and dispose of this "removed" waste in ways comparable to the wastes that are currently in the Waste Management program.

DOE's argument for not including the "removed" wastes in the Programmatic EIS is that it "still does not have enough information on the volume or contaminant composition of these wastes to perform a meaningful impact evaluation at this time."[26] Instead of developing a plan to obtain more information about these wastes, such as beginning retrieval of buried waste or investigating the contents of facilities to be decontaminated and decommissioned, so that DOE could address management and disposal of "removed" and Waste Management wastes in a comprehensive fashion, DOE simply rejected the "removed" wastes from consideration. This means DOE is performing no programmatic analysis for short- and long-term environmental, health, and safety impacts from treatment and disposal for the largest portions of the waste it plans to manage and dispose of, to say nothing of the wastes it is leaving in-place. Such wastes are apparently to be managed in an *ad hoc* fashion, such as creating new low-level waste disposal sites as required.

It is also interesting to note that DOE felt confident enough to include wastes resulting from the next 20 years of weapons production and maintenance activities in the Waste Management Programmatic EIS analysis, though these are very uncertain, but excluded existing waste to be "removed" on the grounds of uncertainty and insufficient information.

Several deficiencies in DOE's Environmental Management program are reflected in the fundamentally-flawed Waste Management Programmatic EIS. One example is that DOE's refusal to develop national clean-up standards allows DOE to assert that restoration decisions are to be made on a site-by-site basis, thereby neglecting the largest volumes of waste from consideration in the Programmatic EIS.

Second, instead of developing a comprehensive plan to manage and dispose of "removed" wastes (those currently in shallow land burial or in facilities slated for decontamination and decommissioning) together with wastes currently in the Waste Management program, DOE chose to focus on only the fraction of wastes that are in the Waste Management program. As we discuss in the case study on transuranic waste, the transuranic wastes that lie in shallow land burial pose by far the most serious short- and

[26] DOE, 1997b, page 1-42.

medium-term risks and need to be addressed with a much higher priority than the transuranic wastes in the Waste Management program, which are regularly monitored and stored in covered facilities. The consequences of considering management and disposal of wastes separately are evident at the Idaho Lab, where the Environmental Restoration and Waste Management program have each pursued monumental treatment facilities for transuranic waste in an uncoordinated fashion, rather than a joint program of technology development for treating these wastes. The Environmental Restoration's initial attempt to build a treatment facility (the treatment system for the Pit 9 project) has failed and yet the Waste Management program is proceeding with the planning of an even-larger treatment facility for transuranic wastes.

Third, some of the comparisons in the Waste Management EIS are misleading and some basic data is incorrect. For example, as discussed in the case study on transuranic waste, the Waste Management Programmatic EIS leaves out some 90,000 cubic meters of transuranic waste, as well as large volumes of transuranic-contaminated soil. This undermines DOE's supposed analysis of transuranic waste in the Programmatic EIS. As noted above, DOE decided to focus only on 132,000 cubic meters of transuranic waste (those that are either currently in the Waste Management program or are expected to be generated during the next twenty years). Citing insufficient information, DOE stated that it would not consider the 80,000 cubic meters of transuranic waste that it expects to be transferred from the Environmental Restoration program to the Waste Management program; these wastes are mostly to be generated during decontamination and decommissioning (see Table 4)[27] However, *there is a large volume of transuranic waste that is not mentioned anywhere in the entire Waste Management Programmatic EIS.* This is the buried transuranic waste (at sites other than the Idaho Lab), which by some estimates, is on the order of 89,000 cubic meters plus an additional, most likely larger, volume of transuranic contaminated soil.[28] Thus, DOE's response to an insistent public demand does not even meet the minimal requirement of data quality or consistency, to say nothing of programmatic soundness.

Fourth, the Waste Management Programmatic EIS is deficient in that DOE did not incorporate repeated suggestions that it consider important questions such as a revamped waste classification system or changes to its repository program.[29] These issues could have large impact on the Environmental Management program. For example, by deliberately excluding large volumes of transuranic waste, the Waste Management Programmatic EIS preserves the impression that its proposed repository for transuranic waste, the Waste Isolation Pilot Plant, is a sufficient repository. In fact, if the volumes cited in the above paragraph -- 80,000 cubic meters of "removed" waste, 89,000 cubic meters of buried transuranic waste, plus a comparable or potentially larger volume

[27] The estimate of 80,000 cubic meters does includes 9,700 cubic meters of transuranic waste that represents the treated volume of waste that DOE expects to remove from shallow land burial at the Idaho Lab (Peterson, 1997).

[28] See Chapter Two for a discussion of transuranic waste volumes.

[29] For example, MPN, 1996. See Chapter Five and Appendix B of this report for a discussion and recommendations regarding the present waste classification system and repository program.

of transuranic contaminated soil -- are included, the capacity of the planned repository is clearly seen as insufficient. Instead of taking the opportunity to address this issue, DOE waves its hand and limits its discussion to only what supports its repository plans.[30]

2. The Waste Management Programmatic EIS is not coordinated with the Stockpile Stewardship and Management Programmatic EIS

Not only did the May 1997 Waste Mangement Programmatic EIS fail to meet the 1990 stipulation because it inappropriately dropped the Environmental Restoration component, the Waste Management Programmatic EIS is not consistent with the Stockpile Stewardship and Management Programmatic EIS, which was issued only five months earlier (i.e., December 1996).

The waste inventory that was considered in the Waste Management Programmatic EIS was comprised of current stored waste plus waste to be generated over the next twenty years "as a result of DOE nuclear weapons stockpile stewardship and research programs."[31] As a result, DOE acknowledged that both Programmatic EISs would need to be coordinated.[32]

However, as pointed out in an affadavit filed in court, the waste volumes estimated in the Stockpile Stewardship and Management Programmatic EIS are not consistent with those used in the Waste Management Programmatic EIS. Different numbers for high-level, transuranic, mixed low-level, and low-level wastes were published in the two EIS's. Table 5 shows that the projected waste streams do not match.

Table 5: Comparison of Waste Management PEIS and Stockpile Stewardship PEIS Estimates of Future Waste Generation

Waste Category	Annual generation rate reported in Waste Management PEIS, cubic meters	Annual generation rate reported in Stockpile Stewardship and Management PEIS, cubic meters
Low-level	72,000	8,310
Mixed low-level	6,850	28,531
Transuranic	3,200	692

Source: CCNS, 1997.
Note waste generation rate reported in the Waste Management PEIS is the total for a 20-year period. Waste generation rate in the Stockpile Stewardship and Management PEIS is reported as an annual rate. For the comparison in this table, Waste Management PEIS volumes are divided by 20.

[30] The issue of insufficient capacity for the Waste Isolation Pilot Plant is addressed in the Waste Isolation Pilot Plant Disposal Phase Draft Supplemental Environmental Impact Statement (DOE Carlsbad, 1996), but concludes that the preferred plan is to proceed with WIPP and consider repository disposal only for the current inventory plus the wastes expected to be generated over the next 30 or so years.
[31] DOE, 1997b, Summary page 6.
[32] DOE, 1996g, page 1-10.

The affadavit points out that "these two PEISs, whose Records of Decision DOE acknowledges should be coordinated, present the public and decision-makers with widely varying quantities of future radioactive waste..."[33] This lack of coordination is all too typical. We have found serious inconsistencies in a variety of published waste data. So far as we have been able to determine, there does not appear to be any significant quality control efforts on DOE's part to provide consistent, correct data to the public.

2. "Accelerating Cleanup: Focus on 2006" Plan

As weapons production facilities began to shut down in the 1990's, the Environmental Management program grew rapidly. The program became the "steward of the world's largest environmental cleanup effort" - managing activities at some 130-plus sites. The program found itself ill-prepared for the sudden increase in scope. The program was uncoordinated and few sites had comprehensive strategies for achieving an end-state. In the mid-1990's the Environmental Management program found its funding leveling-off and became concerned that it would not be able to meet its legal and regulatory requirements.[34]

In response to Congressional request, the Environmental Management program prepared the Baseline Environmental Management Report, first issued in 1995 and then updated in 1996. These reports were the first estimates of the schedule and lifecycle cost of the program; the 1996 report estimated a total of $227 billion would be required over a period of 75 years.[35]

In 1996, the Environmental Management program began to focus on achieving as much as it could over the next ten years. This effort was dubbed the Ten-Year Plan, and is now called the Focus on 2006 plan.[36] In February 1997, sites submitted draft "Ten Year Plans" based on two levels of funding for the Environmental Management program, $5.5 billion per year and $6 billion per year.

The Ten-Year Plan effort by the sites produced some worthwhile results. Sites assigned all activities to projects and developed budget plans for those projects. The effort also helped sites to identify science and technology needs.[37] The process helped headquarters and site managers to think more strategically about the program and identify ways to improve efficiency and achieve results. Projects were re-sequenced to achieve cost savings and accelerate schedules. Opportunties to deactivate and decommission buildings more rapidly were identified that are expected to save surveillance and monitoring costs in the long-term.

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[33] CCNS, 1997.
[34] DOE, 1997c, pages 1-2 and 1-3.
[35] Cost in constant 1996 dollars. Other results of these reports are described below.
[36] The name was changed to "Focus on 2006" with the release of a Discussion Draft in June 1997.
[37] DOE, 1997c, page ES-5.

In June 1997, the Environmental Management program issued a Discussion Draft of the Focus on 2006 plan - a revision of the site Ten-Year Plans submitted in February. Anticipating limited Congressional funding, the plan included a discussion of how it can improve the performance of the program. Between fiscal year 1999 (when the Focus on 2006 plan is anticipated to take effect) and fiscal year 2006, the Environmental Management program set a goal of completing an additional $8 billion of work through improved performance, a 12% increase in overall performance during this period. Whether or not DOE has the capability of achieving this ambitious goal is questionable, but at least the planning effort has forced DOE to think about improving efficiency.

Despite some successes and setting of performance goals, the Focus on 2006 plan contains serious fundamental flaws and its implementation has been cause for serious concern, especially among people living near the sites.

The central goal of the Focus on 2006 plan is to "complete" at as many sites as possible by 2006. The Focus on 2006 plan adopted the following definition of "completion":

- Deactivation and decommissioning of all facilities currently managed by the program, with the exception of long-term surveillance and monitoring
- Releases to the environment are in accordance with agreed-upon standards
- Groundwater contamination is contained, and long-term treatment or monitoring is in place
- Nuclear material and spent fuel have been stabilized and/or placed in safe long-term storage
- "Legacy" waste (waste produced by past weapons activities) has been disposed of in an approved manner.[38]

This guiding definition is incomplete and vague. For example, the definition uses the term "agreed-upon standards" to describe DOE's inconsistent and piecemeal approach to environmental remediation. It obscures the fact that DOE is proceeding without national clean-up standards. In this report, we describe how this type of approach can lead to serious discrepancies between sites and foisting of unacceptably high levels of "residual" contamination on communities. Specifically, at Rocky Flats, DOE has proposed allowing "residual" contamination of up to 651 picocuries per gram of plutonium-239/240 -- levels about 40 times the maximum set for remediation of Rongelap and Johnston Atolls. We strongly recommend DOE work under strict national standards.

Additionally, the definition of "completion" states that "legacy" waste will be disposed of in an approved manner. However, this means large volumes of transuranic waste, mostly generated before 1970, may remain in shallow land burial. As we discuss in Chapter Two, this waste has already contaminated soil and groundwater at several sites

[38] Ibid, page 1-5.

and presents serious short- and medium-term threats. Yet, the preferred approach seems to be to cover up this waste with a few additional feet of dirt and declare the problem resolved and DOE obligations "completed." The Focus on 2006 plan thus presents a seriously weakened vision of "cleanup."

Implementation of the Ten-Year Plan / Focus on 2006 plan has also been seen as a way for DOE to pursue approaches to environmental remediation and waste management other than those contained in legally-binding Records of Decision. These approaches are being presented as quicker and cheaper "solutions." For example, in 1996, under the auspices of the Ten-Year Plan, site officials at the Lawrence Livermore National Laboratory proposed to change the groundwater remediation requirement for volatile organic compounds to 25 parts per billion - five times higher than the 5 parts per billion requirement agreed to by DOE in a Record of Decision (ROD). In a letter to Assistant Secretary Al Alm, the citizen's group Tri-Vally CAREs in Livermore, California warned that

> If the 10-Year planning process is used as a device to allow facilities to abrogate their legal requirements or to walk away leaving 5 times the contamination in the groundwater than is allowable in their RODs, then its major effect will be to undermine cleanups rather than promote them.[39]

Despite these objections, the Livermore Lab's Focus on 2006 plan released in June 1997 continued to assume that DOE would pursue changes to the Record of Decision and continued to use a 25 parts per billion standard for volatile organic compounds. Tri-Valley CAREs also noted that DOE's strategy for on-site groundwater contamination plumes involved the "containment zone" approach - one of the components of DOE's definition of "completion." This strategy would involve addressing groundwater remediation so that the concentration at the site boundary would meet state and federal limits, rather than remediating the on-site plume to the state and federal limits. DOE stated that the "containment zone" approach to groundwater remediation at the Livermore Site is not consistent with the Record of Decision.[40] We have not examined whether or not this approach is common to other site Focus on 2006 plans. However, if this is the "containment zone" approach to groundwater remediation implied by definition of "completion" in the Focus on 2006 plan, then this is another example of the environmentally unsound approach to environmental remediation being taken by DOE. Moreover, in keeping with the past record, it is one that decreases short-term costs at the expense of long-term environmental protection.

The Focus on 2006 plan is being promoted as a way "to streamline and to save taxpayer dollars."[41] The idea of "completing" the Federal government's obligations to address the environmental legacy of the Cold War by 2006 is an attractive way to market the Environmental Management program to Congress, which approves funding

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[39] Tri Valley CARES, 1996.
[40] Tri-Valley CARES, 1997, pages 1-3 of the attached memorandum from P. Strauss.
[41] DOE, 1997c, preface.

for the program. However, "completion" is a misleading term that implies many problems will be resolved in the next eight or so years. In fact, the approach under the plan is reminiscent of the short-sighted, expedient approaches that were promoted in the past as waste management "solutions." The Focus on 2006 plan allows DOE to proceed with its Environmental Management program while ignoring major flaws such as an inadequate waste classification system, a disjointed approach to environmental restoration and waste management, a lack of national clean-up standards, and an institutional structure that is failing. We address these issues in Chapter Five.

A coalition of community and national groups has rejected the plan as "unsalvageable." We agree. The groups state that "it appears that cleanup decisions are being made on a piecemeal, site-by-site basis and without a comprehensive national framework or a public involvement process." Additionally, the groups state that "continuing to formulate budgets and programs based on this ill-conceived plan is irresponsible." The groups also raised concerns about federal and state compliance agreement milestones not being met under the plan.[42]

D. Some Successes of the Environmental Management Program

Despite the lack of a systemic approach to environmental management, the expenditures in the past few years have produced some worthwhile results. Most important have been the gains in knowledge about the scope of the problem. At the start of the 1990s, little but the broad outlines were known of the huge tasks facing environmental remediation of the complex. By 1997, knowledge of what needs to be done is much clearer, though as our case studies show, far from complete. DOE has undertaken a number of efforts that have improved that state of knowledge. The most important ones have included:

- The Plutonium Vulnerability study, in which the various problematic forms of plutonium including those at risk of fires or explosions, were discussed;
- A Highly-Enriched Uranium Vulnerability study, similar to the plutonium vulnerability study;
- Baseline Environmental Management Reports in 1995 and 1996 that for the first time attempted to give a nearly complete picture of the scope of the environmental management program, including remediation projects and costs;
- Linking Legacies -- this recent DOE publication does a remarkable job of connecting the history of various phases of nuclear weapons production to the environmental and waste management problems that exist today;
- The report entitled "Plutonium: the First 50 Years" where many of the overall plutonium accounting efforts were laid out (though some important discrepancies are not yet resolved);

[42] MPN, 1997. IEER is a part of this coalition.

- Various reports of the Technical Advisory Panel on the Hanford tanks as well as certain characterization efforts on Hanford tanks that helped clarify the nature of their contents, and the diverse sources of risks of fires, explosions or criticalities;
- Taking Stock: A Look at the Opportunities and Challenges Posed by Inventories from the Cold War Era -- this initiative was an important look into how to promote proper management and disposition of a wide variety of materials.

In addition, there have been some actual remediation successes. The most important has been the start-up in 1996 of the high-level waste vitrification plants at Savannah River Site in South Carolina and at West Valley in New York. These plants are vitrifying highly-radioactive liquid wastes. Complete solidification of these wastes, while it carries its own risk of accidents, is needed to eliminate the persistent risks of leaks, fires, and explosions that could result from storage of high-level liquid wastes for indefintely long periods. The much-delayed and over-budget project at Savannah River site is still, however, marred by serious problems.

First, only a part of the process is working. A part of the sludge waste, which contains the highest amount of radionuclides per unit volume, is being extracted from the high-level waste tanks and vitrified. But pretreatment of cesium-contaminated waste has not begun. The main problems seem to be due to a premature scale-up of a laboratory-tested process to industrial-scale, without an intermediate step of pilot plant testing. A second problem with Savannah River high-level waste management is that the tanks that are almost, but not completely empty of radionuclides are to be filled with cement. One tank has already been filled with cement, though it contained about 1,000 gallons of high-level waste. These nearly-empty tanks will still contain large residual amounts of radioactivity and pose risks for future soil and groundwater contamination. In case these problems arise, they will be essentially impossible to remediate. Cementation of tanks around which there have been leaks will also prevent effective remediation of the underlying contaminated soil (the vadose zone).

Some successes have also been achieved at Hanford. One of the most important was resolution of a major flammable gas safety issue that was mitigated by the installation of a "mixer pump" in a high-level waste tank, 241-SY-101, that had previously been releasing concentrations of hydrogen above the lower flammability limit of the gas. The official Technical Advisory Panel appointed to gain a scientific understanding of the most serious safety issues at Hanford brought together a wide variety of expertise to recommend an approach to reduce this serious risk. In addition, Hanford has achieved progress in developing sampling technologies and capabilities and instituting a program to address safety as well as retrieval and treatment issues.

DOE has also initiated a wide-ranging technology development program. We have not evaluated this program, especially as regards its relative priorities or financial efficiencies. However, many promising approaches to remediation as well as basic research on waste management are being developed. These include basic waste

chemistry studies, new approaches to soil remediation and metal decontamination, volume reduction of radioactive waste, treatment of mixed wastes to eliminate the non-radioactive toxic compounds, and development of ceramic radioactive waste immobilization. Other areas of progress include programs to reduce the volume of radioactive waste (notably "Class A low-level waste") along the lines already adopted in the commercial sector and the decommissioning of many old buildings.

Finally, DOE has completed remediation of 26 relatively small contaminated sites. However, a principal component of this remediation has been to transfer the resultant radioactive wastes to other sites for shallow land burial.

E. Environmental Management Program Costs

In 1995 and 1996, the Office of Environmental Management published cost estimates in the Baseline Environmental Management Report.[43] These efforts led to the development of life-cycle costs for Environmental Management projects; the estimates are for a 75-year time frame. One hundred and nineteen sites in over 25 states, as well as the U.S. test sites in the Pacific, are considered in the study. Activities have been completed at an additional 26 sites.

A range of $189 to $265 billion dollars, with a base case of $227 billion dollars is the current best estimate for the 75-year Environmental Mangement program (constant 1996 dollars). In the Baseline Report, it is estimated that activities at roughly 80% of the sites will be completed in 2021, and 90% of expenditures will have been incurred by 2037. These cost estimates are subject to limitations and uncertainties, as described below. Other costs include health impacts to workers and members of the public, which are not quantified.

We are ignoring the costs presented in the Discussion Draft of the Focus on 2006 Plan because the plan is flawed and incomplete and defers so many important environmental restoration and waste management activities beyond 2006, rendering the cost estimates meaningless for any overview of the problem.

Moreover, the presentation of the Focus on 2006 Plan is flawed because the data are presented according to "Operations Offices" rather than specific sites. This aggregation of problems into administrative artifacts has resulted in a document that is neither rigorous nor transparent enough to enable independent reviewers to evaluate the results or methodology. Finally, the plan seems to replace the much more complete Baseline Environmental Management Report, which the DOE has not published in 1997. The DOE is required by law to submit an annual report "on the activities and projects necessary to carry out the environmental restoration of all Department of Energy defense

[43] DOE, 1996c.

nuclear facilities."[44] The Focus on 2006 plan is a poor substitute for the Baseline Management Report.

The 1996 Baseline Report estimates that the five most expensive sites account for 70% of the environmental management costs, as shown in Table 6.

Table 6: DOE Estimates for Five Highest Cost Sites

Site	Base Case Cost	Projected Completion
Hanford Reservation, Washington	$50 billion	2052
Savannah River Site, South Carolina	$49 billion	2040
Oak Ridge Reservation[1], Tennessee	$25 billion	2045
Idaho National Engineering and Environmental Laboratory, Idaho	$19 billion	2045
Rocky Flats Site, Colorado	$17 billion	2055
All other sites	$67 billion	2070

Source: DOE, 1996c, Table 4.1.
[1] Includes Oak Ridge National Laboratory, K-25 site, and Y-12 site.

The major cost components of the Environmental Management program fall under the categories of Waste Management ($111 billion), Environmental Restoration ($63 billion), Nuclear Material and Facility Stabilization ($21 billion), Landlord ($13 billion)[45], and Science and Technology Development ($12 billion).[46]

The two Baseline Reports were the first DOE attempts to estimate overall environmental restoration and waste management costs. Unlike the Waste Management Programmatic EIS, these reports attempted to integrate environmental restoration and waste management and provide a starting point for assessing the scope of the problem of reducing the risks from the contamination and wastes generated by nuclear weapons production.

A major shortcoming of the Baseline Reports is that they do not include a full accounting of all of the environmental liabilities in the Department of Energy. The Baseline Reports were acknowledged to be only an accounting of the liabilities currently identified within the purview of the Environmental Management program. Subsequent to issuing the 1996 Baseline Report, DOE addressed this limitation by estimating the liability for all facilities that have not been transferred to the Environmental Management program -- for example, facilities at Los Alamos National Laboratory that are still in use. The total additional liability is estimated to be $14 to 38 billion beyond what is included in the Baseline Reports.[47]

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[44] *National Defense Authorization Act for FY 1994*, as quoted in DOE, 1996c, page A.1-1.
[45] "Landlord" costs are those associated with infrastructure support activities at the sires such as communication, transportation, and security systems.
[46] DOE, 1996c, page 4-17.
[47] DOE, 1997d, page 51.

The Baseline Reports also do not include cost estimates for problems was judged that no feasible remediation approach is possible, either because of technological limitations or because addressing them would result in "unacceptable ecological damage." These sites are listed in Table 7.

Table 7: Problems Not Included in Baseline Report Cost Estimates

Site	Projects	Official Reasons for Exclusion
Hanford	Columbia River, Hanford Reach Groundwater	No feasible remediation approach currently available Limited pump-and-treat followed by natural attenuation and monitoring
Oak Ridge Reservation	Clinch River Watts Bar Reservoir Poplar Creek Embayment White Oak Creek	No feasible remediation approach currently available
Oak Ridge National Laboratory	Deep Hydrofracture Grout Sheet	No feasible remediation approach available
Savannah River Site	L Lake Savannah River Swamp Par Pond	No feasible remedy without causing collateral ecological damage
Fernald	Great Miami River	No feasible remediation approach available
Idaho National Engineering and Environmental Laboratory	Snake River Plain Aquifer	Limited pump-and-treat followed by natural attenuation and monitoring
Rocky Flats	Walnut Creek Woman Creek Great Western Reservoir Stanley Lake	No feasible remedy without causing collateral ecological damage
Nevada Test Site	Underground Test Areas	No feasible remediation approach available
Sandia National Laboratory	Groundwater Chemical Waste Landfill	Natural attenuation and monitoring assumed

Reproduced from DOE, 1996c, page 3-9.

Most of these contaminated sites for which costs were not estimated (referred to as "unquantified liabilities") present enormous challenges. For instance, plutonium and other radionuclides in the underground environment at the Nevada Test Site may contaminate limited groundwater supplies of the region, creating additional costs and

impacts. Plutonium from tests has already been found to be migrating in groundwater underneath the site.

Other factors may increase the estimated $227 billion dollar cost. First, costs will be incurred because of the fact that after many sites are "completed," residual contamination will remain and land use restrictions may be in place. These restrictions will reduce the value of the land and also require continued funding for enforcement.

Second, the effectiveness of solutions is poorly understood because of the time frame that these wastes will present hazards. The history of the nuclear weapons complex to date has been that yesterday's waste management "solutions" have become today's environmental problems. Dumping plutonium-contaminated wastes in cardboard boxes into shallow pits, injecting wastes into the ground, and building cheaper high-level waste tanks are but a few examples. While some of today's solutions appear more sophisticated, the case studies show that at least some of the major remedial actions being pursued are not robust enough. That is, their "design life" is likely to be far shorter than the time-scale for which the problems will persist. Further, as we will illustrate in this report, DOE is still implementing short-sighted "solutions" making long-term problems more likely.

Third, the costs associated with monitoring and surveillance are also poorly understood, again because of the long time frames involved. DOE estimates that 130 sites may require "stewardship" in the year 2070.[48]

Fourth, the Baseline Report costs estimates do not include costs for a repository other than $8.3 billion for the Waste Isolation Pilot Plant that has been proposed as a repository for transuranic waste. However, even under existing lax regulations, many other DOE wastes, including spent nuclear fuel, reprocessing waste, and Greater Than Class C waste also need to be disposed of in a geologic repository.

Fifth, if current projects are any guide to future ones, DOE's cost and schedule estimates are characteristically overly-optimistic. Although the future could bring new cost-saving technologies and efficiency improvements, a look at the cost escalation for specific projects leave room for doubting whether DOE is capable of achieving such savings unless project planning and implementation is substantially improved.

For example, two of the projects discussed in this report have come close to or already exceeded projected costs, yet neither has progressed past the pilot-scale phase. At Fernald, cost estimates for treating radium- and thorium-contaminated waste in three large silos have increased from $92 million to $400-$600 million. At the Idaho Lab, a project to dig up and treat transuranic waste in a one-acre pit was estimated to cost roughly $200 million in December 1994 (one year earlier, the estimate was $50 million). Through June 1997 the contractor had already spent $257 million and estimated that its

[48] Alm, 1997.

costs to complete the project would essentially double the cost of the contract -- bringing the project's cost estimate close to half a billion dollars.

F. Clean-up Scenarios

To evaluate the impact of remediating contamination to different levels, the 1996 Baseline Report includes an analysis of how costs at the 5 most costly sites would change based on what restrictions were placed on future land use. For example, if future use were restricted to industrial use only, environmental standards would be relaxed.

Currently, the 5 most costly sites have some areas with remedial action agreements (such as Records of Decision) in place, and some areas that do not have agreements in place. The areas with agreements in place include areas that are remediated to varying levels, e.g., controlled access, industrial, recreational, residential, agricultural. The analysis in the Baseline Report did not change the remediation agreements that are already in effect, but did vary the remediation levels for areas without agreements in place.[49] The scenarios considered are shown in Table 8, along with their cost estimates.

DOE's analysis indicates that a relatively small amount would be gained by pursuing a minimal remediation scenario -- a savings of $10 billion out of $160 billion under the "Base Case" for the 5 highest cost sites. Such a strategy would incur larger costs for long-term monitoring, offsetting its supposed advantages. Conversely, increasing remediation levels from the "Base Case" to the Recreational or the Residential/Agricultural scenarios was estimated to have a small incremental cost (about 2 to 4 percent). Moreover, the benefits would be greater because more land would be available for a wider range of uses.

As we have noted, all of these cost figures must be viewed with a great deal of skepticism. But the Baseline Reports of 1995 and 1996 are the first real attempt by DOE to get an overview of the magnitude of the effort needed. Unfortunately, DOE has abandoned this commendable effort in favor of a far more incomplete and ill-conceived "Accelerated Cleanup: Focus on 2006" plan.

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[49] Except for the "Maximum Cleanup" scenario, see Table 8.

Table 8: Alternative Scenarios for Level of Remediation in Baseline Report for the Five Main DOE Sites

Scenario	Description	Estimated Cost[1]
Disposal / Storage	Areas with existing agreements remediated to the necessary extent. Other contaminated areas monitored and contamination contained in place. Most areas have "controlled access"	$150 billion
Industrial	Areas with existing agreements remediated to the necessary extent. Other contaminated areas remediated to allow industrial use. Most contamination contained in place. Restrictions on groundwater use, etc.	$155 billion
Base Case	Areas with existing agreements remediated to the necessary extent. Other contaminated areas presently remediated to support a mixture of all types of land use.	$160 billion
Recreational	Areas with existing agreements remediated to the necessary extent. Other contaminated areas remediated up to allow limited recreational use. Mixture of containment in place and removal actions.	$162 billion
Residential / Agricultural	Areas with existing agreements remediated to the necessary extent. Other contaminated areas remediated to allow residential and/or agricultural use.	$166 billion
Maximum Clean-up	Existing agreements changed to remediate most sites to allow residential and/or agricultural use. Other contaminated areas remediated to allow residential and/or agricultural use.	$284 billion

Source: DOE, 1996c, section 6.1.

[1] These costs are for the five most costly sites only - Hanford, Savannah River Site, Idaho National Engineering and Environmental Laboratory, Oak Ridge Reservation, and Rocky Flats.

Chapter Two: Transuranic Waste Management

Overview of Transuranic Waste

Wastes contaminated with transuranic radionuclides like plutonium (that is, elements with atomic numbers greater than uranium) have been generated since the Manhattan Project. Prior to 1970, wastes contaminated with such materials were not subject to any special regulations other than very weak ones pertaining to low-level radioactive waste. As a result, they were commonly disposed of along with low-level waste and chemical waste in a variety of ways, including burial in pits and trenches and, in the case of liquid wastes, direct dumping onto the ground and injection into wells.

In 1970, the Atomic Energy Commission, predecessor of the Department of Energy, created a new classification of waste, called transuranic (TRU) waste. A fire at its Rocky Flats Plant located 16 miles upwind of Denver in 1969 resulted in high levels of plutonium contamination. It also required dismantlement of several buildings. The large volume of waste resulting from the clean-up and the fact of the fire so close to Denver created strong political pressure to move the waste out of Colorado and the AEC promised to do so. As of April 30, 1970, transuranic waste was required to be segregated from other waste and kept in such a fashion that it would be readily retrievable.[50]

Transuranic waste from Rocky Flats was shipped to the Naval Reactor Testing Station in Idaho (now known as the Idaho National Engineering and Environmental Laboratory, referred to in this report as the Idaho Lab) beginning in 1954. Shortly after the 1969 fire at Rocky Flats, then-Senator Frank Church of Idaho pressured Atomic Energy Commissioner Glenn Seaborg into agreeing to remove all transuranium-contaminated waste from Idaho by 1980.[51,52]

Emerging from this long history, are three broad categories of transuranic wastes to be managed:

1. **Buried TRU waste:** This is waste containing TRU elements in relatively high concentrations. Most was buried before 1970.

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[50] AEC, 1970 and IDB, 1990, page 75.

[51] As cited in Lipschutz, 1980, pages 118-119.

[52] Lipschutz provides a description of how the Rocky Flats fires led to a decision to develop a waste disposal facility for transuranic wastes in an abandoned salt mine under Lyons, Kansas. In 1971, the Atomic Energy Commission announced that permanent disposal of transuranic and high-level wastes would soon commence at the Lyons site, which was considered by the AEC to be fully developed, safe, and suitable. The AEC was so confident that it requested the full estimated cost of the repository for fiscal year 1972 during congressional testimony. Independent investigations, however, soon concluded that the site was grossly inadequate and by 1973, the project was abandoned. A year later, in 1974, the Waste Isolation Pilot Plant project was established to fulfill the promise to Senator Frank Church, and the selected location was east of Carlsbad, New Mexico. See Lipschutz, 1980, Chapters 4 and 5.

2. **TRU contaminated soil:** This is soil with relatively high concentrations of TRU elements. Some TRU contaminated soil is due to dumping of transuranic liquid wastes directly into the soil at some nuclear weapons plants. Some is due to dispersal of TRU elements from buried waste to the soil around it.
3. **Retrievably stored TRU waste:** Some "retrievably stored" waste is kept above ground in buildings and hence relatively easily retrievable, while other "retrievably stored" waste was buried in a manner that would supposedly lend itself to retrieval. However, such hopes have not been uniformly realized because of the poor manner of waste packing or burial.[53]

The most recent DOE estimates of TRU waste volumes are presented in Table 9.

Buried TRU waste and TRU contaminated soil (which we will call "TRU soil" for short) has been given a low priority by DOE. Most TRU waste management expenditures have been on the third category, retrievably stored waste, and have been associated with a decision to build a deep underground repository for this waste (the Waste Isolation Pilot Plant, or WIPP) near Carlsbad, New Mexico. However, it is generally acknowledged that buried wastes and highly contaminated soil pose the greatest short-term and medium-term risks of polluting groundwater and even larger volumes of soil than currently exist. At a meeting with stakeholders on July 12, 1997, DOE acknowledged that the focus on stored transuranic waste and WIPP was due to the fact that political realities had to be taken into account.[54] Presumably, this meant the DOE had to follow-up on the promises and legal strictures that followed the creation of TRU waste in 1970. One of those promises was made to the state of Idaho, where the waste were taken for "temporary" storage to be taken to a repository by 1980.

Among the health and environmental risks from buried TRU waste, the pollution of soil and groundwater is arguably the most serious, at least on a time frame of the next several generations, during which time institutional controls are expected to be relatively more effective at restricting access to waste retrievably stored on-site. For this reason we focus our analysis on buried TRU and TRU soil. Then we will present recommendations on TRU waste that will integrate management of all three categories.

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[53] Even though all TRU waste generated after 1970 is supposed to be retrievably stored, some post-1970 TRU waste has been declared to be in the "buried" category. Several sites now claim that some types of storage originally designated as "retrievable storage" are, in fact, not readily retrievable. We will discuss only wastes that are generally still considered retrievable under this category and analyze wastes that are not readily retrievable along with buried TRU wastes.
[54] IEER, 1997a.

Table 9: Official Estimates of Transuranic Waste Volumes at Major Sites

Site	Retrievably Stored TRU Waste[a]	Buried TRU Waste[a]	TRU-Contaminated Soil[b] Associated with Solid Waste	TRU-Contaminated Soil[b] Associated with Liquid Waste
Hanford	11,200	63,000	45,400	32,000
Idaho Lab	39,500[c]	57,000	56,000 to 156,000	no estimates
Los Alamos	11,000	14,000	1,000	140
Lawrence Livermore	230	0	no estimates	
Mound	274	0	0	288
Nevada Test Site	616	0	6,000 contaminated to greater than 10 nanocuries per gram; 170,000 contaminated to greater than 1 nanocurie per gram	
Oak Ridge	3,160	6,600[d]	at least 12,000 to 60,000	1,000 to 35,000
Rocky Flats	1,870	0	13,600	no estimates
Savannah River Site	6,550[c]	4,900	38,000	no estimates
West Valley	522	1,400	no estimates	

Notes to Table 9:
All volumes in cubic meters.
[a] From Integrated Data Base Report-1995, Rev. 12, December 1996 (IDB). Volumes include contact- and remote-handled, and mixed and non-mixed TRU waste, through end of 1994.
[b] Some TRU soil meets DOE's 100 nanocurie per gram definition of TRU waste, some does not. Sites have not reported TRU soil volumes according to a standard definition. The uncertainty associated with the amounts and concentrations of transuranic contaminated soil is very high. Since the most recent Integrated Data Base Report does not list soil volumes, these numbers are taken from past Integrated Data Base reports that did list TRU soil. "No estimates" means we were not able to find these values in past Integrated Data Base reports and should not be taken to imply there is no contaminated soil. Nevada Test Site soil volumes taken from DOE Nevada, 1995, page 2-15 (we assumed the depth of contamination to be 0.12 meters (page 2-31)).
[c] Retrievably stored TRU wastes at these sites are mixed with wastes that were defined as TRU waste under an older definition (waste with greater than 10 nanocuries per gram of TRU radioactivity was considered TRU waste until 1984, when DOE changed the limit to 100 nanocuries per gram). The Idaho Lab estimates that 39,500 cubic meters of TRU waste is mixed with approximately an additional 28,000 cubic meters of waste containing between 10 and 100 nanocuries per gram (IDB Revision 8). At the Savannah River Site there appears to be about 9,000 cubic meters of waste in the retrievable TRU storage area (SRS, 1994). The 6,550 cubic meter figure listed in the table is the portion estimated to contain above 100 nanocuries per gram.
[d] IDB Rev. 12 reports this value to be 176 cubic meters, although we have found no explanation for changing this number from the 6,600 cubic meters used in earlier Integrated Data Base reports. In fact, 6,600 cubic meters was cited by the site manager in his June 1996 submittal to the TRU Baseline Inventory Report. At least an additional 8,700 cubic meters of transuranic sludges were disposed of by mixing them with grout and injecting them into deep wells. In some years, the site reported this waste as "buried waste," but it is now reported as a separate category, "hydrofracture disposed waste." However, this large volume of waste has "disappeared" from the most recent Integrated Data Base Report

The risks arising from buried TRU waste and TRU soil are poorly understood for a number of reasons:

- data is lacking on burial location and radionuclide inventory for early waste;
- characterization of buried TRU and TRU soil has not been given priority;
- the mobility of transuranic radionuclides in the environment is uncertain; and
- modeling efforts have been poor and have not taken adequate account of existing data on migration of transuranic elements, in the soil, notably plutonium,.

In this case study, we examine the problems posed by the buried TRU waste and TRU soil at five DOE sites where the reported volumes of such waste are the greatest: the Hanford Reservation, the Idaho Lab, Los Alamos National Laboratory, Oak Ridge National Laboratory, and the Savannah River Site. This examination includes a critical review of the existing data on quantities of waste because we have found serious inconsistencies in much of the official TRU waste data. We also discuss the environmental contamination resulting from this waste and describe some of the efforts to deal with these problems. Finally, we will draw conclusions as to the nature of the problem and make a set of recommendations for TRU waste management.

We will also examine DOE's decision to focus most of its resources on the management and disposal of retrievably stored waste rather than on buried TRU waste and TRU soil and its consequences for short-, medium-, and long-term environmental protection.

We have not investigated TRU waste issues at the Nevada Test site or the Rocky Flats site, although indications are that contamination from transuranic radionuclides is a very serious problem at both sites. We discuss both briefly.

At the Nevada Test site, a 1995 study estimated the amount of plutonium-contaminated soil from weapons testing.[55] Five hectares (12 acres) of land is estimated to be contaminated to levels of 10 nanocuries per gram or higher, estimated to yield a total volume of 6,000 cubic meters of TRU soil.[56] One hundred and forty hectares (roughly 350 acres) of land is estimated to be contaminated to levels greater than 1 nanocurie per gram, estimated to yield a total volume of 168,000 cubic meters of TRU soil. Additionally, researchers at Lawrence Livermore and Los Alamos National Laboratories studying groundwater at the Nevada Test Site have presented findings that radionuclides, including plutonium, bind to small particles such as zeolites and clays ("colloids") that are ubiquitous in groundwater. The researchers concluded that "radionuclides can and do bind to colloids that then may be transported significant distances in the saturated zone."[57]

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[55] DOE Nevada, 1995, page 2-15.

[56] We have assumed an excavation of these areas to a depth of 12 centimeters (DOE Nevada, 1995, page 2-31).

[57] Kersting and Thompson, 1997.

At Rocky Flats, activities and accidents have resulted also in contamination of soil by TRU radionuclides. Experience at the site unfortunately seems to indicate that plutonium may be, contrary to long-standing official denial, mobile in the environment. Plutonium mobility also is thought to be increased because of hydrogeochemical mechanisms associated with saturated soil conditions, as occurred during a wet April and May 1995 at Rocky Flats.[58] Plutonium concentrations of up to 247 picocuries per liter in surface runoff during this period were reported by DOE.[59]

Serious concerns have been raised at the site as a result of DOE proposing that residual plutonium-239/240 levels of up to 651 picocuries per gram and 117 picocuries per gram of americium-241 would be allowed in the site "buffer zone" where activities such as farming and residential development would be likely to occur after active controls no longer exist.[60] A lapse of controls is highly likely, given the long half-life of plutonium-239. The Rocky Flats Citizen's Advisory Board has called for an investigation of these "Soil Action Levels" set by the site, which are roughly 16,000 times higher than plutonium fallout levels.[61] Also, the plutonium level is about 40 times the maximum set for remediation of Johnston Atoll and Rongelap, both contaminated by U.S. nuclear weapons testing.[62] In the absence of strict standards, DOE is proceeding in an *ad hoc* manner that is likely to compromise the health of future generations. It is also ignoring precedents in remediation programs elsewhere that were much more stringent, underlining the problems associated with proceeding without clearly-defined standards. In Chapter Five and in Appendix A we discuss the issue of clean-up standards.

A. Characteristics of Transuranic Waste

The term *transuranic* refers to elements with an atomic number[63] greater than 92 (the atomic number of uranium), which are essentially man-made elements.[64] The waste category defined by government regulations as transuranic waste (or "TRU waste") is more limited.[65] According to DOE's definition, TRU waste includes waste that contains transuranic elements with half-lives greater than 20 years (that is relatively long-lived

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[58] Litaor, 1996, pages 1144 and 1148-1149.
[59] Schonbeck, 1995.
[60] AFSC et al., 1997.
[61] Global plutonium-239/240 fallout is reported as 1.5 becquerels per kilogram, or about 0.04 picocuries per gram, in Litaor, 1996, page 1147.
[62] Bramlitt (1988) cites a remediation goal of 15 picocuries per gram.
[63] The atomic number is the number of protons in the nucleus of an atom; an element is defined by the number of protons it has. Isotopes of the same elements have the same number of protons but differing numbers of neutrons in the nucleus; they have the same chemical properties but different nuclear properties. Unstable nuclei emit radiation and are therefore called *radionuclides*.
[64] A few transuranic radionuclides occur in nature in extremely tiny concentrations. Their presence arises from the emission of neutrons by spontaneous fission of uranium isotopes and other nuclear processes that occur naturally at very low rates.
[65] DOE, 1988; EPA, 1989; Nuclear Regulatory Commission, 1988.

transuranic elements), in concentrations greater than 100 nanocuries per gram.[66] As a point of reference, the natural concentration of alpha-emitting radionuclides in soil (consisting mainly of uranium, thorium, and radium isotopes) is typically on the order of 0.01 nanocurie per gram.

When the TRU waste category was first created by the Atomic Energy Commission in 1970, it included all waste with concentrations of long-lived transuranic elements greater than 10 nanocuries per gram. DOE relaxed this definition by a factor of ten in 1984, in theory considerably reducing the volume of waste to be managed as TRU. However, neither the long-term cost or environmental and health consequences of this relaxation of the rule are clear as yet. Waste containing long-lived transuranic radionuclide concentrations of less than 100 nanocuries per gram are classified as "low-level" waste and put in shallow land burial sites. The ability of these sites to adequately contain waste for long periods of time is questionable and has not been carefully assessed. The change in definition has also created some new problems for the DOE weapons complex, since waste classified in the past as TRU but now belonging to the "low-level" waste category cannot easily be segregated from TRU waste as currently defined.

The Department of Energy order governing transuranic waste[67] does allow for some exceptions to the definition of transuranic waste given above. For example, site managers can require that other waste be managed as transuranic waste. As a consequence of this provision, waste containing radionuclides such as uranium-233 (which does not have an atomic number greater than 92), plutonium-241 (a beta-emitter with a half life of 14.4 years), and curium-244 (an alpha-emitter with a half-life of about 18 years), which do not meet DOE's definition of TRU waste but is of similar hazard, is sometimes managed as TRU waste.[68]

Table 10 lists data on the main transuranic isotopes of concern in TRU waste as well as uranium isotopes (shown for comparison).

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[66] One nanocurie is one-billionth of a curie. The Nuclear Regulatory Commission implicitly uses a half-life of 5 years. See the discussion of this inconsistency in Appendix B.

[67] DOE, 1988.

[68] Depleted uranium has not been treated as a TRU waste. Depleted uranium, an alpha emitter with a half-life of 4.5 billion years and a specific activity of 270 to 400 nanocuries per gram (depending on the chemical form and degree of depletion), has been declared a "Class A" low-level waste by the Nuclear Regulatory Commission despite its resemblance to TRU waste. DOE is preparing a Programmatic Environmental Impact Statement on how to manage over half-a-million tons of depleted uranium that it owns. This material is currently classified as a "source material" but for practical purposes is now a waste.

Table 10: Uranium and Transuranium Isotopes

Isotope	Half Life (years)	Specific Activity (curies per gram)	Main Mode of Radioactive Decay
Uranium-233	162,000	0.0095	alpha
Uranium-234	245,000	0.0063	alpha
Uranium-235	704,000,000	0.0000022	alpha
Uranium-238	4,460,000,000	0.00000034	alpha
Neptunium-237	2,140,000	0.000713	alpha
Plutonium-238	88	17.3	alpha
Plutonium-239	24,110	0.063	alpha
Plutonium-240	6,537	0.23	alpha
Plutonium-241	14.4	104	beta
Plutonium-242	379,000	0.0038	alpha
Americium-241	432	3.47	alpha
Americium-243	7,370	0.202	alpha
Curium-244	18	83	alpha

Note: Specific activity is the number of disintegrations of an isotope or a material over a given period of time (referred to as "activity") per unit mass of that isotope or material. Specific activity is expressed in units of becquerels per gram or curies per gram.

Transuranic radionuclides pose special risks. First, the half-lives of some of the most important ones are very long. For example, plutonium-239 has a half-life of over 24,000 years and neptunium-237 has a half-life of over two million years. Despite this, the radioactivity per unit of weight (the "specific activity") for these radionuclides is high enough for tiny quantities of the material to be dangerous. For instance, plutonium-239 is about 100,000 times more radioactive than natural uranium (which consists of a mixture of uranium-238, uranium-235 and a trace of uranium-234). One-millionth of an ounce (about 30 micrograms) of plutonium-239 deposited in small particles in the lung is very likely to induce cancer.[69] Further, alpha radiation is far more damaging per unit of energy deposited in the body relative to gamma and beta radiation.[70] The high concentrations of long-lived radionuclides in TRU waste require this waste to be disposed of in a geologic repository under Environmental Protection Agency rules similar to those for high-level waste (codified in 40 CFR 191).

TRU waste is often mixed with other radionuclides, such as fission products and tritium. Some of these fission products, such as cesium-137, emit strong gamma radiation. Some TRU elements, notably americium-241, also emit strong gamma radiation. In cases where waste has high levels of gamma radiation, it is not safe to handle them. Management of such waste must therefore be done remotely, and, accordingly, this waste is called "remote-handled TRU waste" -- defined as having an

[69] Makhijani, Hu, and Yih, eds., 1995, pages 99-102.

[70] Regulatory practice assumes that alpha radiation is twenty times more damaging per unit of energy deposited in the body than gamma and beta radiation, though the differences are organ-specific

external measured dose rate of more than 200 millirem per hour.[71] The majority of TRU waste, however, does not have high levels of gamma emitters, and is classified as "contact-handled."[72]

Another important characteristic of TRU waste is that much of it is contaminated with non-radioactive hazardous materials, notably organic solvents and toxic metals. Such TRU waste is known as "mixed" TRU. Examples include radionuclide-contaminated sludges from plutonium recovery, discarded materials contaminated with both solvents and radioactive materials, scintillation fluids (e.g., organic liquids such as toluene, which were used as part of a procedure to measure radioactivity), and discarded contaminated lead shielding. Organic compounds, including carbon tetrachloride, chloroform, tetrachloroethylene, and trichloroethylene, are also mixed with the transuranic-contaminated waste. According to a report of studies done at the Savannah River Site, organic and phosphate compounds can combine with plutonium in the soil and "have the greatest potential for mobilizing plutonium" under conditions typically found there -- that is "acidic sandy clay soils" in a humid area. [73]

The presence of considerable quantities of non-radioactive hazardous materials means that TRU waste must be managed both for its radioactive and for its non-radioactive hazardous constituents. The latter are regulated under the Resource Conservation and Recovery Act (RCRA). Remediation of hazardous waste disposal sites is regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) commonly called "Superfund."

B. Buried Transuranic Waste and Transuranic-contaminated Soil: Inventory and Historical Management Practices

1. Inventory

The Integrated Data Base Report, published annually by the Department of Energy, is the main compilation of data about radioactive waste of both military and commercial origin in the United States. Each year, locations, quantities (both volume and radioactivity content), and various other data are published by site for each radioactive waste classification.

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[71] IDB Rev.12, 1996, page 61.

[72] DOE's current proposed repository for TRU waste, WIPP, is limited to 250,000 cubic feet, or 7,080 cubic meters of remote-handled TRU waste, according to a 1981 agreement between DOE and the State of New Mexico (DOE Carlsbad, 1995, Volume 1, page 1-5). However, estimated volumes of remote-handled TRU waste have ranged from 27,000 cubic meters to over 51,000 cubic meters between 1994 and 1996. This fluctuation was due to the revisions in the estimates of remote-handled TRU waste from Hanford. DOE has not addressed the fact that the projected amounts of remote-handled TRU waste are far above the levels agreed to in 1981. It is pushing ahead with the repository without a new agreement and apparently without a re-evaluation of the impact of larger remote-handled waste volumes on overall repository capacity and performance.

[73] Towler, 1989.

Our review of these data revealed that, at many sites, the values given for the volumes, radioactivity, and kilograms of buried transuranic waste often vary from year to year in ways that do not always seem to have reasonable explanations. In general, these changes do not reflect new waste being buried or old buried waste being dug up, but rather appear to be the result of:

1. recategorization of waste containing between 10 and 100 nanocuries per gram from TRU waste to "low-level" waste,
2. realization that some "retrievably stored" waste is, in fact, not readily retrievable,
3. re-examination of old records, and
4. mistakes.

We will discuss these issues in detail as we consider site-by-site data. Table 11 shows the wide range of estimates of the potential buried transuranic waste and TRU soil at five main sites that IEER has complied from various data sources, including the Integrated Data Base Reports, historical records and reports, official submittals by site managers to various databases, and other sources of information (see the description of each site for details on these estimates). How these estimates will stack up against actual waste quantities cannot at this time be stated with much confidence.

Table 11: Ranges in Reported Values for Buried TRU Waste and TRU Soil

Site	Buried TRU Waste	TRU-Contaminated Soil[1] Associated with Solid Waste[2]	TRU-Contaminated Soil[1] Associated with Liquid Waste[3]
Hanford	63,000 - 192,000	45,400	32,000
Idaho Lab	57,000 - 65,000[4]	56,000 - 156,000	no estimates[5]
Los Alamos	0 - 18,000	1,000 - 4400	140
Oak Ridge	176 - 15,000	12,000 - 1,600,000	up to 35,000
Savannah River	4,500 - 33,000	38,000	no estimates[5]

Compiled from various sources and various years, as described in the individual descriptions of the sites. Note that except for two entries in the table (56,000 - 156,000 and 12,000 - 1,600,000), the sources did not list a range of values. That is, the sources used to compile this table listed only one number as the volume, and the ranges shown in this table reflect variations from report to report.

Notes:

All volumes are in cubic meters.

1. Some of the TRU-contaminated soil meets the 100 nanocurie per gram definition of transuranic waste, some does not. As mentioned in Table 9, the uncertainty in estimates of the amounts and concentrations of transuranic contaminated soil is very high.
2. TRU contaminated soil associated with solid waste is that which became contaminated as a result of pit and trench disposal of TRU waste.
3. TRU contaminated soil associated with liquid waste resulted from dumping of TRU contaminated liquids into the soil.
4. Some TRU waste buried at the Idaho Lab was dug up during 1974-1978 and placed on storage pads, accounting for some of the difference in reported volumes. See discussion of Idaho Lab below.
5. "No estimates" means we were not able to find these values and should not be taken to imply there is no contaminated soil.

In the Waste Management Programmatic Environmental Impact Statement (EIS), DOE evaluates options for treatment and storage of retrievably stored TRU waste. It does not consider buried TRU waste, which are under the scope of DOE's Environmental Restoration program. Initially, DOE agreed in court to publish an integrated analysis of both stored waste and "environmental restoration waste" but DOE has since abandoned the "environmental restoration" component.[74]

The Waste Management Programmatic EIS presents an incomplete and misleading presentation of TRU waste in the DOE complex. In Appendix B of the Programmatic EIS, DOE compares the current plus 20-year projected inventory of retrievably stored TRU waste (132,000 cubic meters) to "Environmental Restoration" TRU waste (80,000 cubic meters).[75] However, the TRU "Environmental Restoration" waste mostly consists of decontamination and decommissioning waste: 65,000 cubic meters from Savannah River Site, 1,800 cubic meters from Hanford, and 1,500 cubic meters from Oak Ridge. The only buried waste reported in the 80,000 figure is 9,700

[74] See discussion in Chapter 1.
[75] DOE, 1997b, page B-19.

cubic meters for the Idaho Site.[76] As noted in Table 9 and Table 11, the volume of buried TRU waste and TRU soil is much greater than the volume currently in retrievable storage. DOE's failure to even list the buried TRU waste and TRU soil in this "Programmatic" EIS, never mind analyze their environmental impacts, is a glaring oversight.

IEER filed a Freedom-of-Information Act request to DOE to determine the methodology by which TRU buried waste numbers are being generated and how it sets guidelines for assuring that data was of good quality. Specifically, we asked for "DOE guidelines to site managers for providing reliable and uniform quantitative information on transuranic waste" to the Integrated Data Base Reports. Aside from some information about measurement of TRU waste currently being generated, which is irrelevant to estimates of volumes of historically buried waste, we did not get any information that was responsive to this part of our request.

The enormous variances in data from one document to the next and from one year to the next, without explanation and apparently any documentable method, leads us to conclude that DOE's process of generating "estimates" of buried TRU waste is more akin to throwing darts than to any scientific estimating process. We are open to revising this conclusion should DOE provide us with explanations of the discrepancies that we have documented.

2. Historical Management Practices

a. Burial of transuranic waste

Transuranic waste consists of highly-contaminated rags and coveralls, laboratory equipment, metal, filters, glass, absorbed or cemented liquids and sludges, unabsorbed liquids and sludges, and tools contaminated with transuranic elements during reprocessing, machining, and handling plutonium for use in nuclear warheads. Some TRU waste also resulted from clean-up after accidents.

TRU waste has been put in cardboard boxes, metal drums, and wooden crates; sometimes it was wrapped in plastic. The containers were not designed as a means of isolation from the environment, but were simply used as a means of transporting the waste from one location to another. As one might expect, the waste containers have deteriorated over time; many have simply disintegrated. As a result, there is now TRU contamination of soil in and around the pits and trenches. In some cases, groundwater beneath burial pits and trenches is also contaminated with transuranic elements.

[76] Interestingly, the 9,700 cubic meter figure is for final, treated volume of the approximately 57,000 cubic meters of TRU waste estimated to be buried at the site. All other TRU volumes reported are the existing volumes, not the volumes after treatment.

For over 25 years before the Atomic Energy Commission's 1970 directive requiring "retrievable storage," solid waste containing transuranic elements had been buried along with low-level waste in shallow, unlined burial trenches and pits. However, on their own initiative, some sites did segregate transuranic waste (sometimes referred to as "alpha-waste" or "alpha-contaminated waste") from other waste. For example, at the Idaho Lab, transuranic waste and "low-level" waste were mixed together when the disposal area was first established in 1952. After several years, transuranic waste was segregated and generally placed in large, deep "pits," while low-level waste was generally placed in long, narrow, and somewhat more shallow "trenches."[77]

Due to the varied practices at individual sites before 1970, and to some extent even after that, identification of buried TRU waste areas is a complicated issue. The ability to identify certain areas of the burial grounds or certain areas of trenches and pits as containing buried TRU waste is a key factor in estimateing the alternatives and costs for managing the buried TRU waste. However, because DOE's distinction between pre-1970 and post-1970 transuranic waste legitimizes leaving older buried transuranic waste in the ground, there is minimal incentive to characterize the burial grounds with respect to TRU waste. The main exception to this is the Idaho Lab, which is at least undertaking a serious effort to study its buried TRU waste.

b. Transuranic-contaminated soil

Some soils mixed with TRU waste have become contaminated as a result of the degradation of waste containers. Rainwater, snowmelt, and rise of groundwater levels in the pits and trenches have all contributed to the leaching and increased mobility of transuranic radionuclides as well as other contaminants in the waste.

In addition to burying solid waste, transuranic liquids and sludges were directly dumped onto the ground or injected into wells. At Hanford, the Idaho Lab, Oak Ridge, Los Alamos, and Savannah River Site liquid waste containing transuranic elements was spilled on or pumped into the ground. For example, an estimated 32,000 cubic meters of soil was contaminated during liquid disposal practices at Hanford, containing an estimated 190 kilograms of transuranic elements.[78] Dumping of liquids to the ground was believed at the time to be a safe practice since it was thought that the upper layers of soil would filter and trap a large portion of the radioactive contaminants. However, in some places, TRU elements have readily contaminated the groundwater, moving thousands of times faster than predicted by models.

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[77] Arrenholtz and Knight, 1991, page 2

[78] DOE Richland, 1987, page A.22. This is equivalent to a concentration of TRU elements of roughly 4 micrograms per gram of soil. (Hanford uses a soil density of 1.8 grams per cubic centimeter, which yields a total weight of the contaminated soil of about 58,000 metric tons). If all the transuranic material were plutonium-239 (which has an intermediate specific activity among the common TRU radionuclides in TRU waste), the average concentration of radioactivity would be somewhat in excess of 200 nanocuries per gram.

Another disposal practice was used at Oak Ridge, where two facilities were used to inject a mixture of "low-level" liquid waste and transuranic sludges along with grout into 700 to 1,000 foot deep formations by a process known as "hydrofracturing." It was believed that the grout would form thin, solid sheets in the subsurface to which the contaminants would bind. However, monitoring wells have shown that radionuclides have migrated from the grout sheets and are present in groundwater, both in the formations in which the injections took place as well as in overlying formations.[79]

The volume of TRU soil is potentially much larger than the volume of either retrievably stored or buried TRU waste, as shown in Table 11. However, there is simply insufficient reliable data to be able to estimate how much total soil is contaminated to limits greater than 100 nanocuries per gram or even 10 nanocuries per gram. We also do not know the total amount of transuranic radionuclides present in contaminated soil.

The lack of information on TRU soil was apparent in the Integrated Data Base Reports. In most years, the entries for TRU soil were essentially all "unknown," "no data submitted," or "not applicable" -- making this part of the Database practically worthless. Moreover, there was no uniform definition given in the Integrated Data Base regarding what the sites should report as transuranic-contaminated soil. In 1996 DOE stopped reporting information on transuranic contaminated soil in its Integrated Data Base. It has not published any useful information or guidelines for defining the criteria under which it would resume reporting TRU soil estimates. And it has not undertaken systematic surveys and sampling to characterize the TRU soil problem.

This lack of understanding as to the quantity and character of TRU soil contamination is especially troublesome as it comes seventeen years after the DOE made a confident statement that

> the problem of transuranic contaminated soil at these specific sites [SRS, Hanford, Idaho Lab, Los Alamos, Oak Ridge, Rocky Flats, and Mound Lab in Ohio] is well defined and the site contractors have considerable knowledge about the contaminated areas. The information submitted by these contractors and compiled here will serve as a foundation for planning remedial actions, and supports decontamination process development.[80]

DOE should conduct a thorough investigation as to the basis of this report and the subsequent collapse of the content of this 1980 statement. As we have discussed, DOE has reported a wide variety of numbers in the years between 1980 and 1995. By December 1996 (when the most recent Integrated Data Base was published), DOE seems to have thrown up its hands and stopped reporting on the TRU soil quantities. Revision 12 of the Integrated Data Base Report does not even report that quantities are unknown. The category of TRU soil has vanished from DOE's catalog altogether.

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[79] ORNL, 1987, Appendix A.
[80] Arnold, 1980, page 19.

C. DOE Management of Transuranic Waste

1. "Retrievably Stored" Wastes that Aren't

The 1970 AEC requirement that TRU waste be stored so that it is relatively easily retrievable has not been carefully and uniformly followed. At some sites, waste that was supposed to be to "retrievable" were mixed with cement, packed into containers and buried in stacks under several feet of dirt. Some of this buried waste that was supposedly "retrievably stored" have recently been recategorized by site managers as "buried waste" -- that is, as non-retrievable buried waste. At Oak Ridge, 350 cubic meters of transuranic waste generated between 1970 and 1984 have been recategorized as buried waste. In the 1996 submittal to the Baseline Inventory Report, the Oak Ridge TRU program manager explained that "by today's standards" the waste is not readily retrievable.[81] And at the Savannah River Site, TRU waste put into "retrievable storage" between 1970 and 1974 were recategorized as "pre-1970 buried TRU" in 1994.[82]

Some sites (Idaho Lab, Los Alamos, and Savannah River Site) have been taking some post-1970 retrievably stored transuranic waste out from underneath their dirt cover, placing them in covered areas. This finally puts the storage of these wastes in compliance with the intention of the Atomic Energy Commission's 1970 directive. The ineffectiveness of DOE management of TRU waste is shown by the fact that these removal actions are being taken in order to comply with Resource Conservation and Recovery Act (RCRA) regulations, not DOE Orders.[83]

The tangled history of TRU waste classification and related problems has also resulted in an artificial bureaucratic separation in TRU waste management. Currently, the Department of Energy's Office of Waste Management is responsible for the transuranic waste in retrievable storage, while the Office of Environmental Restoration is responsible for transuranic waste generated before 1970. Thus, the twists and turns over the decades of a faulty waste classification system has given rise to a flawed bureaucratic structure for TRU waste management. Moreover, DOE's entire management of high-level and transuranic waste is segregated into two distinct bureaucracies. The WIPP repository in New Mexico for TRU waste is under DOE's Office of Environmental Management, while the high-level waste repository for high-level military waste is being developed under the Office of Civilian Radioactive Waste Management. Such bureaucratic compartmentalization hampers coordination of efforts to respond to health and environmental risks, increases costs, and tends to create inconsistencies in approaches to managing hazards that are by their nature quite similar.

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[81] ORNL, 1996a.
[82] SRS, 1994.
[83] RCRA applies to these wastes because they also contains hazardous materials regulated under RCRA.

2. Redefinition of Transuranic Waste: from 10 nanocuries per gram to 100 nanocuries per gram

The change in the definition of TRU waste has given rise to serious waste management problems. From 1970 until 1984, waste containing more than 10 nanocuries per gram of long-lived transuranic elements was stored as TRU waste.[84] Distinctions between waste containing 10 to 100 nanocuries per gram and waste containing greater than 100 nanocuries per gram were not required. If the reclassification is to have any technical meaning for waste management, the wastes containing between 10 and 100 nanocuries per gram of long-lived TRU elements must now be separated from those having more than 100 nanocuries per gram. Under the post-1984 scheme, the former would be classified as low-level waste, and the latter as TRU waste.

However, sampling and reclassifying is a difficult and expensive process because TRU wastes are highly heterogeneous, containing a variety of radionuclides as well as non-radioactive hazardous materials. The Savannah River Site is currently assaying its TRU waste to separate "low-level" waste. Under the old definition, the site had 9,000 to 10,000 cubic meters of TRU waste. It plans to reclassify an estimated 28% of this amount as low-level waste. However, an estimated 90% of the site's TRU waste is "mixed waste" (i.e., it contains radioactive and hazardous contaminants) and as such "does not currently have an identified treatment and/or disposal plan at SRS."[85] One indication that reclassification may not be worth the time and expense is provided by the Idaho Lab, which manages its waste classified as TRU waste under the 10 nanocurie per gram definition along with waste that qualifies under the 100 nanocurie per gram definition. Current plans call for these wastes to be treated together, if the Advanced Mixed Waste Treatment Facility is built at the site.[86]

3. 1987 Defense Waste Management Plan for TransuranicWaste

The Defense Waste Management Plan, issued in 1987, outlined the approach that still essentially guides the DOE Transuranic Waste Management Program. It is now known as the "National Transuranic Waste Management Program." DOE's objectives, as set out in the Defense Waste Management Plan, are to:

1. Establish procedures and facilities to dispose of newly generated transuranic waste routinely, safely, and effectively;
2. Begin certification and disposal of stored transuranic waste by funding processing facilities and pursuing the Waste Isolation Pilot Plant (WIPP);

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[84] The limit of 10 nanocuries per gram was "based upon then upper range of concentrations of Ra-226 in the Earth's crust." Lakey et al., 1983, p. 39.
[85] SRS, 1996d, page 9.
[86] DOE Idaho, 1997.

3. Monitor the buried waste and contaminated soil, take remedial actions as necessary, and periodically re-evaluate the safety of the waste. This is supposed to comply with CERCLA and NEPA.[87]

These are fine sounding intentions. However, in regard to the crucial third point, which involves quantities of buried TRU and TRU soil that are larger than the retrievably stored TRU waste, they do not appear to be backed up by any operational plan and real resources to implement it. For instance, there are no criteria to determine how frequently and by what procedures buried TRU and TRU soil will be monitored. Nor are there clear criteria as to when remedial actions will be triggered or how compliance with CERCLA and NEPA will be achieved. Finally, the failure over the last quarter of a century to develop technologies to deal safely and efficiently with buried TRU waste and TRU soil means that in many or most cases, remedial actions cannot be implemented if and when they are determined to be necessary. This is best exemplified by the failure of the Pit 9 project at the Idaho Lab, discussed in detail in this case study.

DOE's focus has been on part of the second item in the above list: building the WIPP repository and disposing of stored TRU waste in it. The third item makes clear that repository disposal is not to be considered seriously for buried TRU waste and TRU soil. Rather, these are to be monitored and remedial action taken if needed. But even this low level of commitment has not been maintained. Indeed, we still do not even know how much buried waste there is, despite the fact that it has been contaminating groundwater at several sites.

The buried transuranic waste component of the Defense Waste Management Plan (leaving the waste as is, with monitoring) is premised on the assumption that it is satisfactory to manage the TRU waste generated before 1970 in a far more lax manner than wastes that were put into retrievable storage after that date. The arguments used for claiming the soundness of lax management of buried TRU waste have included the following:

1. The total volume of buried transuranic waste is greater than the volume of stored waste, but contains only a small fraction of the radioactivity.
2. The behavior of plutonium and other TRU radionuclides in the environment is characterized by strong adsorption to soil particles or sediment.
3. Techniques for greater confinement of waste can be implemented should the need arise.

Our research shows that these arguments are not based on sound data and, indeed, that such reliable data as exists indicates that DOE's premises for giving low priority to buried TRU waste and TRU soil are wrong. We will examine these points for every one of the five sites.

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[87] DOE, 1987.

Site-by-Site Volume and Radioactivity Inventories

A. Hanford

Main Points

- According to available data, Hanford has a greater volume of buried waste than any other DOE site and a very large, but as yet undetermined, volume of transuranic-contaminated soil.
- An estimated 540 kilograms of plutonium from solid and liquid wastes are currently in the burial ground areas.
- The currently estimated volume of buried waste and contaminated soil are almost 12 times as much as the TRU waste in retrievable storage at Hanford. The volume of Hanford buried TRU waste and TRU soil alone would be enough to fill about 80% of the proposed Waste Isolation Pilot Plant repository for TRU waste.

Transuranic solids and liquids were disposed of mostly in the "200 Area" of the Hanford Reservation.[88] The 200 Area is split into "200-East" and "200-West." It contains six chemical processing plants, more than 250 support and research buildings, 177 high-level waste storage tanks[89], most of Hanford's waste disposal sites, and 100 hectares (roughly 250 acres) of contaminated surface soil. The 200 Area is one of the most contaminated sites in the world.

1. Disposal of Solid Transuranic Wastes

a. Burial practices

Large volumes of solid waste have been buried in the 200 Area. Eight sites have been identified that contain significant quantities of transuranic waste, as shown in Table 12. These 200 Area sites contain an estimated 340 kilograms of plutonium.

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[88] DOE Richland, 1987, page A.24.
[89] See the Hanford High Level Waste Tanks case study in this report.

Table 12: Buried TRU Waste Sites in Hanford 200 Area

Site Number	Waste Volume (cubic meters)	Soil Cover (cubic meters)	Plutonium in Waste (kilograms)
200 West			
218-W-1	9,000	7,400	94
218-W-2	23,000	24,000	130
218-W-3	25,000	55,000	68
218-W-4A	25,000	80,000	35
218-W-4B	6,800	23,000	9.9
200 East			
218-E-1	3,000	8,200	0.9
218-E-5A	2,200	1,300	1.4
218-E-12B	4,400	7,700	1.2
Total			
	98,400	206,600	340.4

Source: DOE Richland, 1987, page A.24.
Note to the table: The data in the full table in the EIS imply a waste density of 1.8 grams per cubic centimeter (excluding soil overburden), which is the figure in the EIS for soil density. This in turn implies that DOE is estimating that most of the TRU volume is contaminated soil because the density of waste is unlikely to be exactly the same as that of soil. SRS uses a figure for TRU waste drums of 0.125 grams per cubic centimeter (125 kilograms per cubic meter).

Some of these sites are listed as having averages of less than 100 nanocuries per gram, while others have considerably more than 100 nanocuries per gram.[90] However, if these wastes are treated as a unit, which they should be, given the uncertainties surrounding the characterization of each, the data in the EIS show that the entire waste volume in the areas listed contains more than 100 nanocuries per gram of TRU radioactivity.

Two types of burial structures were used for these wastes. Long trenches, typically 275 meters long by 6 meters wide by 6 meters deep, were used. Caissons were also used. Some caissons consisted of oil drums welded together end-to-end and sunk into the ground while some consisted of cylindrical sections of corrugated metal pipe measuring 7 feet in diameter and 10 feet high.[91]

[90] DOE Richland, 1987, pages A.21 and A.24.
[91] Rockwell Hanford, 1985, page 2-46.

These burial methods were also used for retrievable storage of post-1970 transuranic waste. Some caissons used as a means of "retrievable" storage were essentially the same design as the pre-1970, "non-retrievable" caissons; the only distinction being the year in which the wastes were put in the caissons. Such an arbitrary distinction is irrelevant for distinguishing between "non-retrievable" and "retrievable" TRU waste. Hanford, as well other DOE sites, should concentrate instead on examining the condition of all buried wastes to evaluate the possibility of retrieving them, regardless of whether or not they were produced before 1970.

The post-1970 trenches were improved by using plastic liner or asphalt pads on the bottom, and the wastes were covered with plywood and plastic sheeting before being backfilled. Waste drums were stacked in these trenches. These "retrievably stored" wastes are supposed to be removed from the ground and sent to a geologic repository.

b. Buried transuranic waste inventories

Various figures have been reported for the volumes and radioactivity of buried TRU waste at Hanford, as shown in Table 13 and Figure 2.

Table 13: Estimates of Hanford Buried TRU Waste

Source (date)	Volume, m^3	Mass of TRU elements[a], kg	TRU Radio-activity, curies	Comments
DOE (1983) (cited in DOE 1984)	192,200	377	820,100	Radioactivity is "alpha radioactivity."
DOE (1984)	92,100	350	29,230	Radioactivity is "alpha radioactivity." Footnote states "a detailed analysis...indicated that previous estimates of waste quantities were too high, and a reevaluation of the data to DOE Order 5820.2 criteria [i.e., the 100 nCi per gram definition] brought about a reclassification of a significant portion of the inventory...Waste is being reclassified as LLW."
Hanford Defense Waste EIS (1987)	109,000[b]	350	31,800[c]	Text states this is "waste volume" as opposed to waste volume plus soil volume.
IDB 5 thru 8 (1989-92)	109,000	350	29,230[d]	Footnote states "includes soils mixed with buried waste."
IDB 9 thru 12 (1993-96)	63,600	Not reported in these IDBs. However, IDB 9, page 106, lists a total of 352.6 kg of buried TRU elements for <u>all</u> DOE sites.	as stored: 114,500; decayed: 93,800	IDB 10 footnote states "upon retrieval of this waste, a significant amount of the soil will become contaminated and increase the volume of waste. The estimated waste and associated contaminated soil volume is 109,000 m^3." Higher radioactivity. Estimate of 352.6 kg is not credible (for example, the Idaho Lab alone now reports some 1,160 kilograms of TRU elements - see Table 15).

Notes to Table 13:

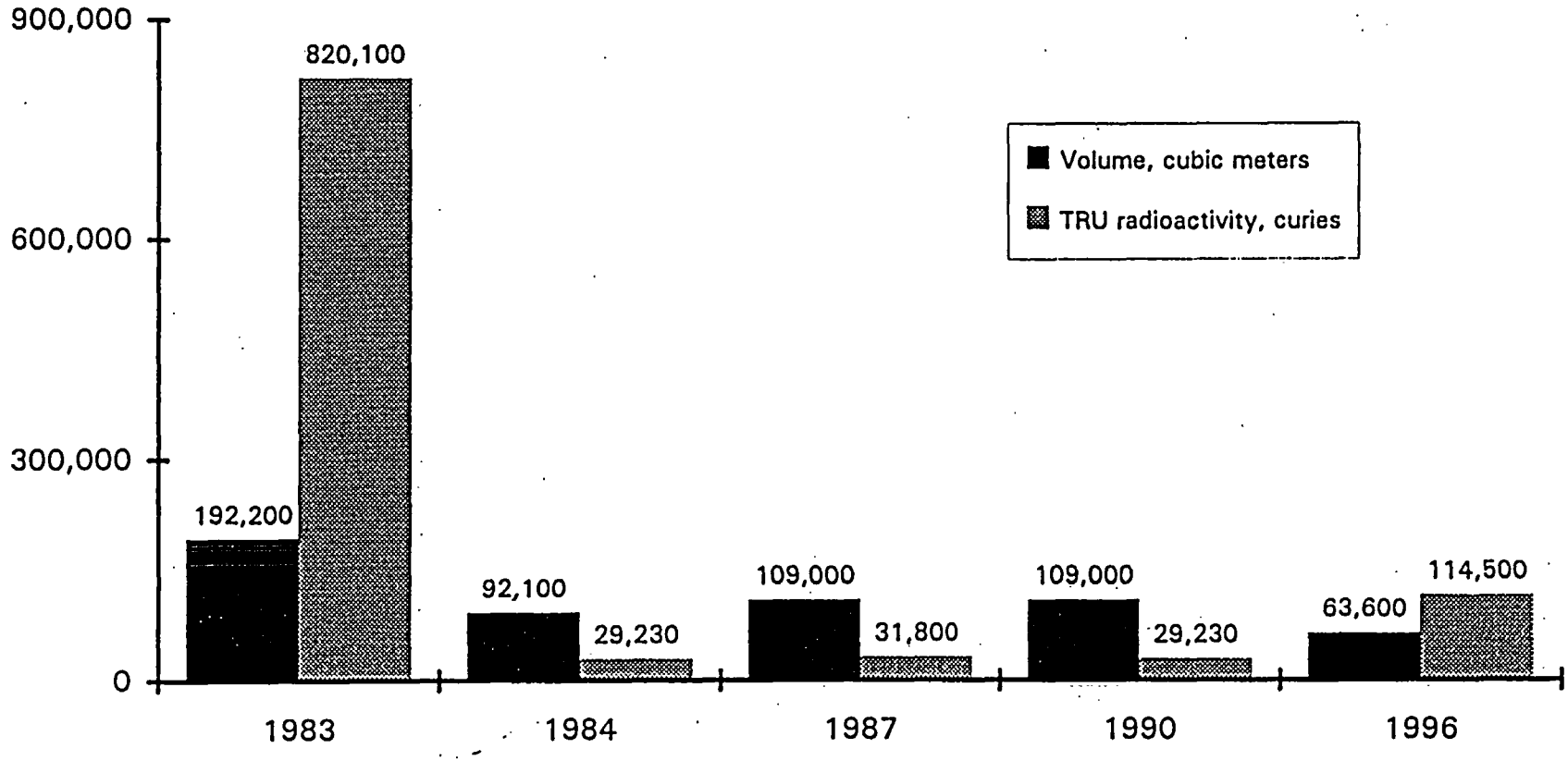
[a] Engineering support data for the Hanford Defense Waste EIS reports 350 kg of plutonium only. The IDB values in some years also list 350 kg, but state that this covers all TRU elements. Thus, it is unclear whether or not the 350 kg refers to plutonium alone or to all TRU elements.

[b] This value includes 9,080 cubic meters of waste containing an estimated 12 kg of plutonium that were buried in Area 618. Two sites have been reclassified as low-level waste sites, due to a discovery of an error that resulted in their being listed as containing 1,000 grams of plutonium -- later investigations concluded that there was actually only 1 gram of plutonium at each site. Thus, Hanford stated in the EIS that there was only 7,900 cubic meters of TRU waste buried in Area 618, containing an estimated 10 kg of plutonium (DOE Richland, 1987, page A.24). It is unclear as to whether or not the other estimates include TRU waste from Area 618.

[c] The support data for the Hanford Defense Waste EIS (Rockwell Hanford, 1985) states that radioactivity concentrations are based on maximum americium-241 buildup (plutonium-241, which has a half-life of 14.4 years, decays to americium-241).

[d] This value listed in IDB 5-7. IDB 8 only lists total radioactivity in the waste (TRU plus non-TRU).

Figure 2:
Variation in Data for Hanford Buried TRU Waste



The inconsistencies shown in Table 13 and Figure 2 are particularly troubling for several reasons:

- *TRU wastes may have been inappropriately reclassified as "low-level" waste*
  It appears that after DOE changed the definition of transuranic waste from 10 nanocuries per gram to 100 nanocuries per gram, approximately 100,000 cubic meters of transuranic waste was reclassified as "low-level" waste. These wastes were not dug up and re-measured before reclassification. We have not been able to determine whether or not records were accurate enough to allow the site to determine which 100,000 cubic meters of waste were no longer considered transuranic waste. It is unclear why wastes less than 100 nanocuries per gram would have been kept separate from wastes over 100 nanocuries per gram when, at the time they were disposed of, the only distinction of importance was whether or not they were over 10 nanocuries per gram.
- *Mass of radionuclides and radioactivities vary independently of each other*
  Apparently, the 820,100 curie estimate in 1982 was a major error, since current estimates are only about 10 percent of that value. Additionally, for eight years in between these estimates, a much lower radioactivity number was used. No explanation was given in IDB 9 when the radioactivity jumped from the previous 29,320 curies to 93,800 curies (decayed value). At the same time, the weight of transuranic elements stayed at 350 kilograms for some time. In IDB 9, all of DOE's buried TRU waste was estimated to contain 352.6 kilograms of TRU elements, which would imply that Hanford had 350 out of 352.6 kilograms of DOE's buried TRU wastes (that is, 99.3% of the total), which is, on the face of it, not credible. Such "data" gives the impression that DOE may either be publishing arbitrary numbers or, at best, numbers that only have an incidental relation to reality. It is difficult to escape the conclusion that DOE is not exercising even a minimal level of quality control over the TRU waste numbers that it publishes.
- *Mass of TRU elements may in fact only be mass of plutonium*
  The 1987 Defense Waste EIS states that 350 kilograms is the mass of plutonium in Hanford buried TRU waste. Since the Integrated Data Base Report also uses 350 kilograms, but states that it is the mass of all TRU elements, it is possible that the amount of other transuranic elements are not reported, unless the only TRU elements are the result of decay of plutonium isotopes, as in the case of decay of Pu-241 to Am-241.
- *Different reports list the same volume as representing "waste" as well as "waste plus soil"*
  The Defense Waste EIS lists the TRU "waste volume" as 110,000 cubic meters, while the Integrated Data Base Report Revision 10 (1994) states that the volume of waste is 63,600 cubic meters, but that upon retrieval, there will be a total of 109,000 cubic meters of TRU waste due to associated contaminated soil.
- *It is unclear how the 92,100 cubic meter estimate in Table 13 is derived from the previous estimates, or how it corresponds to later estimates.*
  We have found no other references to this number.

- *Contrary to the estimate of 7,900 cubic meters of TRU waste in area 618-11, containing 10 kilograms of TRU elements, DOE now states that the area contains only 276 cubic meters of TRU waste.*
  As explained in a footnote to Table 13, DOE stated in the 1987 Defense Waste EIS that area 618-11 contained 7,900 cubic meters of TRU waste.[92] However, in the 1996 Baseline Environmental Management Report, DOE states it will "retrieve all transuranic soil and buried waste" from this area, but the volume cited is only 276 cubic meters.[93]

Based on the available information, it appears that the figures reported for buried TRU waste at Hanford not only have considerable uncertainties, but that the 1984 redefinition of TRU waste has introduced additional uncertainties and randomness in the reporting of waste quantities. Some of the data are certain to be wrong. Indeed, they may all be wrong since, so far as we have been able to determine, the data do not appear to be based on any serious scientific investigation of the characteristics of the buried wastes. It is impossible at present to assess the scope of the buried waste problem, other than to say that is very substantial indeed, if there is anything like 350 kilograms of plutonium plus an unreported amount of other transuranic elements.

2. Transuranic-contaminated Soil Associated with Solid Wastes

The soil used as backfill in the pits and trenches may have become contaminated as the waste containers degraded and contaminants migrated into the surrounding soil. Revision 10 of the Integrated Data Base states that "upon retrieval of this waste [63,600 cubic meters], a significant amount of the soil will become contaminated and increase the volume of waste. The estimated waste and associated contaminated soil volume is 109,000 m^3." According to the IDB Revision 10 estimate, then, there are 45,400 cubic meters of soil mixed with the waste in the pits and trenches that would become contaminated upon retrieval.

Additionally, 230,000 cubic meters was used as "backfill" in the pits and trenches.[94] Some portion of this soil may also be contaminated with transuranic elements.

3. Transuranic-contaminated Soil Associated with Liquid Wastes

Liquid disposal has contaminated large volumes of soil with transuranic radionuclides. These soils are estimated to contain 190 kilograms of plutonium in a total volume of 32,000 cubic meters. This waste has been dumped in an area of 12,000 square meters (about 3 acres). Essentially all of the 32,000 cubic meters of TRU soil cited by

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[92] DOE Richland, 1987, page A.24.
[93] DOE, 1996c , page Washington-27.
[94] DOE Richland, 1987, page A.24.

Hanford as being contaminated by liquid waste is above the concentration (100 nanocuries per gram) that defines transuranic waste.[95]

Radioactive liquid wastes were discharged directly into shallow excavations and wells as a waste management practice. Several types of "systems" were used for shallow disposal of liquid wastes, such as cribs, ponds, trenches, ditches, and French drains. Basically, each involved discharging liquids to shallow excavations, which were filled with various materials, such as sand or gravel.

The rationale behind this practice was that the upper layers of soil would filter and trap a large portion of the radioactive contaminants. However, characterization of some of the TRU contaminated soil sites has shown that radionuclides have migrated down into the soil. TRU concentrations of up to 40,000 nanocuries per gram have been measured in the first 0.3 meters, concentrations up to 1,000 nanocuries per gram at depths of 2 meters. Soil as deep as 15 meters at some these sites contaminated with as much as 100 nanocuries per gram of TRU radioactivity.[96]

Another liquid waste disposal practice involved pumping liquids into deep wells. These "reverse wells" directly injected waste containing plutonium into the groundwater. The maximum concentration of plutonium-239 measured in 1994 was 2,670 picocuries per liter.[97] For reference, the EPA drinking water standard for gross alpha radioactivity is 15 picocuries per liter.[98]

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[95] Ibid, 1987, page A.22.
[96] Ibid, 1987, page A.21.
[97] DOE, 1996b, page D-24
[98] 40 CFR 141.15.

B. Idaho National Engineering and Environmental Laboratory (Idaho Lab)

Main Points

- A 1995 study, based on knowledge of waste-generating processes, estimates that there are 640,000 to 900,000 curies of TRU radioactivity and 1,163 kilograms of TRU elements in the burial grounds -- roughly nine to twelve times greater TRU radioactivity and 3 times greater mass of TRU elements buried at the Idaho Lab than previously thought.
- Dumping of transuranic wastes at the Subsurface Disposal Area was based on the premise that an arid climate would prevent water from reaching the deep groundwater. This assumption has been proven wrong by observation of contaminants originating in the burial ground in the Snake River Plain Aquifer, approximately 600 feet below the burial ground.
- The Idaho Lab initiated the first major attempt at remediating buried TRU waste in the DOE complex. The site hoped to excavate and treat some of the waste in Pit 9, which would help in designing remediation plans for the rest of the pits and trenches.
- The Pit 9 project is experiencing major technical and managerial difficulties, significant cost increases, schedule delays, and disputes over the terms of the contract.

TRU waste at the Idaho Lab consists of waste generated on-site (mainly from activities associated with its test reactor programs) and of waste shipped from other sites (notably the Rocky Flats Plant, where most of the plutonium pits for US nuclear warheads were manufactured). Most of the volume of transuranic waste at the Idaho Lab is from Rocky Flats. Two plutonium fires at Rocky Flats, one in 1957 and the other in 1969, resulted in increased shipments of TRU waste to the Idaho Lab. Indeed, as we have noted, the uproar over the latter was the occasion for creating the category of TRU waste.[99]

1. Disposal of Solid Transuranic Waste

The Radioactive Waste Management Complex (RWMC), in the southwestern part of the Idaho Lab, was established in 1952 for burial of solid radioactive waste. It contains the 36 hectare (88 acre) Subsurface Disposal Area where TRU waste was buried. The Radioactive Waste Management Complex also includes the 23 hectare (57 acre) Transuranic Storage Area, where "retrievably stored" TRU wastes are kept. Approximately 65,000 cubic meters of TRU waste was buried between 1952 and 1970.[100]

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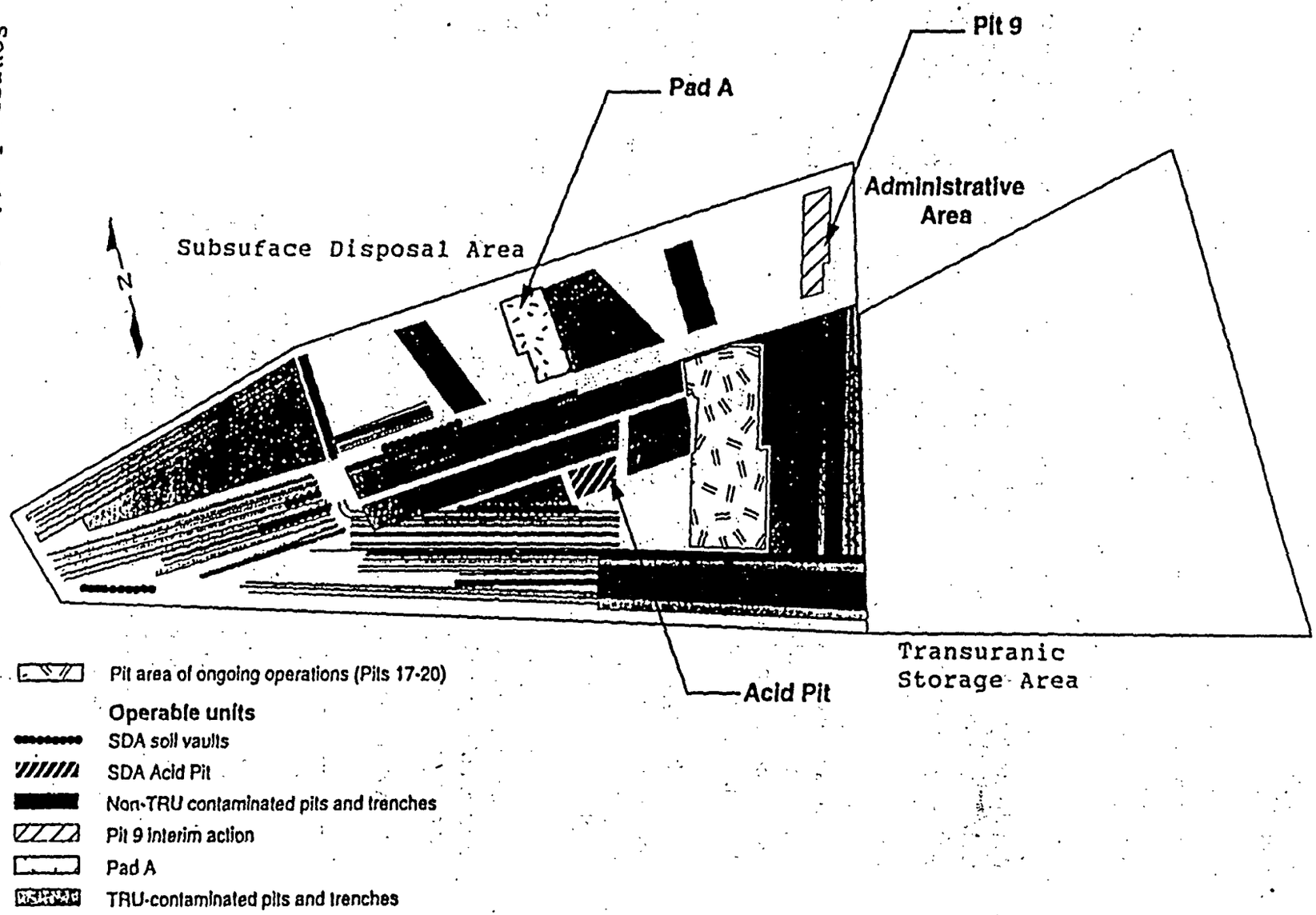
[99] The Environmental Defense Institute in Troy, Idaho, has done extensive work on issues relating to the Idaho Lab, and covers buried TRU issues in its "Citizens Guide to the US Department of Energy's Idaho National Engineering Laboratory" (Broscious, 1996).

[100] McKinley and McKinney, 1978, page ii. About 4,400 cubic meters of waste was dug up during 1974 to 1978 and placed in retrievable storage.

Figure 3: Idaho Lab Radioactive Waste Disposal Area



Source: Lockheed, 1995, p. 1-5.

When disposal of radioactive wastes at the Subsurface Disposal Area began in 1952, wastes were disposed of in trenches, which are long and narrow. The trenches vary in size, but range from 2 to 3 meters wide and from 300 to 600 meters long. They were generally excavated down to the basalt bedrock, 3 to 5 meters deep.

The first wastes buried in the trenches were mixed fission products from the Idaho Lab (then called the Naval Reactor Test Station). In April, 1954, the Rocky Flats, Colorado, plant began shipping transuranic-contaminated waste to the Idaho Lab.[101] Between April 1954 and November 1957, the Rocky Flats TRU waste was mixed in trenches with mixed fission product waste from the Idaho Lab.

In 1957, the volume of waste from Rocky Flats increased rapidly. It was decided that the Rocky Flats TRU waste would be buried in pits, which were larger and deeper than the trenches.[102] This decision indicates that at this time (if not before), the Idaho Lab realized that waste contaminated with large amounts of TRU elements needed to be more carefully managed. A more or less systematic segregation of TRU waste from other categories of waste was thus initiated at the Idaho Lab, though there were no formal or regulatory requirements. However, some non-TRU wastes (especially large items[103] and materials from clean-up of the SL-1 reactor accident at the Idaho Lab) were also disposed of in the pits, and TRU waste was sometimes disposed of in the trenches. TRU wastes were disposed of in pits 1-6 and 9-12, as well as in trenches 1-10, possibly in trenches 11-15, and, in lesser amounts, in trenches 16-54.[104]

The largest number of containers in the TRU pits are metal drums. Records indicate that 130,356 drums were buried in the pits. Other containers of TRU waste in the pits include 6,365 wooden boxes, 18,388 cardboard boxes, 1,280 "other" containers (such as plastic bags), as well as "loose" transuranic waste.[105]

Initially, the drums were stacked in the pits, but due to concerns about worker exposure, this practice was stopped around 1963.[106] Between 1963 and 1970 the drums were simply dumped into the pits from the edge. However, this practice was again reversed in 1970, the last year of burial of TRU waste at the Idaho Lab:

> A change in the storage philosophy occurred in 1970. The large volume of waste coming to the INEL from Rocky Flats, due to the fire, emphasized the need to conserve space at the burial

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[101] Lockheed, 1995, page 1-4.

[102] The pits are irregularly shaped, with surface areas ranging from 2,900 to 10,000 square meters and volumes of 9,700 to 30,000 cubic meters (Arrenholtz and Knight, 1991, page 6).

[103] From 1960-1963, the Idaho Lab received wastes from commercial operations and was also designated as one of two "interim" burial grounds for disposal of wastes from any Energy Research and Development Administration (a predecessor agency to the DOE) source. Some of this waste included 16 metric tons of reactor shielding from Kelley Air Force base, a 9 metric ton heat exchanger from Nuclear Engineering Company in Pleasanton, CA, and a carbon steel reactor vessel placed in Pit 9.

[104] Arrenholtz and Knight, 1991, p.3

[105] Ibid, p.18-19.

[106] Ibid, p.3

ground. When Pit No. 11 was opened, the drums were stacked in rows as they had originally been stacked in Pits No. 1 and 2.[107]

TRU waste drums, then, were stacked in the last two pits. The stacking facilitated the removal of waste several years later (1974-1978) and its placement in above-ground storage. Although dumping of drums reduced worker exposure initially, the greater difficulty of retrieving and processing these wastes will lead to far higher worker exposures and costs.

Quality of TRU Waste Inventory Data

While records that go back to the initial opening of the Subsurface Disposal Area exist for buried waste, they contain significant limitations. Complete information about waste was not always obtained before it was disposed. For example, one of the inventories used at the Idaho Lab is the Radioactive Waste Management Information System (RWMIS). Its usefulness for understanding the nature of the radioactive and hazardous inventory of the Subsurface Disposal Area is limited by some of the following problems described in 1995 by DOE's site contractor, Lockheed Idaho Technologies Company (now Lockheed Martin Idaho Technologies Company):

> For waste shipments before 1960, RWMIS has shipping record entries for only the Rocky Flats Plant waste, and those entries generally provide no quantitative information concerning the contaminants. Some textual descriptions are generic (e.g., plant waste) and do not provide insight into the actual contents of the waste. RWMIS contains very little information concerning nonradiological contaminants in the waste. The radionuclide listings in RWMIS have problems, such as (a) entries with only one radionuclide identified (e.g., Pu-239) although knowledge of the waste-generating process indicates that other radionuclides must also be present, (b) entries with only the element specified (e.g., uranium) with no designation of a particular radionuclide, (c) entries with only generic radioactivity terms [mixed activation products] and/or [mixed fission products] identified, with no designation of particular radionuclides, and (d) entries with only one fission product identified (e.g., Cs-137) although others must also be present.[108]

In order to support a remedial action program, site managers realized that a better understanding of the Subsurface Disposal Area inventory was needed. This inventory could then be used as part of a "baseline risk assessment" for the process that will determine how the burial area is remediated.[109] In 1995, the Idaho Lab developed a new inventory of contaminants in the Subsurface Disposal Area with an approach that was mainly based on the processes that generated the waste. This was supplemented by information from various reports, shipping records, databases, and nuclear physics calculations.

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[107] Card, 1977.

[108] Lockheed, 1995, pages xx-xxi.

[109] This process is outlined in the Comprehensive Emergency Response, Compensation, and Liability Act (referred to as CERCLA and also as Superfund). The process involves an investigation of the site (the "remedial investigation") as well as a study to determine the options for cleanup (the "feasibility study"). Based on these studies, a preferred alternative is suggested. After a comment period, a Record of Decision may be signed, which establishes the legally-enforceable remedial actions.

To date, this is the most comprehensive attempt by a DOE site to characterize the inventory of buried TRU wastes. Other sites have not undertaken such an effort. DOE should initiate similar efforts at other sites to try and develop scientifically defensible estimates of waste volume and radioactivity.

The results cannot yet be said to be definitive because the calculations have not been corroborated by measurements of the TRU content of actual waste samples drawn for the pits and trenches. Moreover, some of the data are incomplete. For instance, the shipping records for on-site generators of wastes buried at Subsurface Disposal Area were destroyed during previous "housekeeping" efforts; the study noted that the records could be reconstructed to "a limited extent."[110]

Despite the incompleteness and the uncertainties still present in the Idaho Lab re-evaluation of the TRU waste inventory, the results are instructive, especially with regard to DOE's TRU Program. The study indicates that a far greater amount transuranic radionuclides were disposed of than previously estimated. Table 14 and Figure 4 show a summary of Idaho Lab TRU data published in various years.

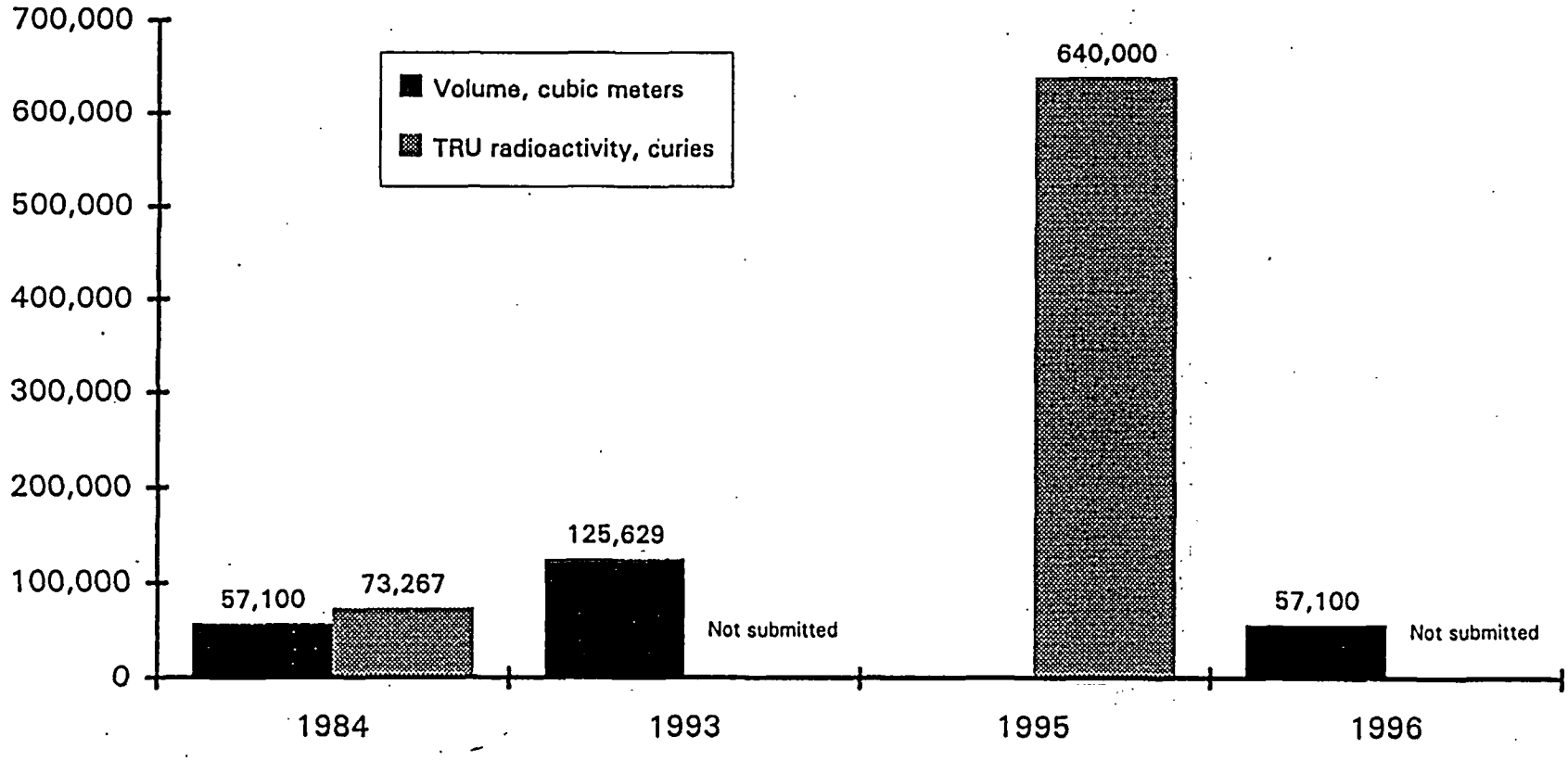
[110] Arrenholtz and Knight, page 34.

Table 14: Estimates of the Idaho Lab Buried TRU Waste

Date of Estimate, Source	Volume of waste, m^3	Mass of TRU elements, kg	Radioactivity of TRU elements, curies	Comments
1984 (DOE) and 1989-1992, (IDB 5-8)	57,100	357	73,267	Initial buried waste volumes were somewhat higher - about 5,000 m^3 retrieved during 1974-78.
1993 (IDB 9)	125,629	not listed in this revision	"no data available"	Increased volume may reflect inclusion of contaminated soil
1994 (IDB 10)	57,100	not listed in this revision	"INEL did not include isotopic compositions, so radioactivity for TRU radionuclides cannot be determined"	Reversion to old volume number
1995 (Lockheed Comprehensive Inventory Report)	not listed	1,146	640,000 to 900,000	Even the lower bound of this radioactivity estimate is far larger than earlier estimates of buried TRU radioactivity at all DOE sites - 125,000 curies was estimated in DOE 1987
1995 (IDB 11)	57,100	not listed in this revision	"INEL did not include isotopic compositions..."	
1996 (IDB 12)	57,100	not listed in this revision	"INEL did not include isotopic compositions..."	

Sources: DOE, 1984, IDB, 1985-1996 and Lockheed, 1995.
Note: Card (1977), gives a waste volume of 65,100 cubic meters; most IDB editions give 57,100 cubic meters. The difference may be at least in part due to retrieval carried out in the 1974-78 period. The last wastes that were buried (in Pits 11 and 12, from 1968-1970) were retrieved a few years later. 20,262 drums with a total volume of 4,397 cubic meters were retrieved from Pits 11 and 12 during 1974 through 1978 (McKinley and McKinney, 1978, page 6).

Figure 4:
Variation in Data for Idaho Lab Buried TRU Waste



DOE was aware for many years that the data it was using was not reliable. As the 1995 assessment by Lockheed noted, the information was general in nature and "the reliability of the information on the activities of the radionuclides has long been questioned."[111] Means of counting the radioactivity contained in the drums were not developed until 1964, and, for several years after that, shipping personnel did not use the results.[112] Further, acceptable techniques for measuring the radionuclide content of boxes were not available at Rocky Flats before 1978 -- eight years after the last of the Rocky Flats waste was buried.[113]

The uncoordinated nature of DOE data on TRU wastes is indicated by the fact that although the the Idaho Lab inventory of waste had been reassessed in detail by August 1995 at considerable expense and effort, the Integrated Data Base Report published in December 1996 did not include any of this new information.

Part of the Idaho Lab's comprehensive inventory includes new estimates of the plutonium, americium, and uranium buried at the Subsurface Disposal Area. These estimates were developed by Rocky Flats personnel based on material accounting calculations for the entire Rocky Flats Plant. The results from the plant-wide balance are shown in Table 15. The new estimates, which supposedly reflect "the best current thinking of both RFP and INEL personnel," are more than three times greater than the site's previously published mass of 357 kilograms of total transuranic elements.[114]

Table 15: Comparison of Estimates of TRU Mass in Idaho Lab Burial Grounds

Radionuclide	1992 DOE Integrated Data Base	1995 Lockheed Study "Best Estimate"
Plutonium-239	[a]	1,047
Plutonium-240	[a]	65
Americium-241	[a]	43
Total TRU	357	1,163[b]

Figures reported are in kilograms.
Sources: IDB, 1992, page 106 and Lockheed, 1995, Table S-2. Mass of radionuclides calculated from "Best Estimates" of the activities at time of disposal.
[a] The Integrated Data Base Report only listed the total mass of TRU elements. It did not report TRU mass by radionuclide.
b Includes 3.8 kilograms of plutonium-241 and 3.4 kilograms of neptunium-237. In addition, Lockheed's "Best Estimate" indicates there are 2,318 kilograms of U-235 and 323,529 kilograms of U-238 in the burial grounds.

These new, significantly increased estimates of transuranic radionuclides highlight the possibility that as other sites take a closer look (none currently have such plans in place) at their burial grounds, they may find some surprises. While the efforts at

[111] Lockheed, 1995, p.2-73.
[112] Ibid, 1995, p.C-4.
[113] Ibid, 1995, p.C-4.
[114] Ibid, 1995, p.C-3

the Idaho Lab have produced a better understanding of the inventory of transuranic radionuclides at the Subsurface Disposal Area, many questions about the risks that they pose remain, especially with regard to the physical and chemical forms of the TRU waste and the impact of associated non-radiological contaminants such as solvents and organics.

The findings at the Idaho Lab challenge one of key assumptions that has contributed to the lower priority that DOE has given to "buried" relative to "stored" transuranic waste. Prior to the re-evaluation of the Idaho Lab TRU waste inventory, DOE estimated the alpha radioactivity of buried waste and TRU soil to be about 147,000 curies, with about sixty percent of that being at the Idaho Lab. This was compared to the stored TRU alpha radioactivity of 4.8 million curies.[115] The comparison was misleading even then. In this 1987 study, DOE compared the alpha radioactivity in buried TRU waste with the alpha radioactivity of TRU stored waste that would be generated through the year 2013! Note that at that time, there were no plans to shut the reprocessing plants or the Rocky Flats plant nor were there plans to reduce nuclear weapons production activities below levels characteristic of the Cold War, so the projections through 2013 would have been quite significant.

A proper comparison, of course, would be to compare the alpha radioactivity in stored waste to that in buried TRU waste in the same year. According to the Integrated Data Base of 1989, the stored TRU waste in 1988 had an alpha radioactivity of 1.16 million curies compared to an alpha radioactivity of 122,000 curies for buried TRU waste.[116] Thus, buried TRU waste amounted to 10.5 percent of the alpha radioactivity of the stored waste around the time of DOE's misleading estimate.

The Lockheed survey showed the Idaho Lab total for the alpha radioactivity in buried TRU waste to be wrong by about an order of magnitude -- instead of the previously estimated 73,300 curies, the new range was 640,00 to 900,000 curies. Were there no more alpha radioactivity in buried TRU waste in the rest of the DOE complex, this figure alone would make buried TRU waste a long-term environmental threat comparable to or greater than stored waste. The quantity of alpha radioactivity is the same order of magnitude (or a factor of two lower perhaps) but the threat to the groundwater and other resources is greater because of the way in which the waste was disposed and the effort that it will take to remediate it.

Of course, given that there are large amounts of buried TRU waste at other sites, the total amount of TRU radionuclides in buried wastes will be far larger. From the data currently available about the nature of the TRU waste problem, we have no hesitation in saying the DOE has made a huge mistake in focusing its short-term efforts and most of its resources on disposing of stored TRU waste in WIPP and giving buried TRU waste and TRU soil a far lower priority. Despite the startling 1995 findings on the nature of transuranic waste at the Idaho Lab, DOE has not revisited its mistaken assumptions about

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[115] DOE, 1987, page 6.
[116] IDB 1989, pages 84 and 86

TRU waste management, despite having spent 31 million dollars on a Waste Management Environmental Impact Statement that was supposed to have been "programmatic" in its scope. The effort to pursue WIPP should be abandoned and the program focused on urgent threats.

2. Transuranic-contaminated Soil

There is an unknown volume of TRU soil associated with the buried waste at the Idaho Lab. Contaminated soil potentially includes the layer of soil that was placed at the bottom of some of the pits and trenches before they were filled with waste, soil used to cover the waste while the pits and trenches were open, and the soil used as a cover when the pits and trenches were finally closed.[117]

Soil has become contaminated as the waste containers deteriorate over time. Infiltration of water - from percolation of rain as well as flooding of the area - has accelerated the degradation of the containers and helped to mobilize contaminants in the waste. The burial areas were flooded several times (in 1962, 1969, and 1982) as a result of local runoff from snowmelt. These events have inundated some of the pits, and are thought to have contributed to the migration of radionuclides and hazardous contaminants from the pits to the underlying geologic strata and groundwater. The Subsurface Disposal Area, although not technically in a floodplain, is prone to flooding because it lies in a local depression.[118] Several flood control and diking projects have been undertaken, and the site is currently protected by a 4.5 meter dike.

A 1991 study estimated the upper limit of the amount of potentially contaminated soil as 60,000 cubic meters of underburden and an additional 112,000 cubic meters of soil that is mixed with the waste.[119] Thus, there is potentially a very large amount of transuranic-contaminated soil in the pits. In fact, the Initial Drum Retrieval (IDR) program was limited to Pits 11 and 12 because of high levels of "alpha contamination" that were measured. Examination of pits 6, 9, and 10 led to measurements of 500 "counts per minute alpha" to greater than 2,000,000 "counts per minute alpha."[120] The conclusion of the initial drum retrieval program was that "because of the intermixing of drums and boxes that have completely deteriorated, thus releasing high levels of loose alpha contamination, retrieval of the drums under the IDR program in these pits was not recommended."[121]

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[117] Generally, waste was covered with soil on a weekly basis as part of standard operating procedures.
[118] Barraclough, 1976.
[119] Arrenholtz and Knight, 1991, page 5.
[120] The conversion to disintegrations per minute was not reported, but from context, these values are very high. Even if the lowest reported value could be considered "background," the highest reported value was greater than 4,000 times this number. Assuming a "background" of 0.01 nanocuries per gram, that would mean contamination of 40 nanocuries per gram were detected. Given the context of the report, it does not seem that 500 counts per minute was meant to imply a "background" value.
[121] McKinley and McKinney, 1978, page 17.

Despite the likelihood that a significant amount of soil may be contaminated, the Idaho Lab's submittal to the Integrated Data Base stated that the category "soil contaminated by solid transuranic waste" is "not applicable."[122] The extent to which the associated soil in the pits and trenches has become contaminated represents a major uncertainty in understanding the scope of remediation of these areas (see the section on the Pit 9 project at the end of this chapter).

Soil is also contaminated with other radionuclides as well as with hazardous chemicals that were disposed of in the pits and trenches.[123]

[122] IDB, 1995, page 107.
[123] Lockheed, 1995.

C. *Los Alamos National Laboratory*

Main Points

- Poor quality of data and records is demonstrated by the fact that over the whole of Los Alamos National Laboratory, a discrepancy of 765 kilograms of Pu-239 exists between different DOE estimates. It is not known how much this discrepancy affects the buried wastes at Los Alamos because no systematic, serious effort has been made to correct deficiencies in the data.
- For several years, the site ignored the AEC's 1970 directive requiring retrievable storage of transuranic waste, burying some 2,500 cubic meters of transuranic waste during the 1970's.

Los Alamos National Laboratory has a wide variety of facilities that generate TRU waste, including chemical processing of plutonium, machining facilities to fabricate weapons components from plutonium as well as testing of components. The first plutonium bombs were made at Los Alamos (as were the first bombs made from highly enriched uranium). These activities have created large quantities of TRU wastes. Precise information is lacking due to poor record-keeping in early years and low priority given to buried TRU waste and TRU contaminated soil. Los Alamos is still generating TRU waste from various weapons-related activities, including laboratory testing of nuclear-weapon components. It is currently the third largest generator of TRU waste, after Hanford (waste from remedial activities) and Savannah River (wastes primarily from reprocessing, laboratory work, and research and development).[124]

Potential plutonium contamination of the soil and water from activities at Los Alamos has caused special concern because of its location. The site is located on the Pajarito Plateau on the eastern flank of the Jemez Mountains in north-central New Mexico. The plateau is adjacent to the Rio Grande River and rises about 300 to 1,000 feet above it. Numerous intermittent streams flow into the Rio Grande from the plateau. There are many Native American pueblos in the region.

1. Site Inventory of Buried Transuranic Waste

Six areas - A, B, C, G, T, and V - have records that show burial of transuranic waste. Records for other waste disposal sites used in the early years of the laboratory (especially before the early 1950's) are poor. The sometimes sketchy nature of available information for these early years can be deduced from the following:

> Area E, located at 'New Hot Point,' TA-33 [Technical Area-33], includes an underground chamber destroyed in 1950 and six pits. The area was in use through 1962. Records on the underground chamber and the pits have not been found ...

[124] IDB, Rev. 12, page 67.

Area F, TM Site, TA-6, may not be a radioactive waste disposal area. The first pit was dug in 1946. The exact size, location, and number of pits is not known. No records of disposal have been found.[125]

Numbers presented by the Laboratory for buried transuranic waste have to be understood in the context of uncertainties caused by poor or non-existent records.

A 1981 report done by the Laboratory estimated roughly 18,000 cubic meters of TRU waste was buried at the six sites mentioned above.[126] About 8 percent was estimated to be combustible material (rags, clothing, etc.), 27.5 percent metals, and 64.5 percent non-metal, non-combustible.[127] At the time of the estimate, TRU waste included waste with greater than 10 nanocuries per gram of transuranics. Table 16 and Figure 5 show a summary of waste disposal sites containing transuranic waste at Los Alamos. The estimates in Table 16 were made when the definition of TRU waste was 10 nanocuries per gram. Los Alamos has since revised these estimates downward due to the redefinition of transuranic waste in 1984, which requires greater than 100 nanocuries per gram (see Table 17).

Table 16: Buried TRU Waste Sites at Los Alamos

Area	Number and Type of Buried Waste Sites	Buried TRU and Low-Level Waste Volume, m^3	Estimated Buried TRU Waste Volume, m^3
A	5 pits, 4 of which received TRU waste	14,000	700[a]
B	number and location of pits unknown	21,000	430
C	6 pits 48 shafts	100,000 145	4,900 (pits and shafts combined)
G	7 pits 66 shafts	170,000 430	8,000 (pits and shafts combined)
T	4 absorption beds 56 shafts	2,700 3,800	170 3,500
V	absorption beds	4,300	210[a]
	TOTAL	*316,000*	*18,000*

Source: Walker, 1981.
[a] For the TRU volume estimates, 5% of the total volume was assumed to be transuranic waste in Walker, 1981.

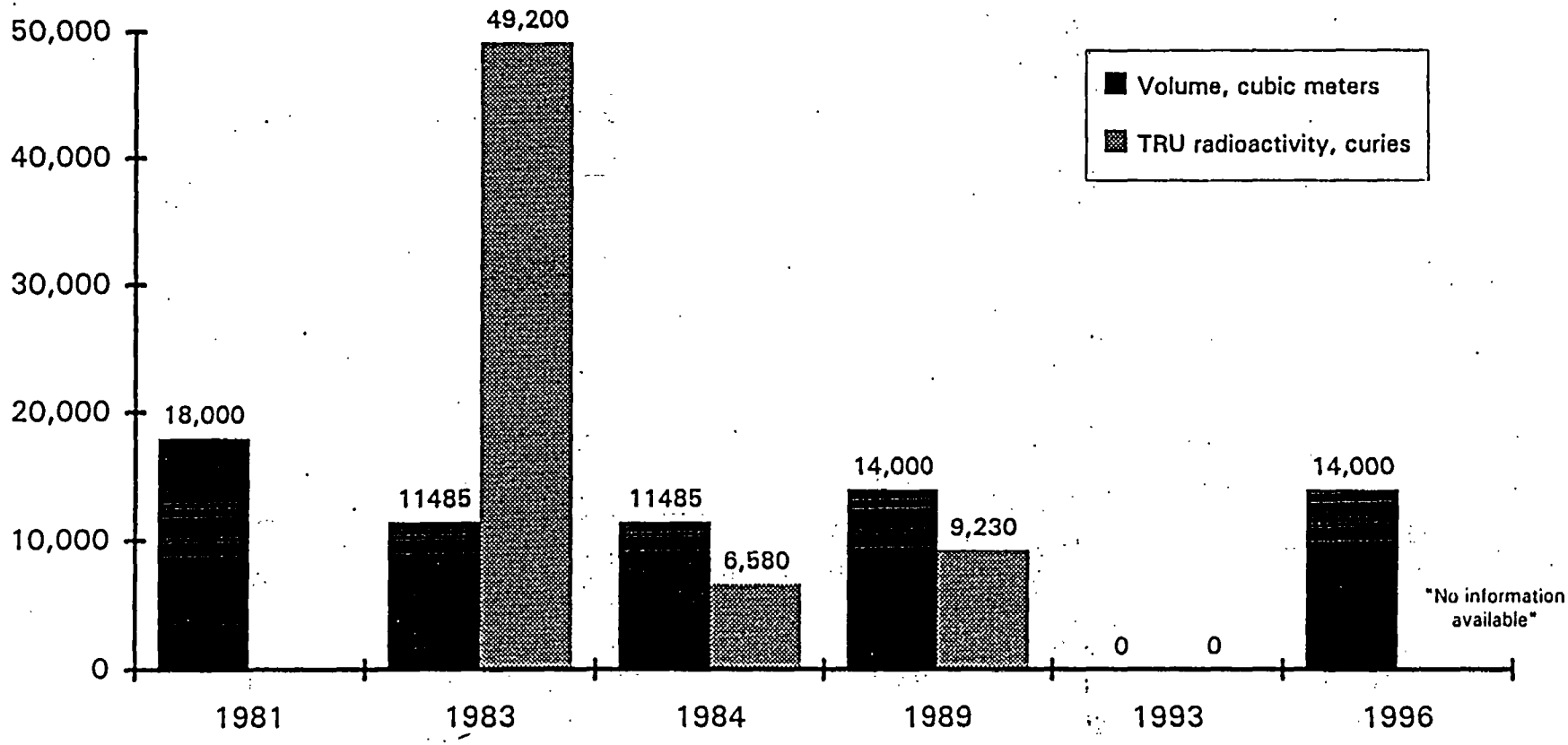
[125] Rogers, 1977, page 8.
[126] Walker, 1981, Appendix D.
[127] Ibid, page 107.

Table 17 shows the range of TRU data reported by the site. DOE's 1996 estimate of the amount of buried transuranic waste at Los Alamos is 14,000 cubic meters. Most of the reduction from the earlier estimate of 18,000 cubic meters is presumably based on the 100 nanocurie per gram definition, as opposed to the 10 nanocurie per gram definition that was in effect when the Walker report was published in 1981. It is unclear as to whether or not the available data are sufficient to support the reduction in the volume estimates. Additionally, for two years, the amount of buried transuranic waste at Los Alamos was inexplicably reported as "0" in the Integrated Data Base Report.

Table 17: Estimates of Los Alamos Buried TRU Waste

Reporting date, Source	TRU volume, m^3	Mass of TRU, kg	Alpha Radioactivity of TRU, curies	Comments
1981, Walker	18,000	not given	not given	According to 10 nanocurie per gram definition of TRU waste.
1983, DOE (cited in 1984, DOE)	11,485.7	14	49,200	Highly doubtful that record data quality is sufficient to report volume to the nearest tenth of a cubic meter.
1984, DOE	11,485.7	14	6,580	Footnote states "a detailed analysis of waste during 1983 indicated that earlier estimates of radioactivity were too high" - but no reference given. Radioactivity changed, but volume and mass unchanged.
1989-92, IDB Rev 5-8	14,000	53.5	9,230	Increases from 1984 estimate due to reclassification of 2,500 cubic meters of post-1970 waste previously classified as "retrievable."
1993-94, IDB Rev 9-10	0	0	0	No technical explanation available for changes.
1995-96, IDB Rev 11-12	14,000	not listed in this revision	"information not available"	Returns to the 14,000 m^3 volume figure, but no information on mass or radioactivity is given.

Figure 5:
Variation in Data for Los Alamos Buried TRU Waste



2. Disposal of Solid Waste

Solid radioactive wastes have been disposed of at Los Alamos since 1944 in pits and shafts. The pits were large, ranging from 120 to 180 meters long, 8 to 30 meters wide, and 8 to 11 meters deep. The pits used to have a more colorful name than the current "near-surface land disposal facility." When they were being used, they were referred to as "contaminated dumps."[128] The shafts were generally 0.6 to 2.5 meters in diameter and a few meters to 20 meters deep.[129]

Trucks used to haul the waste to the pits were both driven to the edge of the pits, where the wastes were dumped over the edge, and driven into the pits, where the wastes were then dumped from the trucks. Apparently, problems were encountered with both methods, as noted in Rogers:

> The practice of backing a truck up to the edge of a disposal pit and throwing trash off the rear was abandoned in 1959..., after a man fell into the pit when the edge crumbled beneath him. However, in 1964,...because the pit walls began to crumble, it was decided to dump material into the trench from the top of the pit rather than risk being struck by falling rock.[130]

Radioactive wastes were packed in cardboard boxes, 5-mil thick plastic bags, and 55-gallon drums. The drums contained sludges from water treatment facilities. Chemical and radioactive wastes were disposed of in the pits as well as uncontaminated wastes.

Packing of wastes in cardboard boxes began to be phased out in 1957, after a study found that about 3 months after being placed in the pits, they had weathered considerably and broken open.[131] The plastic bags had not disintegrated during the 3-month period. We could not find any assessments as to whether or not placing the waste in plastic bags reduced contamination of the surrounding soil over the long term (although a report did note that sealing plastic bags used about half as much of janitor time as cardboard boxes, and that the plastic bags did not get stuck when being emptied from the dump trucks at the pits[132]).

Lax and potentially dangerous disposal practices at Los Alamos are further illustrated by the fact that accidental fires occurred in the burial grounds.[133]

> "When boxes were being unloaded, one box caught fire ..." (June 5, 1952)

> "Upon arriving, we discovered a fire that had burned itself out with the exception of several barrels of paraffin which were boiling and burning to a small extent ... The wind was from the west and brisk, so that smoke was carried east and traveled a path between Ten Site and Beta

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[128] Rogers, 1977, page C-1
[129] Walker, 1981, pages 8-9.
[130] Rogers, 1977, page G-16
[131] Ibid, page C-8
[132] Ibid, page C-8.
[133] Ibid, quoted from pages C-23, C-24

Site...[Two days later] The area east of the pit and parts of the canyon from Beta Site to Ten Site were checked, but no trace of contamination could be found. Any contamination that may have gotten into the air was well diluted and carried away rather than being deposited in the vicinity." (March 24, 1953)

"One box from Sigma building was smoking while being thrown into the dump ..." (April 22, 1953)

Shafts were generally used for wastes with higher levels of radioactivity, although this generalization may be "too simple."[134] These wastes contain tritium, mixed fission products, uranium, and mixed activation products, as well as transuranic radionuclides. Some of the waste is from "hot cells" and glove boxes, and is packed in stainless steel canisters. The solid wastes were dumped into the shafts, and covered with a thin layer of dirt. When full, the shafts were covered with about 1 meter of cement. Detailed records on the shaft locations and contents seem to have been kept.[135] However, in light of recently-revealed accounting discrepancies regarding plutonium-239 at the site, they may not be accurate (see below).

Site records of buried waste indicate 66 shafts in Area G containing transuranic waste. According records of the contents of the shafts in Area G, only 18 of these shafts had received transuranic waste prior to 1970.[136] Thus, 48 shafts in Area G contain transuranic waste that was placed there after the AEC required that the waste be kept in retrievable storage. This disposal of transuranic waste -- in violation of the 1970 AEC directive -- continued at least until 1975. Some 2,500 cubic meters of transuranic waste were buried at Los Alamos in violation of the AEC's directive. This waste, which was supposed to have been kept in retreivable storage, was the reason for the increase in the site estimate of buried TRU waste from 11,500 cubic meters to 14,000 cubic meters.[137]

A brief description of the pits and shafts where records indicate solid transuranic waste being buried is given below.

Area B

Area B was the first common radioactive burial ground for the Laboratory. It was used from 1944 through 1948. The exact number and locations of the pits is not known; engineering drawings only show the outline of Area B.[138] Records prior to January 5, 1947 have been reported as missing.[139]

Area A

Area A was the second common burial ground for radioactive waste at the Laboratory. Five pits are in Area A, one of which was used for disposal of construction debris. Pits

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[134] Walker, 1981, page 8.
[135] Rogers, 1977, page C-12 and Appendix G.
[136] Ibid, Appendix G
[137] Christensen, 1997. See Table 17.
[138] Rogers, 1977, page 6
[139] Ibid, page 6.

for disposal of radioactive waste were used in 1945 and 1946. Records on radioactive waste disposal have been reported as "missing."[140]

Area C
Excavation of the first "contaminated dump" in C area began in May 1948. Beginning with Area C, US Geological Survey representatives were involved with the selection and oversight of Los Alamos burial grounds. Six pits were used for disposal of radioactive wastes from 1948 through 1964. In addition, a seventh pit was used for disposal of chemical wastes from 1960 until 1964.[141]

The first shafts were built in Area C in 1958. From 1958 until 1969, 107 shafts were used for disposal of mostly high-activity wastes. Most of these shafts were unlined (10 were lined with cement or corrugated steel), and measure from 0.3 to 1 meter in diameter and 3 to 6 meters deep. It is estimated that 42 unlined shafts and 6 lined shafts contain transuranic waste.[142]

Area G
Area G contains the most buried waste at Los Alamos. It has been in use since 1957. As of 1980, there were 21 pits in Area G, seven of which contain transuranic waste. Additionally, 66 of 120 shafts in Area G are thought to contain transuranic waste. Shafts range from 0.3 to 2 meters in diameter, and from 8 to 20 meters deep.[143]

3. Disposal of Liquid Waste

Liquid wastes have been disposed of in absorption beds and also in shafts. The absorption beds are long, shallow trenches excavated into the tuff underlying the site. The beds were backfilled with coarse material, grading from 0.2 m boulders in the bottom, to fine sand at the surface. Liquid wastes were also mixed with concrete and pumped into shafts.

Revision 7 (1991) of the Integrated Data Base reported 140 cubic meters of TRU soil containing roughly 10 curies of TRU alpha radioactivity. Assuming a soil density of 1.8 grams per cubic centimeter, this would give an average of 40 nanocuries per gram.

A brief description of the areas where records indicate liquid transuranic waste being disposed of is given below.

Area T
From 1945-1952, four absorption beds were used for the disposal of untreated liquid wastes from plutonium processing, which included americium and plutonium. The

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[140] Ibid, page 6.
[141] Ibid, page C-1
[142] Walker, 1981, page 105.
[143] Ibid, page 10 and page 105.

absorption beds are trenches roughly 35 meters long by 1.2 meters deep by 6 meters wide. The trenches together have a volume of 2,700 cubic meters. A treatment plant was installed in 1952 for removal of plutonium and other radionuclides from liquid wastes. The beds were used infrequently between 1952 and 1967 for the disposal of a few hundred gallons of treated liquid waste.[144]

Beginning in 1968, plutonium-containing residues from a new treatment plant were mixed with cement and pumped down shafts augered between the absorption beds. The shaft dimensions are typically 1.2 to 2.4 meters in diameter and up to 24 meters deep. The volume of these 62 shafts is about 3,800 cubic meters. Fifty-six of these shafts are estimated to contain transuranic waste. Walker states that these wastes were buried before 1971.[145]

Area V

Three absorption beds received waste water from a laundry at the "DP" site from 1945 to 1961.[146] This area is estimated to have one-tenth of a curie of TRU radioactivity. If averaged over the 210 cubic meters listed inTable 16, the concentration would be several thousand times less than the 100 nanocurie per gram definition of TRU waste. If the official estimate is correct, this area would not come under the TRU waste classification, although there could be some TRU soil "hotspots."

4. Transuranic-contaminated Soil

Los Alamos has reported 1,140 cubic meters of TRU soil in past Integrated Data Base Reports, comprised of 1,000 cubic meters due to solid waste disposal and 140 cubic meters due to liquid waste disposal.[147] However, in Integrated Data Base Revisions 9-11 (1994-1996), the amount of TRU soil was listed as "unknown." DOE's 1996 Integrated Data Base Report does not report data on TRU soil for any site.

It appears that about half of the volume of the pits is estimated to be soil that was periodically used to cover the wastes while the pits were open; this amounts to over one hundred thousand cubic meters of soil.[148] It is unclear as to whether or not Los Alamos' estimate of 1,000 cubic meters of TRU soil is an accurate reflection of how much of the soil in the pits has become contaminated over time as water infiltrated the pits and as waste containers (such as cardboard boxes and plastic bags) degraded. Accumulation of water at the surface of the burial grounds, due to uneven compaction of the soil cover placed over the pits and due to sagging of the surface as waste settles, has been noted at Los Alamos.[149] Such ponding of water increases the ability of waste to contaminate surrounding soil.

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[144] Ibid, page 11.
[145] Ibid, page 11.
[146] Ibid, page 15.
[147] IDB, 1991, pages 85-86.
[148] Walker, 1981, pages 105-106.
[149] Jacobs, 1980, page 5.

Arnold (1980) also lists TRU soil sites at Los Alamos. This "Site Survey Report" seems to indicate that there are other TRU soil sites in addition to the transuranic waste areas A, B, C, G, T, and V. One of the sites, "Ten-Site Canyon," was reported to have contamination of 50 nanocuries per gram of gross alpha radioactivity, but Arnold did not give volume estimates, total mass, or total radioactivity. Additional sites had lower reported concentrations of TRU radioactivity.[150]

One other source of contaminated TRU soil is in Chapter 6 of the 1996 Integrated Data Base Report. Table 6.4 of this report indicates that 4,400 cubic meters of TRU waste is to be left in place.[151] This waste is apparently the result of "criticality experiments" in relatively deep holes (a few hundred feet). This deep soil contamination is located in "Field Unit 5."[152] This volume does not appear to repeat other volumes that we have noted elsewhere in this section on Los Alamos. To our knowledge, this figure has not been reported in prior revisions of the Integrated Data Base.

5. Site-wide Plutonium-239 balance

Considerable amounts of TRU materials have been processed at Los Alamos. Serious unresolved issues regarding materials accounting for plutonium-239 have been identified by DOE. These accounting issues appear to center around the plutonium content of wastes at Los Alamos. Data released by then-Secretary of Energy Hazel O' Leary in January 1996 in a report entitled "Plutonium: The First 50 Years" (part of DOE's "Openness Program") seem to be at odds with data provided by Los Alamos.

The "50 Years" report states that 610 kilograms of plutonium-239 are contained in Los Alamos wastes.[153] However, an internal DOE memorandum prepared just before the DOE report was released states that Los Alamos waste management officials believe there are 1,375 kilograms of plutonium in Los Alamos wastes.[154]

The 765 kilogram discrepancy for plutonium-239 between what is reported by DOE Headquarters and the site indicates a lack of systematic accounting for weapons-grade material, and transuranic radionuclides in general, at Los Alamos. In the presence of such uncertainties, it will be difficult to:

- determine the volumes and specific activity levels of TRU wastes on site;
- determine the kinds of threats posed to health and the environment;
- design suitable remedial actions for waste in pits and shafts;
- take appropriate measures for protecting worker health;

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[150] Arnold, 1980, pages 9-10.
[151] IDB, 1996, page 164.
[152] Peterson, 1997.
[153] DOE, 1996d.
[154] Guimond, 1996.

- properly account for weapons usable materials (the 765 kilogram discrepancy is enough for about 200 warheads);
- take measures for environmental compliance in other areas, such as preventing unanticipated leaks of plutonium from ducts where it may be held up.

Despite the potential environmental consequences of this discrepancy, DOE has not evaluated the implications for its management of Los Alamos TRU waste.

D. Oak Ridge National Laboratory

Main Points

- Untreated liquid waste containing TRU radionuclides was discharged to pits and trenches and allowed to seep into the ground from 1951-1966.
- Large quantities of TRU sludges were injected (700-1,000 feet deep) by "hydrofracture" from 1966-1979 and again from 1982-1984. Contamination from this practice is possibly upwelling from deeper, pressurized aquifers into shallower ones.
- 6,200 cubic meters of TRU solid waste are mixed with about 150,000 cubic meters of other radioactive and hazardous waste in three main areas that are poorly characterized.
- An estimated 350 cubic meters of transuranic wastes generated after 1970 (not counting those injected by hydrofracture) have recently been stated to be "not retrievable" and thus grouped in with "pre-1970 buried transuranic waste."

Plutonium operations at Oak Ridge National Laboratory[155] began in 1943 with the objective of producing and separating plutonium as part of the Manhattan Project. Oak Ridge has produced wastes contaminated with transuranic elements in liquid, sludge, and solid forms.

Solid wastes containing transuranic radionuclides are generated at various facilities on site. The site also manages U-233 contaminated waste as transuranic waste.[156] The TRU processing area has been the main source of TRU liquid waste at Oak Ridge since the late 1960's.[157]

Oak Ridge also generated large amounts of liquid waste. The wastes were categorized as "low-level" (also called "process"), "intermediate-level," "TRU liquid," and "high-level."[158] These classifications were specific to Oak Ridge.[159] Intermediate-level, TRU liquid, and high-level wastes all contained transuranic radionuclides. Although a distinct classification system was in place, these wastes were not kept separate. For example, both TRU liquid and high-level waste were "diluted" with intermediate level waste and sent into a labyrinthine system where wastes were precipitated, piped through ion exchange systems, evaporated, and/or kept in holding

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[155] Oak Ridge National Laboratory along with the K-25 gaseous diffusion plant and the Y-12 electromagnetic separation plant comprise the Oak Ridge Reservation. In this report, we do not explicitly discuss either the K-25 or the Y-12 plants. Thus, when we use the term "Oak Ridge" we are referring to "Oak Ridge National Laboratory."

[156] Coobs and Gissel, 1986, page 89.

[157] Ibid, page 104.

[158] It is noteworthy than an "intermediate waste" category appears to have been in use at Oak Ridge since 1944.

[159] Coobs and Gissel, 1986, pages 67, 104, and 105.

ponds before they ultimately ended up in local creeks and rivers, concrete and stainless steel tanks, and deep injection wells.[160]

1. Disposal of Solid Waste at Oak Ridge

It has been estimated that between 1944 and 1969, Oak Ridge disposed of 6,200 cubic meters of transuranic waste in Solid Waste Storage Areas (referred to as SWSAs) 1 through 5. These areas also contain 150,000 cubic meters of other radioactive and hazardous wastes.

To some extent the site did separate transuranic waste from other waste prior to the 1970 requirement of the Atomic Energy Commission. For example, "alpha wastes" (a term that was generally used prior to the AEC creation of the "transuranic waste" classification) were sometimes placed in auger holes, which were vertical shafts from 0.3 to 4.5 meters in diameter and 4.5 meters deep. They were also placed in concrete lined and unlined trenches.[161]

Other special burial practices were used for alpha wastes that were disposed of in trenches.[162] To "prevent inadvertent disturbance of the plutonium-contaminated waste," the alpha wastes (and "higher level wastes and some special high-level wastes") that were placed in trenches were generally covered with 0.45 meters (18 inches) of concrete. The extent to which the volume of transuranic waste can be linked to certain locations within the burial grounds or specific trenches is unclear, mostly because of a loss of some records in an accidental fire in 1961.[163]

Even if the fire destroyed all records prior to 1961, there would still be records dating from 1961. These records could give some important information on the buried TRU wastes, such as location of burial, quantities of waste buried, etc. If procedures such as drilling auger holes and covering waste in trenches with concrete were indeed used, then records of such site preparation activities would help to delineate TRU wastes from non-TRU wastes in the burial ground. Full disclosure of extant records should be made and an effort to reconstruct the data to determine where locations of TRU waste may be in the SWSAs should be made. For areas without records, the site should investigate whether it is possible to determine which parts of the burial grounds contain concrete trenches (which may indicate possible burial of TRU waste). Such efforts would provide a basis for examining the feasibility of exhuming the wastes from its present shallow-land burial configuration.

SWSA 1 is a one-acre triangular-shaped area that was used in 1943 and 1944 to dispose of radioactive waste. It is located near the Laboratory's main plant area, and is

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[160] Ibid, sections IV.B., V, and VI.C.
[161] Ibid, pages 89-90.
[162] Ibid, pages 89-92.
[163] Ibid, page 31.

about 25 feet to the south of White Oak Creek. A 1986 report states that "it is suspected that only a small amount of solid radioactive waste was buried in SWSA 1 since fissionable material was conserved and the operations did not include isotope separation and concentration during its use." However, there appear to be no records showing the quantity or type of materials disposed of in this area.[164]

SWSA 2 is located on the south side of a hill near the east entrance and main parking area of the Laboratory, northwest of building 4500. The area covers about 3.5 acres. Wastes were buried here from 1944 to 1946. The area received solid waste contaminated with beta or gamma activity, liquid waste contaminated with plutonium in stainless steel drums, and alpha-contaminated material from off-site.

SWSA 3 was used from 1946 to 1951 to store radioactive wastes. It consists of about 7 acres. An estimated 17,000 cubic meters of waste was buried at SWSA 3. The wastes in SWSA 1 and 2 were dug up and re-buried in SWSA 3. Some records concerning SWSA 3, as well as SWSAs 4 and 5, were destroyed in a fire in 1961. However, existing records indicate that "alpha wastes" were disposed of differently from other wastes:

> During the early operational period of SWSA 3, alpha wastes in drums were deposited in concrete-lined trenches in the NE part of the burial ground but were later placed directly into unlined trenches and covered with concrete as the burial ground was extended to the west.[165]

SWSA 4 was opened in 1951, after closure of SWSA 3. SWSA 4 encompasses 23 acres, approximately twice the size of the previous 3 burial areas combined. Wastes were placed in trenches and auger holes. Early records of waste disposed in SWSA 4 were lost in a fire; apparently some records exist from 1957 and 1958. Oak Ridge estimates that a total of 57,000 cubic meters of TRU and other radioactive waste was buried in SWSA 4. Burial of radioactive waste in SWSA 4 ceased in 1959 when there was no more space; however, uncontaminated fill was disposed of there until 1973.[166]

From 1955 to 1963, the Atomic Energy Commission designated Oak Ridge as the Southeast Regional Burial Ground for hazardous and low-level waste. During this time, Oak Ridge received waste from approximately 50 different sources; the waste was "poorly characterized."[167] Records from 1957 and 1958 indicate that the largest off-site sources (at least during these years) were Knolls Atomic Power Laboratory, Argonne National Laboratory, GE of Evandale, Ohio, and Mound Laboratory.[168] Mound Laboratory processed plutonium-238 and other alpha-emitting isotopes. It is estimated that half of the waste in SWSA 4 is from off-site.

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[164] Ibid, page 33.
[165] Ibid, page 40.
[166] ORNL, 1987, page I-47.
[167] Ibid, page I-47.
[168] Coobs and Gissel, 1986, page 27.

SWSA 5 received radioactive waste from 1959 until 1973. The area set aside for SWSA 5 is 80 acres. Oak Ridge estimates that a total of approximately 85,000 cubic meters of radioactive waste was been buried in SWSA 5.[169] Wastes in SWSA 5 are in more than 220 unlined trenches and nearly 1,000 unlined auger holes.

In 1970, after the AEC's directive that required transuranic wastes to be kept in retrievable storage, a ten-acre area in the northern part of SWSA 5 (referred to as SWSA 5N) was set aside for transuranic wastes. Three types of "retrievable" transuranic storage were used at Oak Ridge:

1. 30 and 55 gallon mild steel, stainless steel, and black iron drums containing "contact-handled" transuranic waste stored in specially-designed buildings (numbered 7823, 7826, and 7834).
2. small stainless steel or brass capsules containing remote handled transuranic waste stored in auger holes lined with stainless steel and encased in cement. The auger holes are covered by Buildings 7827 and 7829.
3. concrete casks containing remote handled transuranic waste, with wall thicknesses of 11 to 30 centimeters and interior volumes of 0.5 to 1.5 cubic meters, placed in trenches or stored in the "cave" building (Building 7855).[170]

Some of this retrievably stored waste has recently been declared "buried transuranic waste," i.e., non-retrievable. In Oak Ridge's submittal to the 1996 Baseline Inventory Report, the TRU Program Manager explained that:

> while at the time it was judged that all transuranic waste was being retrievably stored, by today's standards an additional 350 cubic meters of TRU waste was also disposed of [i.e., non-retrievably stored] in SWSA 5 from 1970 to 1984.[171]

It is estimated that this 350 cubic meters of waste contained 370 curies of radioactivity at the time of storage, with 41 of those curies attributable to transuranic waste.[172]

It is hard to determine the location of these 350 cubic meters because of vague and seemingly inconsistent references. One reference notes that four unlined trenches in the northeast corner of SWSA 5N were used for disposal, as opposed to retrievable storage of remote-handled transuranic waste from 1970-1976.[173] Transuranic wastes buried in these trenches were primarily packaged in wooden boxes. The boxes were covered with cement after being placed in the trenches. There is no mention of the volume of transuranic waste in these trenches. Because these dates do not match the ones cited in the TRU manager's submittal to the Baseline Inventory Report, we cannot determine whether or not these 4 trenches contain the 350 cubic meters cited in the Oak

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[169] ORNL, 1987, page I-51.
[170] Coobs and Gissel,1986, page 98.
[171] ORNL, 1996a.
[172] Ibid, 1996a.
[173] Material sent by ORNL TRU Program as response to Freedom of Information Act request by IEER.

Ridge submittal to the Baseline Inventory Report, or whether they represent additional waste that was supposed to be retrievably stored, but, in fact, was not.

An additional 22 trenches were used for "retrievable storage" of transuranic waste (mostly stored in concrete casks) in SWSA 5N.[174] It is unclear as to whether or not these will, in fact, continue to be considered "retrievably stored," or if the site will try to reclassify these as "buried transuranic waste" as the waste in the 4 unlined trenches were. Since 1984, the casks have been kept in the "cave" building.

2. Disposal of Liquid Transuranic Waste

The historical management practices for liquid wastes from Oak Ridge facilities has resulted in a great deal of contamination of soil, surface water, and shallow and deep groundwater at the site, including contamination from transuranic radionuclides. Oak Ridge used its own waste classification system for its liquid wastes, which consisted of the categories shown in Table 18.

Table 18: Oak Ridge Liquid Radioactive Waste Classification System

Liquid Waste Category	Main Source of Waste
Low-level, or "process" waste	Evaporator condensate, cooling water from process vessels, supernatant from precipitation of tank waste
Intermediate-level waste [a]	Basic radiochemistry studies, development of reprocessing methods, production of transuranic isotopes for research
TRU liquid waste	Reprocessing of Savannah River Site fuel slugs and target tubes were a large source
High-level waste.	Pilot plant (Building 3019), Fission Product Development Lab (Building 3517), Transuranium Processing Facility (Building 7920)

Source: Coobs and Gissel, 1986.
[a] Referred to in early documents as "highly radioactive" liquid waste (Coobs and Gissel, 1986, page 67).

The Oak Ridge waste classification system seems to have been mostly defined by the total radioactivity of the waste per unit volume, and, except for the TRU liquid category, not according to what types of radionuclides are in the waste. For example, "intermediate level" waste was defined as containing greater than 4 millicuries per gallon and less than 5 curies per gallon and "high-level" waste was defined as greater than 5 curies per gallon.[175] As a result, TRU radionuclides are present in significant quantities in three of Oak Ridge's liquid waste categories - intermediate level, TRU liquid, and high-level.[176]

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[174] Ibid.
[175] Coobs and Gissel, 1986, pages 67 and 105.
[176] ORNL, 1987, page App-32 provides evidence that at least some "intermediate level" waste contains significant levels of TRU radioactivity. In one instance, 76,000 gallons of intermediate level waste is

Oak Ridge's management of liquid wastes, however, did not corresponded to its own waste classification system. For example, high level and TRU liquid wastes were diluted by mixing with intermediate level wastes. These wastes were then stored together in storage tanks. Between 1966 and 1984, these highly radioactive wastes were injected into the ground 700 to 1,000 feet deep via two "hydrofracture" facilities (see below). Since 1984, these wastes have accumulated in storage tanks.[177] In addition to disposal via hydrofracture, liquid wastes containing transuranic elements were discharged to "seepage pits and trenches" from 1951 until 1966.

3. Disposal by Hydrofracture

"Waste management" techniques used in the 1940s and 50s for intermediate level wastes, such as discharge to settling ponds and pits and trenches, later came to be seen as environmentally unacceptable. In 1959, Oak Ridge began to investigate the possibility of injecting these wastes, mixed with grout, deep into the ground -- this procedure is known as "hydrofracturing." It was felt that the grout would harden into thin (less than one inch) sheets in the bedrock beneath the site and that the radionuclides and other contaminants would be retained in the grout sheets, thereby preventing the spread of contaminantion.[178]

In order to get the grout to form a thin sheet in the subsurface, a well was drilled and a slot would be cut into the casing of the well at the desired depth. Water was then injected into the well at pressure, creating a fracture in the subsurface. A mixture of liquid waste and grout was then injected into the well, and the mixture would flow into the thin fracture, eventually hardening.

The 1959 hydrofracture test involved injection of 20,000 gallons of water mixed with solids containing 35 curies of cesium-137 as a tracer, injected to a depth of 290 feet. At the end of the test, the mixture began flowing out of an observation well 200 feet away, having traveled underground and then upwelled to the surface via the observation well.[179] Unfortunately, this failure did not halt the investigation into disposal of highly radioactive wastes by hydrofracture; instead, it was decided to inject at deeper levels.

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identified as containing 156 curies of curium-244, equivalent to roughly 500 nanocuries per gram - much higher than the TRU definition of 100 nanocuries per gram (based on an assumed liquid waste density of 1 kilogram per liter).

[177] Ninety-six tanks of varying sizes, construction materials and design, and integrity contain about 1 million gallons radioactive waste. This tank waste consists of layers of liquids, sludges, and solids, and contain an estimated 160,000 curies of radioactivity (DOE, 1996a, pages 10-14). Management of these tank wastes is not discussed in this report. These wastes pose similar technical challenges, although on a smaller scale, to the high-level waste tanks at other sites, including the Hanford site discussed in one of the case studies in this report.

[178] Coobs and Gissel, 1986, pages 79-82.

[179] ORNL, 1987, page App-58.

From 1966 through 1979, the "Old Hydrofracture Facility" (located about 1.6 kilometers southwest of the Laboratory's main plant) made 22 injections of radioactive waste at depths of 792 to 872 feet. The volume of waste injected is estimated to be 1,426,054 gallons, plus about 2,300,000 gallons of grout. The waste contained hazardous chemicals and radionuclides, including at least 233 curies of curium-244 and 5.8 curies of plutonium-239.[180]

The New Hydrofracture Facility was built in 1982, about 300 meters southwest of the Old Hydrofracture Facility. This facility was designed to handle wastes with much higher radioactivity than the Old Hydrofracture Facility -- up to 20 curies per gallon of waste, versus 1 curie per gallon.[181] The New Hydrofracture Facility operated for 1 test injection and 13 operational injections. Three injections included "intermediate-level" waste, and ten included sludge from the gunite tanks. The injections during operation of the New Hydrofracture Facility took place at depths between 1,069 and 990 feet. Waste classified by Oak Ridge as "intermediate-level," "transuranic," and "high-level" were injected by hydrofracture.[182]

The New Hydrofracture Facility injected into the ground approximately 2.2 million gallons of intermediate level waste and sludge with about 2.8 million gallons of grout. The waste contained an estimated 644,000 curies of strontium-90, 83,000 curies of cesium-137, 7,464 curies of curium-244, 2,125 curies of other transuranics, and 13,000 curies of "other" radioactivity.[183] The sludge waste was highly radioactive and similar to the waste now managed by Oak Ridge as remote-handled transuranic waste. In effect, in the 1980's, Oak Ridge disposed of, by injection into wells, waste that was supposed to be sent to a geologic repository, in apparent violation of the 1970 AEC directive that required retrievable storage of TRU waste.

Numerous problems were experienced with the hydrofracture facilities during their operation. Significant groundwater contamination was noted in some observation wells at the time of operation, wells were poorly constructed, some waste was injected without grout, other waste was injected with insufficient grout, and groundwater from the injection zone traveled into other geologic formations.[184]

The last hydrofracture injection was in January 1984. This practice was stopped due to concerns about groundwater contamination.[185] In the Pumpkin Valley Shale (into which the waste was injected), strontium-90 contamination in the groundwater is severe -- 94,000 becquerels per liter (2.5 million picocuries per liter) have been measured, along

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[180] Ibid, page App-32. The total amount of transuranics is unknown because transuranics in the waste were not analyzed for the first ten injections.
[181] Coobs and Gissel, 1986, page 81.
[182] Ibid, page 106.
[183] ORNL, 1987, page App-33.
[184] Ibid, page App-58 to App-68.
[185] Ibid, page I-81.

with 400,000 becquerels per liter (10.8 million picocuries per liter) of gross beta.[186] Significant amounts of strontium-90 have also been measured in the Rome Formation (which underlies the hydrofracture zone) -- up to 20,000 becquerels per liter (540,000 picocuries per liter).[187] Contamination attributable to hydrofracturing has also been measured to a lesser degree in formations that overlie the injection zone.[188] There are at present no reliable estimates of whether and how this underground contamination can be remediated, and if so, what the cost and consequences of such an operation might be -- one more example of yesterday's "solutions" for waste management becoming tomorrow's environmental problems.

4. Transuranic-sontaminated Soil

a. Volume of soil in pits and trenches from liquid disposal

Past waste management of liquids containing transuranic radionuclides has created an unknown volume of transuranic contaminated soil. A 1980 soil survey of potentially transuranic contaminated soil at various facilities in the United States reported that there were potentially 30,000 cubic meters of soil at Oak Ridge in pits 1-4 and trenches 5-7, which were used from 1951-1966.[189] Data on the concentrations of transuranic radionuclides in the pits and trenches are poor, but indicate that the concentration of TRU elements is well under the 100 nanocurie per gram definition of TRU waste. The same is true of the 70 by 76 meter settling basin near Building 3513. However, hot spots may exist at both sites. In fact, a 1996 estimate by Oak Ridge officials estimated that up to 1,000 cubic meters of transuranic-contaminated soil contained about 50 curies of transuranic radionuclides, for an average of about 30 nanocuries per gram.[190] Given the historical mismanagement of liquid wastes, the mixing of wastes in different categories, and the poor quality of data, this official estimate is uncomfortably close to the definition of TRU waste and indicates that further careful investigation is needed to determine the appropriate classification and management of the contaminated soil.

Revision 6 of the Integrated Data Base (1990) also mentions "1,000 cubic meters of transuranic-contaminated soil around the tanks" -- presumably this contaminated soil has resulted from leaks and spills. We do not have an estimate of what fraction of these wastes might fall into the 100 nanocurie per gram definition of TRU waste.

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[186] Ibid, page App-64.
[187] Ibid, page App-65.
[188] Ibid, page App-65.
[189] Arnold, 1980, pages 13-14.
[190] ORNL, 1996a.

b. Volume of soil in pits and trenches from solid waste disposal

In addition to the trenches contaminated by liquid disposal, Oak Ridge also has soil which was contaminated as a result of poor dumping practices adopted for TRU solid waste. Revision 6 of the Integrated Data Base lists 12,000 to 60,000 cubic meters of soil (subtracting off the 1,000 cubic meters associated with the tanks). It is unclear if this figure includes the volume of soil in the liquid disposal pits and trenches. Subsequent revisions simply list the volume of soil as "unknown." Given the high mobility of transuranic radionuclides in the Oak Ridge subsurface environment (see the discussion later in this case study on environmental contamination from the Oak Ridge burial areas), and the frequent (in some cases, constan), inundation of the unlined disposal trenches containing transuranic waste, potentially large amounts of soil are contaminated with transuranic radionuclides in and around the disposal trenches.

5. Oak Ridge Inventory of Transuranic Waste

Table 19 shows the wide range of data on buried TRU waste reported by the site. The variations largely stem from

- whether or not pre-1970 buried waste was included
- whether or not hydrofracture waste was included.

For some reason, in the most recent submittals to the Integrated Data Base, the site has not reported the 6,200 cubic meters of pre-1970 buried waste. Revision 12 (December 1996) of the Integrated Data Base lists a total of only 176 cubic meters of buried TRU waste at Oak Ridge. Not only is this value inconsistent with the 6,200 cubic meters published in previous revisions of the Integrated Data Base report, but it is also inconsistent with the Oak Ridge TRU Program Manager's June 1996 letter submitted to the Baseline Inventory Report that states that 350 cubic meters of transuranic waste was recently recategorized from "retrievably stored" to "buried." We have found numerous examples of this type of "accounting" by DOE and the sites, and find it quite disturbing that transuranic waste lying in shallow land burial is "disappearing" from publications like the Integrated Data Base. With such poor record-keeping today, DOE's arguments for relying on "institutional controls" to take the place of proper environmental management are without basis.

DOE's reporting on hydrofracture-disposed TRU waste is also problematic. The point of an "Integrated Data Base" is to keep track of wastes as sites move them from one classification to another. This waste -- much of it essentially equivalent to the high-level wastes stored in tanks at Hanford, Idaho Lab, and Savannah River -- has disappeared from DOE's official Integrated Data Base. While this waste needs to be distinguished from "buried" waste since it is disposed of hundreds of feet below the surface, it is crucial to keep track of it because of the substantial environmental threat is poses. An implicit policy of "dump and forget" will not prevent future contamination. Rather, a careful

research program is needed to assess remediation techniques. Such a program could also be useful in joint United States-Russia cooperation on remediation technologies since Russia has injected high-level waste into the ground at two major nuclear weapons sites (Tomsk-7 and Krasnoyarsk-26).

Table 19: Estimates of Oak Ridge National Laboratory Buried TRU Waste

Reporting dates	Volume, m^3	Mass of TRU, kg	Radioactivity in TRU, Ci	Comments
1984 DOE	6,200	5.6	272	Radioactivity reported as alpha radioactivity.
1989 IDB 5	5,947	unknown	unknown	
1990, 1992 IDB 6-8	6,200	5.6	270	Footnote states 270 curies is for all radioactivity (not just TRU)
1993 IDB 9	10,615	not listed in this revision	2,150	Large changes unexplained. If volume includes hydrofracture waste, then 6,200 cubic meters of solid buried waste is not reported; if it does not include hydrofracture waste, then there is more solid waste than reported elsewhere.
1994-96 IDB 10-12	176	not listed in this revision	100 (includes curium-244, which is managed as TRU waste at Oak Ridge)	Footnote states "unknown amounts were buried before 1970 and are not included in totals." However, this value does not match the 1996 estimate submitted by Oak Ridge TRU Manager (350 m^3, 41 curies of waste formerly classified as retrievable TRU - see next table); appears to not include hydrofracture waste.
1996 Oak Ridge submittal to TRU Program	6,550	not listed	311	Buried TRU waste, not hydrofracture waste, see Table 20 for complete data

Figure 6:
Variation in Data for Oak Ridge Buried TRU Waste

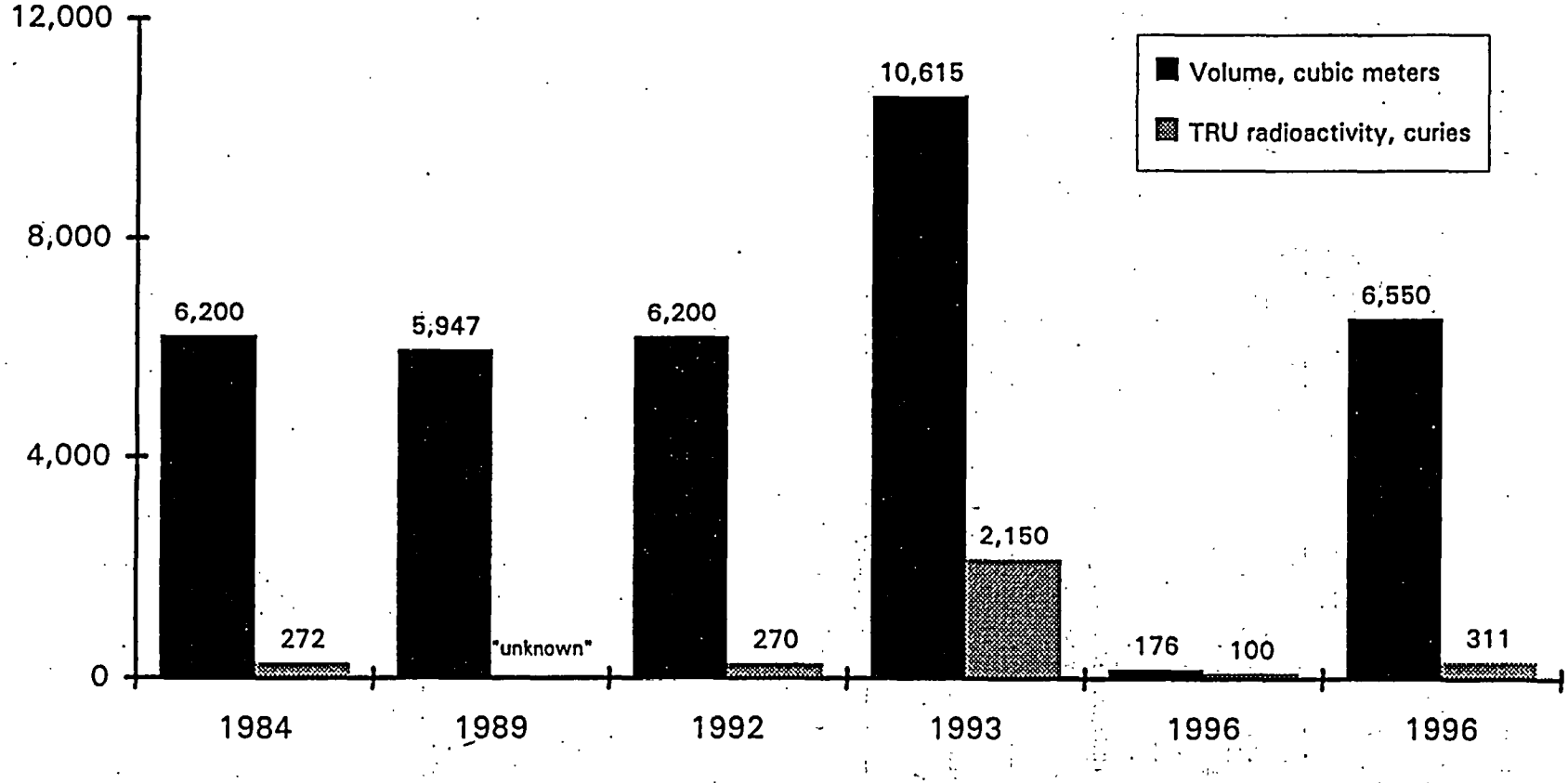

Table 20 is a reproduction of Table A3-1 from the 1996 Oak Ridge Submittal to the Baseline Inventory Report of the National TRU Program, which is supposed to represent the site's best understanding of buried transuranic wastes.

Table 20: 1996 Oak Ridge Assessment of Buried and Hydrofracture-Disposed TRU Waste

Disposal Site	Years in Use	Total Waste Disposed		TRU Waste Disposed	
		Volume, m^3	Curies	Volume, m^3	Curies
SWSA 1-5	1944-1969	170,000	<383,000	6,200	270
SWSA 5N	1970-1984	350	370	350	41
Pits 1-4, Trenches 5-7	1951-1966	159,000	1,100,000	<1,000	50
Old Hydrofracture Facility	1966-1979	8,700	650,000	Unknown	5 [plus 233 curies of Cm-244]
New Hydrofracture Facility	1982-1984	10,800	751,000	8,700	2,125 [plus 7,464 curies of Cm-244]

Source: ORNL, 1996a, Table A3-1.
SWSA: Solid Waste Storage Area.

E. Savannah River Site

Main Points

- Significant discrepancies between different estimates of volumes and curies of transuranic wastes in the burial grounds.
- Transuranic waste generated from 1964 to 1974 was supposedly placed in retrievable storage; however, the site has recently declared all of this waste as "pre-1970 buried waste."
- Savannah River Site seems to have violated AEC regulations regarding retrievable storage of TRU waste during the period 1970-1974 by a factor of several hundred because it used its own definition of TRU waste.

The Savannah River Site is a 325-square-mile site located on the Savannah River in South Carolina. Operations at the site began in the early 1950s, with the objective of producing nuclear weapons materials, primarily tritium and plutonium-239. The site has also produced major quantities of other nuclear materials, notably plutonium-238, most of which has been used to make thermoelectric nuclear generators for the space program, and plutonium-242, which is used in the nuclear weapons program to simulate plutonium-239. Separated neptunium-237 and americium-241 have also been produced.

Five reactors were built to produce nuclear materials by irradiating target materials with neutrons. Two chemical separations (reprocessing) plants, called canyons, were also constructed to separate out nuclear materials from the irradiated targets and to recover unused nuclear fuel. Other major facilities built at Savannah River include a heavy water extraction plant and a nuclear fuel and target fabrication facility.

Operations at Savannah River produced large volumes of liquid, solid, and airborne radioactive and hazardous wastes, including TRU waste.

1. TRU waste in Savannah River Burial Grounds

Solid as well as liquid transuranic wastes were disposed of in the "Old Burial Ground" (referred to as 643-G). The Old Burial Ground consists of a 76-acre area situated between the site's two reprocessing facilities. The Old Burial Ground began receiving waste in 1952 and operated for 2 decades. In 1972, the New Burial Ground, known as 643-7G, encompassing 112 acres was opened just to the north of the Old Burial Ground. Some types of transuranic waste in the burial grounds are listed below:

- obsolete or failed tanks, pipes, and other process equipment
- reactor and fuel hardware
- laboratory waste
- small equipment, clothes, analytical waste, decontamination residues, plastic sheeting, gloves, etc.

- plutonium-238 process waste from Los Alamos Scientific Laboratory and Mound Laboratory
- debris from clean-up of 2 U.S. airplane accidents carrying nuclear weapons in Spain and Greenland
- "bulky" waste
- other solid waste, such as canyon equipment, that may contain transuranic radionuclides but is so intensely contaminated with gamma emitters that it is not feasible to measure the alpha content.

Solid waste containing transuranic radionuclides was mixed with low-level waste in trenches until 1964. Solid wastes were placed inside cardboard boxes that were then dumped into closely-spaced, unlined, 20-foot-deep trenches. For waste with high external radiation doses, a crane was used. Plastic bags were also used for disposal of wastes buried before 1964. The use of plastic bags and cardboard was not primarily intended to isolate the waste from the environment, but rather to prevent the escape of radioactive contamination during transport to the burial ground.[191] The trenches were then backfilled with about four feet of dirt. These general guidelines also governed waste disposal in the 643-7G burial grounds until the mid-1980s.

Problems with burial of wastes through the years at Savannah River included the accumulation of water in trenches while they were being filled with waste and collapse of cardboard boxes inside the trench, which caused the surface to cave in. Water in the trenches accelerated the degradation of waste containers and provided a mechanism for release of contaminants to the environment. Data from 1969-1970 showed that even after trenches were closed the backfilled trenches often had water in the bottom -- referred to as "perched water." Some trenches were almost continually filled with water -- one well indicated an average minimum of about two feet in the bottom of the waste trenches, and other wells showed as much as 6 feet of water at times.[192]

A 1980 study by a DOE Senior Project Engineer found generally poor burial practices at the site:

> trench operations are little advanced over methods first employed when burial ground operations were first begun. These methods are antiquated, no longer technically sound, and the cause of the nuclide migration observed in the burial ground.[193]

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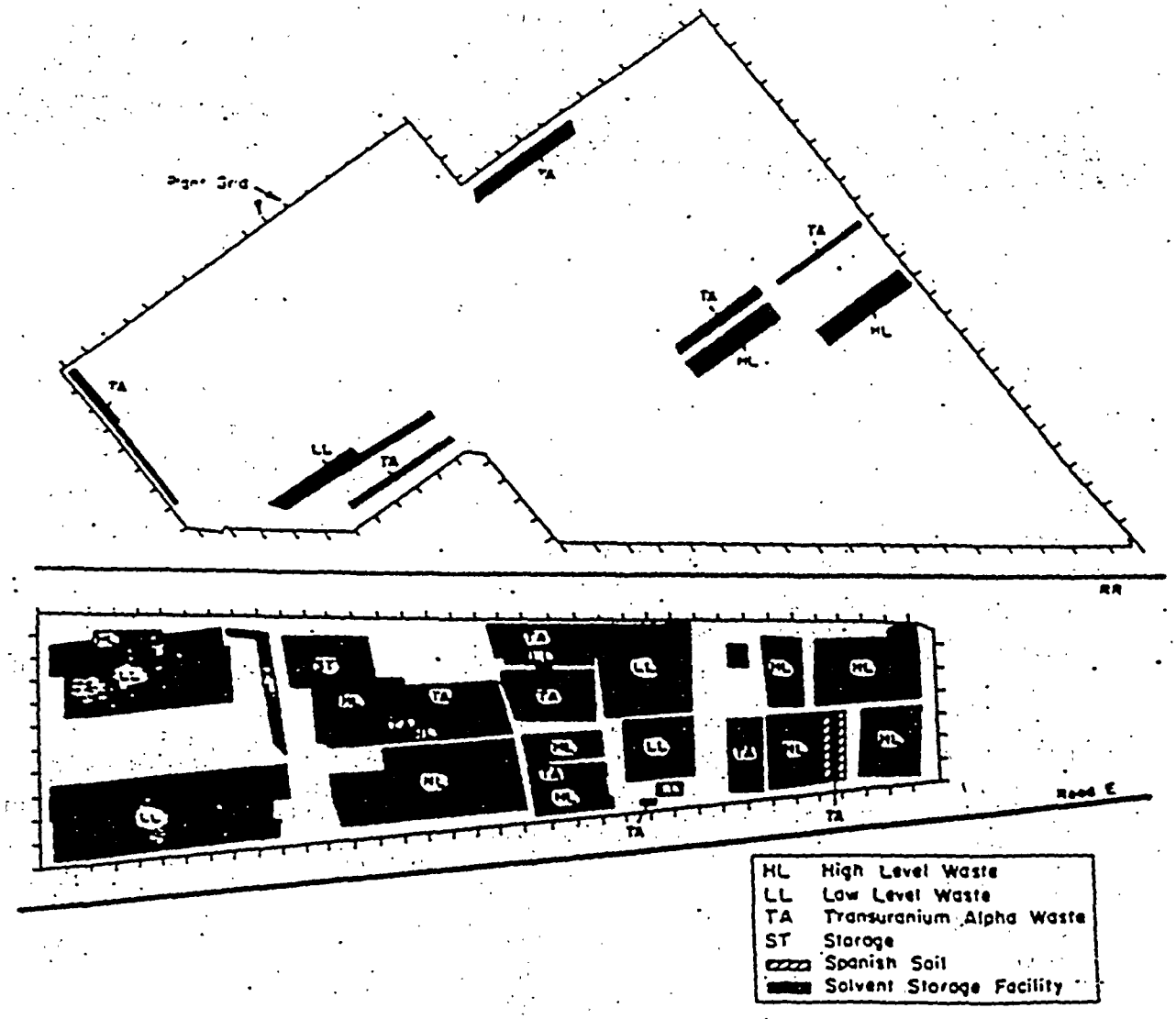
[191] Connor, 1992, page 38, footnote 4.
[192] Horton and Corey, 1976, page 35.
[193] Lawless, 1980, as cited in Connor, 1992, pages 5-6.

Figure 7: Savannah River Site Burial Grounds for Radioactive Waste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In 1964 -- prior to the Atomic Energy Commission's 1970 directive requiring retrievable storage of transuranic waste -- Savannah River Site managers began to segregate TRU waste from other waste. Wastes sent to the Old Burial Ground were segregated by waste type, with individual trenches or sections of trenches designated for receipt of different wastes.

Disposal trenches were designated for low-level waste, "transuranium alpha waste," and high-level waste. From 1964 to 1974, the Savannah River Site used its own definition of "retrievable transuranium alpha waste" -- waste containing more than 0.1 curie of TRU elements per "package."[194] Packages containing more than 0.1 curies of transuranium alpha wastes were segregated from those packages that contained less than 0.1 curie of TRU elements. The latter were designated as "non-retrievable transuranium alpha wastes" and were buried along with low-level waste. The "retrievable transuranium alpha wastes" (i.e., packages containing greater than 0.1 curies of alpha radiation) were buried as described in this excerpt from a site report:

> Waste containing greater than 0.1 curie per package was placed in prefabricated concrete containers and then buried. These containers were 6 feet in diameter by 6.5 feet high. Waste that did not fit into the prefabricated concrete containers was encapsulated in concrete. Transuranium waste from the Savannah River Laboratory was buried in square concrete containers.[195]

While the idea of separating wastes into retrievable and non-retrievable storage is similar to the 1970 AEC directive requiring retrievable storage of transuranic waste, under the Savannah River Plant guidelines, the distinction was based on the total curie content in a "package" whereas under the 1970 AEC directive, waste was segregated by the curie content per unit weight (i.e., 10 nanocuries per gram). However, the qualitative similarity is deceptive: the Savannah River guideline, which the site followed until 1974, was much more lax than the AEC directive.

The difference in the two guidelines can be seen by considering a common type of package of transuranic waste -- a 55-gallon drum packed with waste. According to the 1996 submittal of the site to the TRU Baseline Inventory Report, a typical 55-gallon drum of transuranic waste weighs 123.6 kilograms per cubic meter.[196] Under the AEC guideline such a drum would be required to be retrievably stored if it contained more than 0.00026 curies, while under the Savannah River guideline the container would be required to be retrievably stored only if it had more than 0.1 curies. Thus, the Savannah River TRU guideline was almost 400 times more lax than the 1970 AEC directive (i.e., 10 nanocuries per gram), and 40 times more lax than the 1984 DOE revision of the AEC directive (i.e., 100 nanocuries per gram). While Savannah River appears to have been prudent in deciding to segregate TRU waste during the 1964-1969 period, the site was

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[194] Horton and Corey, 1976, page 20.
[195] Ibid, page 20.
[196] SRS, 1996b, page 2.

actually in violation of the 1970 AEC directive by a very wide margin during the period 1970-1974.

Thus, although the Savannah River proudly took credit for years (e.g., Horton and Carey, 1976 and Towler, 1989) for retrievably storing waste with very high quantities of transuranic radionuclides at an earlier date than some other sites, after 1970 it deliberately practiced non-retrievable burial of large amounts of what the Atomic Energy Commission considered transuranic waste.

The reality of the current situation, however, is that all of the statements about sound management of TRU waste in the 1964-74 period are moot because the site now says that the wastes were actually not retrievably buried. After years of claiming exemplary handling of transuranic waste, the site has declared these wastes to be non-retrievable buried wastes. This is the same waste that the site went through all the trouble to store in "retrievable" concrete casks from 1964-1974 and about which site managers claimed in 1976 that:

> SRP waste management procedures for transuranium wastes are compatible with recovery and removal of buried solid wastes if national policy should dictate. Segregation of waste according to source and radiation levels permits minimum management for much of the area and permits recovery of any one type of waste. Transuranium alpha emitters buried in concrete can be recovered without including soil. Detailed records of waste burial locations will facilitate recovery of wastes.[197]

These claims have turned out to be far too optimistic. Yesterday's "waste management" practices have become today's environmental liabilities.

The Old Burial Ground also contains 22 tanks (numbered S1 - S22) that were used to receive plutonium-contaminated "spent" solvents that were used in the reprocessing plants.[198] Between 1955 and 1974, the tanks in the Old Burial Ground received about 520,000 gallons of solvent from the reprocessing canyons. Between 1956 and 1972, about 370,000 gallons of this solvent were burned off in open pans; this was done to free up volume in the tanks.[199]

In 1975, the Old Burial Ground tanks were reported to contain about 150,000 gallons of spent solvent waste, containing an estimated 90 curies of transuranic radionuclides and 430 curies of fission product radionuclides. The annual production of

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[197] Horton and Corey, 1976, page 42

[198] The spent solvent tanks in the burial grounds are different from the 51 large (740,000 to 1,300,000 gallon capacity) underground high-level waste tanks in the F- and H- areas of the site.

[199] A 1975 memorandum states that "...the inventory of spent solvent was reduced by burning. Incineration was accomplished by slow addition to a fire in a large open pan." (Wilhite, 1975, page 2). The memorandum maintains that burning was halted because "large quantities of black smoke were evolved," in violation of environmental regulations for non-radioactive particulates, and that "very low releases of radionuclides" occurred. Of course, in the context of plutonium-contaminated solvents, "low levels" of radionuclides can be quite harmful.

spent solvent was about 5,000 gallons per year around 1975. The transuranic radionuclides consisted of 60 curies of plutonium-238, 6 curies of plutonium-239, 19 curies of curium-244, with the remainder consisting of neptunium-237 and other "unidentified nuclides."[200] Assuming a density of 1,000 kilograms per cubic meter[201], the waste in the tanks would have a TRU concentration of 158 nanocuries per gram. According to this calculation, this 150,000 gallons would have qualified as TRU waste even under DOE's current definition requiring greater than 100 nanocuries per gram.

However, the spent solvent waste has not been managed as TRU waste. In 1976, some of the liquids from the Old Burial Ground tanks were transferred to tanks in the New Burial Ground (numbered S23 - S32). An incinerator operated during the late 1970s and 1980s that may have burned some of the spent solvent. During the late 1980s and early 1990s, the New Burial Ground tanks underwent a washing process involving a high pressure spray, with the liquids transferred to the New Solvent Storage Tanks (numbered S33 - S36). Tanks S23 - S32 were then filled with concrete and declared "closed."[202]

Currently, three New Solvent Storage Tanks contain 40,000 gallons of spent solvent. The concentration of transuranic elements in the New Solvent Storage Tank with the highest plutonium-238 content is reported as 83 nanocuries per gram. These wastes are slated to be burned over the next 20 years in the Consolidated Incineration Facility.[203]

The spent solvent tanks in the Old Burial Ground still contain residual sludges, although the site does not know how much. Camera surveys of the tanks showed that some tanks also contained liquids. As of Fall 1997, the site was preparing to sample the residuals in the Old Burial Ground tanks, and will use that information in order to evaluate where to send any retrieved spent solvent as well as "closure" options for the tanks.[204]

IEER is investigating how the site accounts for the spent solvent. We do not know how much of the 150,000 gallons present in 1975 might have been incinerated. We also do not know how solvent generated after 1975 is accounted for.

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[200] Wilhite, 1975, page 2.

[201] Ibid, page 1, identifies the solvent as tributyl-phosphate in a hydrocarbon diluent [typically kerosene]. The density of tributyl-phosphate is 972.4 kilograms per cubic meter (Benedict, Pigford, and Levi, 1981, page 511); the density of kerosene is about 800 kilograms per cubic meter.

[202] One tank that was never used was removed from the burial ground. The last two tanks in the new burial ground were closed in 1997. During "closure" of one of the tanks an accidental overflow resulted in release of contamination. On March 3, 1997, while filling a tank with concrete, a contractor accidentally overfilled the tanks, resulting in a release of Pu-238 and Cm-243 to the surface. Levels of 5 million disintegrations per minute (2 nanocuries) of alpha were recorded. An investigation noted a failure to follow procedures and poor planning on the part of the contractor, and concluded that the accident could have been avoided. The subcontractor did not measure the depth of liquid in the tank before pumping grout into the tank, as it was required to do (OE, 1997, pages 4-6).

[203] Sauls, 1997.

[204] Smith, 1997.

2. Quality of TRU Waste Inventory Data

A 1976 report gives the indication that good records of burial trenches and volumes of waste were kept, if not from the very beginning, at least since the site began segregating the waste into different classifications in 1964:

> The supervisor of the solid radioactive waste storage site keeps accurate records of the contents, radiation level, and burial location of each load received. Shipments are described and recorded on a Radioactive Solid Waste Record, and permanent computerized records are maintained on magnetic tape. The exact location of the trenches is defined by use of a 100-foot grid system laid out in 1960. The 100-foot grids are further divided into twenty-five 20-foot squares. Previous to 1960 the trenches were defined with concrete markers.[205]

However, information published by the site between 1994 and 1996 portrays a lack of even the most basic information and includes figures for the volumes and radioactivities of waste that we have not been able to reconcile with historical records.

a. TRU waste volume in burial grounds

The Savannah River Site has reported between 4,500 and 4,900 cubic meters of buried TRU waste in Integrated Data Base Revisions 9 through 12 and the Transuranic Waste Baseline Inventory Revisions 1 through 3 during the years 1994-1996. This waste is classified according to the current DOE definition of greater than 100 nanocuries per gram. A footnote in Integrated Data Base Revision 10 states 4,874 cubic meters is "the volume of [TRU waste] buried from 1952 through 1974.[206]

However, a 1976 report, using the site's own classification of "transuranium alpha waste," reports a total of 1,170,000 cubic feet (approximately 33,000 cubic meters) of TRU waste. This waste was divided between 2,000 cubic meters of "retrievable transuranium alpha waste" and 31,000 cubic meters of "non-retrievable transuranium alpha waste."[207] Recall that under the Savannah River classification used between 1964 and 1974, these wastes were not defined according to the 100 nanocurie per gram definition, but rather according to how many curies per package. While the exact concentration of TRU radioactivity per gram would depend on the package content, typical parameters used by Savannah River indicate that the minimum TRU concentration of the "retrievable transuranium alpha waste" packages would amount to about 3,850 nanocuries per gram. The maximum transuranic content in the "non-retrievable transuranium alpha waste" would therefore be 3,850 nanocuries per gram. Thus, it highly likely that a large proportion, and possibly the vast majority of the 31,000 cubic meters of

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[205] Horton and Corey, 1976, page 17

[206] IDB, 1994, page 116.

[207] Horton and Corey, 1976, page 26. Note that, as discussed above, the 2,000 cubic meters of "retrievable transuranium alpha waste" is now classified as buried (i.e., non-retrievable) waste.

"non-retrievable transuranium alpha waste" might qualify as TRU waste under the current DOE definition (greater than 100 nanocuries per gram).[208]

b. TRU waste radioactivity in burial grounds

For several years, Savannah River submitted to the Integrated Data Base that there were about 9 kilograms of TRU radionuclides, with about 9,800 curies of alpha radioactivity, in the buried TRU waste.[209]

Then, in the 1994 submittal to the Baseline Inventory Report (Revision 1), the mass of radionuclides was not submitted, but the curie content was broken down as shown in Table 21.

Table 21: SRS Estimates for Buried TRU Radioactivity

TRU Radionuclide	Radioactivity, curies[1]	Equivalent Mass, kg
Pu-238	18,455	1.1
Pu-239	15,212	241
Am-241	0.52	0.00015
Total	33,667	241

Note 1: As reported in SRS, 1994.
Conversions: Pu-238 has a specific activity of 17.3 curies per gram; Pu-239 has a specific activity of 0.063 curies per gram; Am-241 has a specific activity of 3.47 curies per gram. There are 1,000 grams in one kilogram.

Converting the curies reported into kilograms based on the specific activity of each radionuclide yields a value of 241 kilograms of TRU elements. This is more than 26 times the amounts reported by the site in any IDB report.

Figure 8 summarizes the volume and radioactivity values reported by the site to DOE's Integrated Data Base report for four different years. Given the discussion above and the information as presented in Figure 8, it is not clear that any of the data published at any time are correct.

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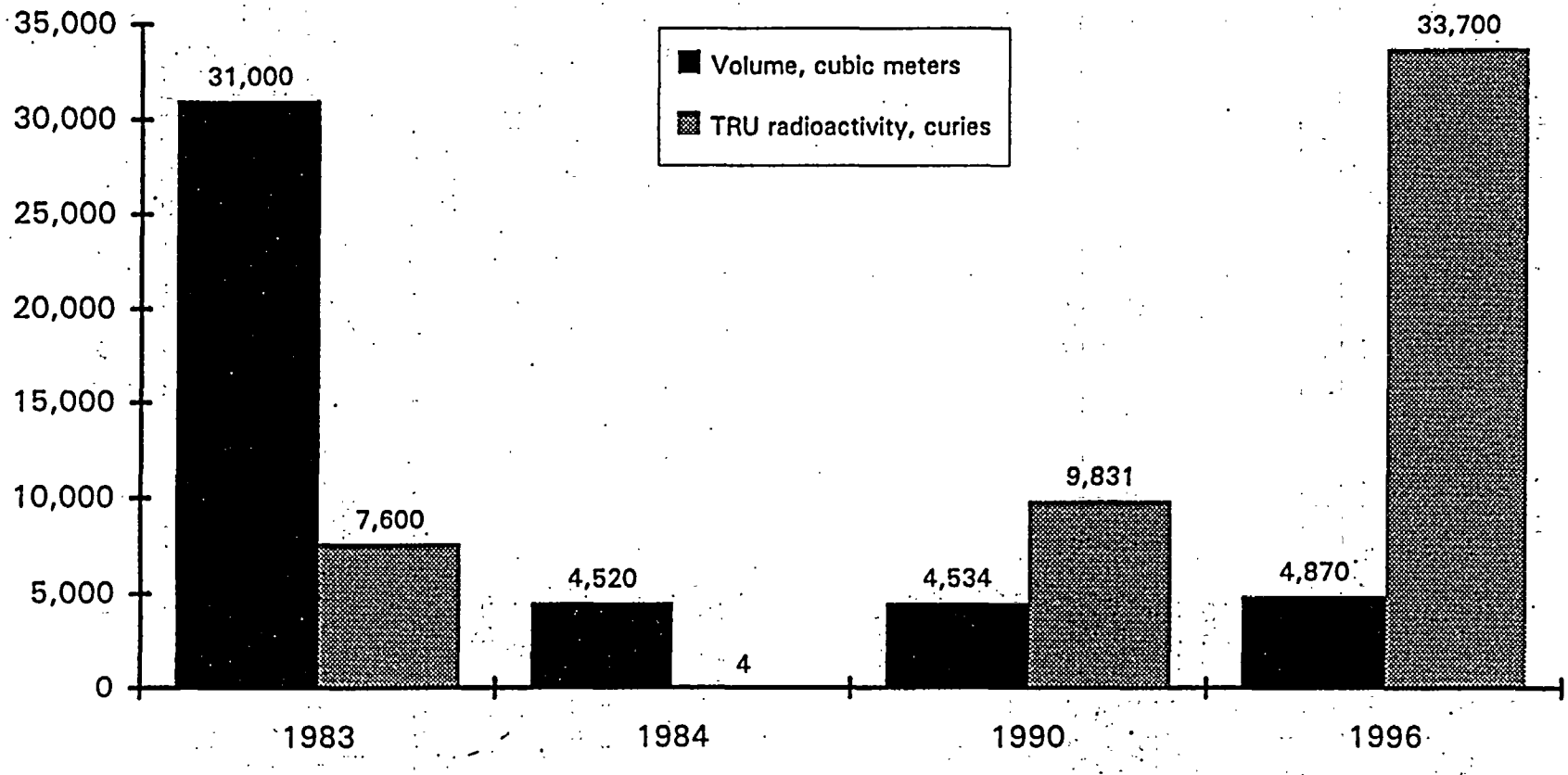
[208] To estimate the nanocuries per gram for "retrievable transuranium alpha waste," we assumed that a typical "package" of waste was a 55 gallon drum weighing approximately 125 kilograms (the figure cited in SRS, 1996b). We also assumed that the package contained the minimum alpha radioactivity to qualify as "retrievable transuranium alpha waste," that is, 0.1 curies. Putting these values together gives a value of 3,850 nanocuries per gram for a package with 0.1 curie:
(0.1 Ci per package) * (1 E9 nCi / Ci) * (package / 0.208 m3) * (m3/125 kg) * (kg /1000 g) = 3,850 nanocuries per gram.

[209] IDB, 1989 to 1991, and DOE, 1984.

Figure 8:
Variation in Data for SRS Buried TRU Waste



Data from Integrated Data Base Reports

Table 22 compares the data on TRU waste to the quantity of plutonium produced during two time periods, 1952 through 1974 and 1975 through 1989. We chose these two time periods because Savannah River classifies TRU waste generated during 1952-1974 as "buried" and TRU waste generated during 1975-1989 as "retrievably stored" and also because 1989 is the last date for which plutonium production data are available.

Table 22: Comparison of TRU Waste Data to Plutonium Production Data

Time Period	1952 through 1974[a]	1975 through 1989
Number of Years in this period	22	14
Quantity of Plutonium Produced, kilograms[b]	25,152	10,927
Volume of TRU waste, cubic meters	4,870[c]	3,143[d]
Alpha Radioactivity of TRU waste, curies	33,500[c]	659,524[d]
Mass of TRU elements, kilograms	Not reported[c] (9 kilograms reported in IDB Rev. 6. The total may be as high as 241 kilograms based on SRS's own data - see Table 21. We have not found any value greater than 10 kg published by SRS, however.)	200.3[d]

[a] Savannah River classifies all TRU waste generated before 1974 as "buried" TRU waste.
[b] Plutonium production data taken from DOE, 1996d, page 33.
[c] Data taken from IDB Revision 12 (1996), page 106, the most recent revision published. As noted in the text, data have varied dramatically.
[d] Data taken from IDB Revision 6 (1990), page 85. Although some of the stored TRU waste data used in this older version appears to have been "revised" in later versions, we use the slightly older data because the data presented in this revision does not go beyond 1989. Using a later IDB revision would result in the inclusion of some TRU waste generated after 1989. In any event, the revisions do not significantly affect the comparison being made.

The data in Table 22 raise two main issues that DOE needs to explain.

1. Despite the fact that less than half as much plutonium was produced during 1975-1989 than during 1952-1974, the site estimates that the alpha radioactivity in waste from the 1975-1989 period is twenty times that in 1952-1974 waste.
2. The source of the discrepancies between the two estimates of the mass of TRU elements in waste from 1952-1974 (9 kilograms, as reported in Integrated Data Base Revision 6, or 241 kilograms, as calculated in Table 21 from Savannah River Site data). DOE should also explain the relation of the 1952-74 estimate to the 200.3 kilograms estimated to be in TRU waste as a result plutonium produced between 1975 and 1989.

The questions raised in our review of Savannah River Site data are disturbing. Not only does the information presented by the site in official documents seem to be changing randomly, the trend is toward a state of less information overall. Site managers in the 1970's described careful record keeping, guidelines set up for location of burial areas, etc. Yet, the 1996 submittal by SRS to the Baseline Inventory Report states that for waste buried between 1952 and 1974 "the waste volumes and activities per year are unknown" - i.e., that records for these wastes are so bad that a year by year account cannot be provided.[210] This begs the question as to what happened to the records kept during waste disposal. These are the wastes that DOE wants to leave buried under a few feet of soil, while at the same time DOE insists on giving priority to putting wastes that are relatively well-characterized and stored in buildings (or being put into buildings) into the WIPP site in New Mexico 2,100 feet underground.

The random variation in data and the lack of consistency and accuracy in reporting indicate a cavalier attitude towards TRU waste. The inconsistencies in the amount of TRU elements in the 1952-1974 waste, amounting to 230 kilograms of TRU materials which include substantial amounts of weapons-usable plutonium, also indicates a lax attitude towards accounting for weapons-usable materials. Savannah River has had similar problems with inconsistencies with the amounts of plutonium in high-level waste tanks - a memo prepared before the release of DOE's "Plutonium: The First 50 Years" report states that Savannah River Site managers believe there are 774.6 kilograms of plutonium in the tanks, whereas the "50 Years Report" claims there are 382 kilograms.[211]

DOE's Environmental Management program presumes that institutional controls will be sufficient to prevent long-lived radioactivity in buried wastes from harming future generations. Such an approach assumes the utmost vigilance and integrity with regard to the amounts, status, and movement of contaminants. The evidence so far leads to a strong conclusion that DOE programs for buried TRU waste do not posess these requisites. In fact, DOE and its contractors do not know the quantities of waste accurately and do not seem to care.

Moreover, all buried TRU waste at all DOE sites should be re-evaluated in terms of the ability to retrieve the waste from its present configuration. Simply declaring a waste as "pre-1970" is a grossly inadequate justification for leaving wastes with dangerous, long-lived, alpha-emitting radionuclides in the ground. The year in which wastes were buried should have no impact on deciding whether it should be left in the ground or not, since what matters is the manner in which it was buried.

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[210] SRS, 1996b
[211] Guimond, 1996.

3. Transuranic-contaminated Soil

Transuranic-contaminated soil has been caused by disposal of solid and liquid wastes. Savannah River reported in Integrated Data Base Revisions 6 - 8 (1990-1992) that solid waste disposal practices had resulted in an estimated 38,000 cubic meters of TRU soil. The site also reported that the transuranic trenches in the "SRP Burial Ground"[212] contained concentrations of 18 nanocuries per gram for trenches where waste was "intimately" mixed with soil.[213] However, in Revisions 9 - 11 (1994-1995), SRS reported "0" as the volume of transuranic-contaminated soil at the site.

Soil has also been contaminated by disposal of liquid wastes containing transuranic radionuclides. Several seepage basins and retention basins have been reported as containing contamination by transuranic radionuclides, although the officially reported values are on the order of less than 5 nanocuries per gram.[214] If these estimates are correct, it would not seem that these areas qualify as TRU waste sites. However, the potential does exist for "hot spots" that contain greater concentrations of TRU radionuclides.

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[212] It is unclear whether this refers to the old, or new, or both, burial grounds.
[213] Arnold, 1980, page 18.
[214] Ibid, page 18.

Mobility Of Transuranic Radionuclides In The Environment

The burial of transuranic wastes has been repeatedly declared as technically sound based on the assertion that transuranic radionuclides are essentially immobile in the environment. For example, at the Maxey Flats commercial radioactive waste disposal site in Kentucky, solid wastes were dumped in unlined trenches and covered with a mounded "cap" that was supposed to prevent water from infiltrating the trenches and mobilizing contaminants in the waste. Arguments for the relative immobility of radioactive contaminants are still in use: a 1995 Environmental Assessment of retrieving waste from a Hanford high-level waste tank assumed that contamination from a leak of 175,000 gallons of high-level liquid waste containing about 100 kilograms of plutonium would have a "remote" chance of reaching the groundwater, since "the majority of radionuclides would be trapped in the top portion of the soil column."[215]

In practice, however, mobility of transuranic radionuclides has been increased by movement of water through the waste trenches, binding of transuranic radionuclides to small ("colloidal") particles that travel unimpeded through groundwater, binding to chemicals and solvents that were also buried along with the transuranic waste, and transport along discrete underground pathways that result in much faster movement than predicted by models using average geologic properties. At the Maxey Flats site, the caps tended to cave in, creating depressions in which rainwater collected. Despite the claims of the site operator (Nuclear Engineering Company, a subsidiary of the Teledyne Corporation) that plutonium would not migrate more than one-half of an inch in 24,000 years, investigations in the 1970s by the State of Kentucky and the U.S. Environmental Protection Agency found plutonium contamination in monitoring wells and drainage streams, concluding that subsurface migration of plutonium off-site had indeed occurred.[216] At the Hanford site, contamination from an estimated leak of 15,000 gallons (about 12 times less than considered in the 175,000 gallon leak mentioned above) from tank SX-113 has gone deeper than the deepest nearby monitoring holes, which are 75 feet deep.[217] In addition, recent studies at the site noted that "plutonium has migrated a surprisingly far distance."[218]

The following section reviews experiences at Oak Ridge and the Idaho Lab.

A. Environmental Contamination at Oak Ridge National Laboratory

Radioactive contaminants present in the groundwater at the Oak Ridge National Laboratory include strontium-90, tritium, cesium-137, cobalt-60, curium-243/244, plutonium-238/239, americium-241, uranium-233/234, radium-226, and radium-228. In addition to contamination resulting from the direct discharge of liquid wastes, significant

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[215] DOE Richland, 1995b, page 5-10.
[216] Lipschutz, 1980, pages 132-134.
[217] DOE Grand Junction, 1996, pages 80-81.
[218] Ibid, page 87.

contamination has resulted from the migration of radionuclides from the burial grounds, transported by percolation of rain and snow through the trenches, as well as inundation of the trenches by high groundwater levels.

Ongoing scientific investigations of the burial areas by the Environmental Restoration program at Oak Ridge indicate that fundamental misconceptions exist about the basic physical and chemical processes by which contaminants move in the shallow groundwater.[219] Findings of these studies have challenged the justifications that have historically been given and continue to be commonly held regarding the safety of buried radioactive wastes, especially transuranic wastes. These investigations, which count among the scientific successes of the Environmental Restoration program, are yielding results contrary to long-held presumptions that transuranic radionuclides are immobile in the environment. As noted in the introduction to this chapter, transport of plutonium via binding to colloidal particles - a mechanism evaluated at Oak Ridge - has also been observed at the Nevada Test Site.

At Oak Ridge, the existence of a high groundwater table, ranging from 30 feet to less than 10 feet below the surface at the burial areas, had been obvious at the time shallow land burial practices took place:

> Even at the onset of waste burials in SWSA 4, it was evident that the buried waste was contacting water during most of the year. Lomenick and Cowser (1961) reported that burial was limited to higher elevations within SWSA 4 during the wet months, whereas the low topography areas were used in the dry summer months.[220]

The groundwater underneath the Oak Ridge site saturates the bottom of burial trenches with water, resulting in the leaching of contaminants from the waste. These contaminants are then carried through the subsurface via the groundwater and are discharged into creeks. The bottoms of some trenches are permanently inundated with water. Other trenches become inundated during periods of high rainfall -- as rainwater infiltrates into the ground, the water table rises high enough so that it inundates these burial pits and trenches. Differences in elevation can also promote the spread of contamination. In long trenches, water leaches contaminants from the waste and accumulates at the lower end, seeping into the soil.[221]

The study by the Environmental Restoration team at Oak Ridge also indicates that the geology of the subsurface layers plays an important role in the movement of radionuclides in the environment. The data indicate that contaminated water can move along "preferred flow paths" in the subsurface that are oriented along bedding and fractures in the soil and shale. Such pathways can result in "significant and rapid transport" of TRU elements.[222]

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[219] The general reference for this section is ORNL, 1996b, chapter 4.
[220] ORNL, 1987, page I-48.
[221] DOE, 1996c, page Tennessee 51.
[222] ORNL, 1996b, page 4-20.

Of special interest are results contradicting theories that adsorption (sticking to the surface) and ion exchange in the soil (chemical trapping) would greatly retard radionuclide migration. For example, measurements have documented the migration of TRU elements from TRU trenches to White Oak Creek. These measurements indicate that the soil and shale does not appear to be retarding migration of transuranic radionuclides to a significant extent.[223]

In fact, the reverse seems to be the case. Transuranic radionuclides appear to adsorb to and form chemical "complexes" with natural organic matter in the soil. These complexes appear to make the TRU radionuclides more mobile. Since the soil has plentiful natural organic matter, transuranic radionuclides complexed with natural organic matter are not retained as they pass through the soil. The Oak Ridge studies concluded that "the organic complex thus permits rapid transport of the actinides [e.g., transuranic elements]."[224] Preliminary estimates indicate that transuranic radionuclides appear to travel 100 to 1,000 times faster "than predicted from batch adsorption studies in the literature."[225] These laboratory "batch adsorption studies" did not include the effect of organic complexant formation in the soil. The fact that the actual composition of the soil is facilitating transport of transuranic radionuclides is in direct contradiction to decades-old assumptions about soil retarding TRU migration. Indeed, even one of the basic assumptions about the geochemistry of transuranic radionuclides in the soil - that they are part of the positively-charged portion (the "cation") of the complexed molecules - appears to be wrong.[226]

The results of the studies by the Oak Ridge Environmental Restoration program contradict DOE's arguments about the immobility of TRU elements in the environment. In fact, there appear to be several mechanisms - including "preferential" pathways in the subsurface and binding of transuranic radionuclides to natural organic matter - that allow for *rapid* transport in the environment.

These results also require a new thinking about proposed "solutions" to the problem of buried TRU wastes. At Oak Ridge, investigations question the standard DOE approach of putting a cap over the trenches and pits to prevent leaching of contaminants from waste since water can enter from the bottom.[227] The conservative assumption, supported by research, is to assume that TRU radionuclides will migrate into the groundwater since their half-lives are very long and there is already evidence of contamination in the course of a few decades. Capping dumps is not a sound remediation strategy. Rather, it just covers up the problem and allows it to fester and become an environmental problem years or decades from now. A strategy that aims at protecting

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[223] Ibid, page 4-19.
[224] Ibid, page 4-20 to 4-21.
[225] Ibid, page 4-20.
[226] Ibid, page 4-20.
[227] Ibid, page 4-22.

land and groundwater resources should aim at retrieval of buried TRU wastes and TRU soil and storage of the wastes in suitable containers in appropriate buildings or sheds so as to minimize the risk to future generations..

B. Environmental Contamination from the Subsurface Disposal Area at the Idaho Lab

Contamination of the Snake River Plain Aquifer, which underlies the Idaho Lab, is of major concern for the state of Idaho and, indeed, the entire country. The Snake River Plain Aquifer is the largest aquifer in Idaho, providing 20% of Idahoan's drinking water and providing irrigation water for farmers. The food from the region is eaten throughout the country and the world.

The groundwater in the Snake River Plain Aquifer generally flows southwestward of the the Idaho Lab, and discharges at a location known as Thousand Springs, about 100 miles southwest of the Idaho Lab. However, the regional groundwater flow is quite complex and only partially understood.[228] Once in the groundwater, it is difficult to predict how the contaminants will be transported. Severe contamination of this sole-source aquifer would, in all likelihood, be impossible to remediate, and would cause long-term irremediable damage to the region. It is, therefore, essential that effective environmental remediation for the buried TRU wastes and TRU soil in the disposal area be implemented.

DOE has relied on the arid climate of the Idaho Lab (8 inches of rainfall per year) and the depth to groundwater (approximately 580 feet) to assume that radioactive contaminants, especially transuranic elements, would not reach the aquifer. It has done so despite long-standing calls for more careful approaches to waste management operations at the Idaho Lab going back to 1960. In that year, the National Academy of Sciences Committee on Geologic Aspects of Radioactive Waste Disposal visited the Idaho Lab. In their report to the Atomic Energy Commission, they state that

> The protection afforded by aridity can lead to overconfidence: at both sites [Hanford and Idaho Lab] it seemed to be assumed that no water from surface precipitation percolates downward to the water table, whereas there appears to be as yet no conclusive evidence that this is the case, especially during periods of low evapotranspiration and heavier-than-average precipitation, as when the winter snows are melted. At the NRTS [Naval Reactor Testing Station - the former name of the Idaho Lab], pipes were laid underground without ordinary safeguards against the corrosion on the assumption that the pipes would not corrode in the dry soil, but they did. At NRTS plutonium wastes are given shallow land burial in ordinary steel drums on the same assumption. Corrosion of the drums and ultimate leakage is inevitable...The movement of fluids through the vadose zone and the consequent movement of the radioisotopes are not sufficiently understood to ensure safety.[229]

Five years later, the National Academny of Sciences revisited the Idaho Lab and noted that "considerations of long-range safety are in some instances subordinated to

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[228] Cahill, 1990.
[229] National Research Council, 1966, page 5.

regard for economy or operation, and that some disposal practices are conditioned on over-confidence in the capacity of the local environment to contain vast quantities of radionuclides for indefinite periods without danger to the biosphere."[230] According to Lipschutz, instead of acting on the 1966 conclusions of the National Academy committe, the Atomic Energy Commission chose to suppress the report. It was only released in 1970 under pressure from the U.S. Senate.[231] Had action been taken after the first National Academy report in 1960, or after the second, in 1966, problems at the Idaho Lab would be far less daunting. For instance, it is now estimated that digging up and treating TRU wastes dumped during 1968 in the one-acre Pit 9 site at the Idaho Lab is estimated to cost over $400 million dollars.[232] This is another vivid example of yesterday's "waste management" becoming tomorrow's environmental problems -- despite warnings at the time that it would be so.

The concerns of the National Academy of Sciences have proven to be well-founded. Contaminant plumes of radiochemical and chemical constituents in the Snake River Plain Aquifer have been linked to waste-disposal practices at the Idaho Lab. Since 1949, the U.S.Geological Survey has monitored the groundwater at the the Idaho Lab. Radionuclides and chemical contaminants in the groundwater that have been detected by the USGS in the Snake River Plain Aquifer include tritium, strontium-90, cesium-137, plutonium-238, plutonium-239/240, americium-241, chromium, sodium, chloride, sulfate, nitrate, lead, mercury, and organic compounds.[233]

Several different waste disposal practices at the Idaho Lab are the source of contaminants in the Snake River Plain Aquifer, including infiltration ponds and ditches, drain fields, and disposal wells. In addition, contamination has resulted from movement of chemicals and radionuclides, including americium-241, from the burial pits and trenches in the Subsurface Disposal Area.[234]

In order to reach the Snake River Plain Aquifer beneath the Subsurface Disposal Area, contaminants from buried wastes must breach their original containers and travel through the waste pit or trench and down through about 580 feet of geologic layers (or strata) which are composed mostly of different types of basalt that have resulted from past lava flows. In addition to the basalt, there are intermittent layers of sedimentary strata (or interbeds), most extensively at a depth of 110 feet and 230 feet, each of which may be up to a few feet thick. Some of these interbeds contain water referred to as "perched groundwater." The geologic layers between the ground surface and the top of the groundwater table of the Snake River Plain Aquifer (at 580 feet depth) are referred to as the unsaturated zone or the vadose zone. Since DOE has relied on this geology to keep

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[230] Cited in Barraclough, 1976, page 4.
[231] Lipschutz, 1980, page 118.
[232] See the discussion of the Pit 9 project at the end of this chapter.
[233] USGS, 1995, p.22
[234] Americium-241 attributable to the burial grounds was measured in the Snake River Plain Aquifer by the U.S. Geological Survey between 1972 and 1982. From September 1982 through 1991, concentrations were "below the reporting level" (USGS, 1995, page 30).

the wastes from reaching the aquifer (and failed), it is worthwhile to consider the issue in some detail.

Each of the different geologic layers that contaminants must travel through in order to reach the groundwater may be thought of as a zone of either *discrete* or *diffuse* flow.[235] In diffuse flow, water carrying contaminants moves uniformly through a homogeneous layer of material; this type of flow would be observed in soil at the bottom of a pit or in the sedimentary interbeds. Flow conditions are relatively homogeneous in diffuse flow. By contrast, in discrete flow, water carrying contaminants moves through a heterogeneous material, and will preferentially flow in certain voids such as fractures, cavities, and lava tubes, Discrete flow would be observed in the buried waste layer (where voids result from gaps between waste packages) and basalt layers. In discrete flow, which is non-homogeneous, the rate of movement of water can be very high under certain conditions, and contaminants are subject to substantially less natural filtration and absorption than they would be in diffuse flow. Layers conducive to diffuse and discrete flow can occur sequentially with depth.

The diffuse zones under the Idaho Lab represent only a small fraction of the total volume of rock between the buried waste and the groundwater table; most of the subsurface water flow involves non-homogeneous conditions.[236] A 1980 review committee formed by DOE's site contractor, EG&G Idaho, suggested that the following assumptions be used when trying to model the transport of radionuclides from the burial areas:

- Substantial quantities of water pass through buried radioactive wastes at the Idaho Lab
- Water infiltrating the soils over buried radioactive wastes will enter the subsurface through both diffuse infiltration and discrete infiltration zones. Significant infiltration will occur through discrete zones.
- The migration of contamination through discrete zones is aggravated by water periodically accumulating at the at the bottom of disposal pits, a phenomenon known as "ponding."
- Groundwater recharge to the Snake River Plain Aquifer may occur through both diffuse and discrete zone recharge. Both of these recharge categories may transport significant quantities of water.
- Interactions between and among discrete zone and diffuse infiltration, discrete zone and diffuse groundwater recharge, need to be modeled appropriately.[237]

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[235] This conceptual description of discrete and diffuse flow is taken from Associated Resource Consultants, 1980.

[236] Site reports generally clam that a few feet of soil was put in the bottom of the pits before waste was emplaced (e.g., Arrenholtz and Knight, 1991, page 3), although at least one report states that "before 1970, little or no sediment was retained between the excavation bottoms and the underlying basalt" (USGS, 1995, p.17).

[237] List taken from Associated Resources Consultants, 1980, pages 67-70.

In view of the established facts of rapid migration pathways and of the contamination of the Snake River Plain Aquifer that has already occurred, DOE's strategy of leaving large inventories of long-lived radionuclides in dumps on site is environmentally unsound and should be abandoned. Even in the one case where DOE has initiated an effort to retrieve buried TRU waste, Pit 9 (see below), it plans to leave a large amount of waste in the pit. All pits and trenches containing substantial amounts of long-lived radionuclides should be excavated and the wastes they contain, including contaminated soil, should be put into retrievable storage.

Additionally, we strongly recommend that the blanket assumptions used by DOE regarding immobility of transuranic radionuclides be abandoned and that groundwater and risk assessment models which rely on these assumptions be thoroughly revised to reflect actual experience.

DOE's Techniques for Remediation -- Examples

A. Capping of Savannah River Site Old Burial Ground

The groundwater beneath the Old Burial Ground contains numerous hazardous and radiological contaminants. Those measured above drinking water standards are listed in Table 23. The plume of groundwater contamination seeps into a stream next to the Old Burial Ground and from there travels to Four Mile Creek, which is about 1 mile from the perimeter of the burial ground. Four Mile Creek is a tributary of the Savannah River.

Table 23: Contaminants in the Groundwater Beneath the SRS Old Burial Ground

Radioactive Contaminants	*Nonradioactive Contaminants*
carbon-14	antimony
cesium-137	cadmium
neptunium-237	carbon tetrachloride
plutonium-238	chloroform
plutonium-239	lead
strontium-90	mercury
technetium-99	1,1 dichloroethylene
tritium	tetrachloroethylene
uranium 233/234	trichloroethylene
uranium 238	

Sources: DOE SRS, 1996b and Connor, 1992.

At the Savannah River Site, a "cap" is being placed over the 76-acre Old Burial Ground as an "Interim Action" to reduce the amount of water percolating down through the buried wastes. The cap will consist of at least a two foot thick layer of compacted soil. The soil will be covered with at least 6 inches of topsoil and seeded with shallow rooted grass to reduce erosion. The 18-month project was estimated to cost $10 million and begin in 1997.[238]

The cap will be placed over the existing soil cover, generally about four feet thick, which was added to provide shielding from radiation from the waste in the trenches. It was not designed to reduce water infiltration. The cap being installed is specifically designed to reduce the amount of rainwater that can leach contaminants from the waste.

In the Interim Action Record of Decision, a more substantial cap, such as a "geotextile," or tarp-like layer, was rejected on the basis that it would hinder on-going characterization of the burial ground area and because it would be ruined if contents of

[238] DOE SRS, 1996b, page 13.

the burial ground were to be dug up. The Interim Action Record of Decision states that the action chosen, installation of a two-foot soil cap,

> provides for a reduction in contaminant mobility without hindering ongoing characterization efforts conducted as part of the BGC [Burial Ground Complex] Field Investigation Plan and without precluding any final remedial action plan developed during the FFA [Federal Facility Agreement] process for the BGC.
> This is an interim RCRA/CERCLA action and in no way constitutes a final action for the ORWBG [Old Radioactive Waste Burial Ground]. A final remedial action will be evaluated and conducted in the future according to the requirements of the FFA.[239]

The site also claims that the cap would increase the amount of shielding for any future removal efforts.[240] However, the two to three feet of additional soil on top of the burial ground could present problems as it ages since the action is not final and some eriosion is anticipated in the normal course of events. All caps will require active maintenance to retain their integrity, and as such, are of questionable effectiveness as a long-term option for areas with long-lived radioactive waste.

Reducing the amount of water infiltrating the burial grounds is an important action, especially given the SRS location in the humid eastern United States. Problems with rainfall have been observed in the burial trenches since they were operational, as water was observed to pond in the trenches while they were open. This issue is being addressed only now, twenty five years too late.

At the time of the Interim Action decision, site managers acknowledged that they had insufficient knowledge regarding locations of "hot spots" or other wastes that might need to be removed. The ongoing Remedial Investigation / Feasibility Study is supposed to provide such information. A Proposed Plan is expected to be announced in 1999, with a final remedial decision by 2001.[241] This is too slow a timetable for acton, given that the groundwater under the OBG has alredy been contaminated. DOE should, in parallel with the effort to reduce inflitration, attempt experimental waste retrieval from hot spots.

As discussed above, the site has published inconsistent and confusing data on the volumes, mass and radioactivities of buried transuranic waste at the site. In order to properly assess the risks of the buried waste, these data quality issues must be addressed with a high priority and technical integrity. Under DOE's TRU waste classification, the incentive is for Savannah River and other sites to recategorize as much of its transuranic waste as "non-retrievable" or "alpha low-level" waste as it can. This reduces cost for short-term waste management, treatment, and repository disposal. DOE seems to be not dealing with this more environmentally-threatening and messy TRU waste because, as

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[239] Ibid.
[240] Ibid, page 13.
[241] Ibid, pages 6 and 33.

discussed in the introduction to this chapter, its focus is on WIPP, mainly for political reasons.[242]

B. In-Situ Vitrification of Seepage Pits and Trenches at Oak Ridge

During 1952 to 1966, seepage pits and trenches at Oak Ridge received an estimated 160,000 gallons of "intermediate level" liquid waste containing large quantities of ruthenium-106, cesium-137 and strontium-90, as well as smaller quantities of transuranic radionuclides. Concentrated liquid wastes and sludges high in transuranic elements were sent to the pits. High concentrations of technetium-99 have been found in groundwater and the leaves of trees. Plutonium-238, -239, and -240 have also been found in nearby soils.

The pits have been backfilled and paved over. In April of 1996, an attempt was made to "vitrify" the contents of pit 1 as a "treatability study." The treatment technology, *in-situ vitrification*, involves placing electrodes into the ground surrounded by materials (graphite and glass frit) that serve as an initial "starter path" for the electrical current. The starter path material carries the initial current until the adjacent material -- the contaminated soil in the pit -- melts. Heat is conducted outward from the electrodes, turning the soil into a vitreous material. As the melt grows in extent, nonvolatile radionuclides and inorganics are incorporated into the molten soil. Organic components are destroyed by the high temperatures. A hood is placed over the melt area to collect the gases that are generated from the melting.

The advantages of the method are that it would destroy the organic toxic material in the soil also and render the radionuclides relatively immobile. However, the formation of glass is a chemically complicated process that is sensitive to the composition of the materials being vitrified. Thus, heterogeneous soils vitrified without additives can be expected to produce non-uniform glass that may frequently be of poor quality. Moreover, lack of annealing could result in a large number of cracks and hence create the potential for rapid leaching of the constituents.

During the April 1996 test at Oak Ridge, an underground explosion occurred during the melting process, that lifted the 7.5-ton hood from the ground, allowing steam containing small amounts of radioactive materials to be released. A technical evaluation of the accident revealed that

> Vent pipes were installed prior to the melt to provide a relief path for pressure that may build up in the volume of soil beneath the melt...However, vent pipes were not installed at the expected lowest levels of the melt ... At the time of the melt expulsion event, the melt had progressed past the deepest pipe vent.[243]

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[242] IEER, 1997a.
[243] OREPA, 1996.

In soils with high moisture content, such as many areas of the Eastern United States, significant volumes of steam can be created during in-situ vitrification. As a result, venting of the subsurface melt is especially critical component of the setup. If done improperly, an explosion such as occurred at Oak Ridge represents a significant danger.

There were other concerns in addition to technical flaws in the project design. Although "expulsions" occurred in three out of seventy large previous in-situ vitrification projects[244], an environmental, health, and safety investigation noted that such an accident

> was judged by the project team and the Pacific Northwest National Laboratory oversight committee to be remote considering the additional precautions that were taken and the characteristics of the site. The conclusion that [an "expulsion"] was remote was not aggressively challenged by the safety analysis ... or the readiness review process.[245]

The investigation also noted that several preventative and mitigative procedures that were committed to were not fully executed. Thus, the possibility of an "expulsion" was dismissed as remote, at least partly due to extra precautions that were then not implemented. In any event, the investigation report concluded that even full implementation of these measures would not have prevented an "expulsion" from occurring.

Aside from inadequate safety precautions and other management and implementation lapses, in-situ vitrification is an inadequate solution to the buried waste and contaminated soil problem for the reasons that we have cited. Soil vitrification is part of a "sacrifice zone" mentality across the weapons complex that DOE needs to get rid of. Consequently, funding of technology development for in-situ vitrification should be completely and immediately discontinued.

C. Extraction and Treatment of Buried Transuranic Waste at the Idaho Lab -- The Pit 9 Remediation Project

In 1991, DOE initiated the first large-scale effort to deal with buried transuranic waste. It proposed to remove TRU waste from one of the pits at the Idaho Lab - Pit 9. The Pit 9 project was to be the first attempt to dig up and treat buried TRU waste at any DOE site.

The Pit 9 project has become one of the highest-profile projects in DOE's Environmental Management program. The implementation of this project and the results to date have been a dramatic example of poor management and technical and financial failure. The project is beset with major difficulties. The retrieval and treatment of the waste was originally estimated to cost $50 million in the 1993 Record of Decision; Lockheed Martin Advanced Environmental Systems (Lockheed Martin AES), the

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[244] ORNL, 1996d, page xviii.
[245] ORNL, 1996c, page v.

contractor for the project, has estimated its costs through June 30, 1997 to be $257 million. This increase has occurred without retrieval and treatment system designs having even been finalized, never mind built, tested, and completed. Major components that have been designed or built are not in compliance with the terms of the contract. In March 1997, the contractor indicated that its final costs would be over $400 million. DOE, its site contractor (Lockheed Martin Idaho Technologies Company), and the project contractor (Lockheed Martin AES) are now in negotiations to determine whether the contract -- a fixed-price contract -- will be upheld, or whether the cost increases will be allowed.[246] In March 1997, Lockheed Martin estimated that it would not be able to complete the contract until April 2001. The initial plans called for completion of the project in February 1998.

Below, we review the history of the project and discuss the implications that it has for completion of the project, for TRU waste management, and for other projects in the Environmental Management program. In addition, since the project is at a standstill, we point out several project assumptions and objectives that should be re-evaluated.

1. Alternatives for Remediation of Pit 9

The entire Idaho Laboratory was placed on the National Priorities List of CERCLA ("Superfund") in 1989. Under CERCLA, sites are divided up into different "Waste Area Groups" to manage remedial actions. One of the Waste Groups consists of the Radioactive Waste Management Complex, which includes pits and trenches used for burial of TRU waste.

In 1991, DOE proposed an "interim action" -- to dig up and treat wastes from one of the pits containing TRU waste. DOE envisioned starting remediation for one pit as an "interim action" before proceeding with remediation for the other pits and trenches in the 36-hectare Subsurface Disposal Area. In this sense, the use of an "interim action" would allow DOE to gain experience before making decisions for remediation of the rest of the disposal area. DOE stated in its 1993 Record of Decision that Pit 9 was chosen because it has a more complete set of disposal records and because it was in a preferable location since it is somewhat isolated from other pits and trenches, allowing for easier operations.[247]

Pit 9 has an area of 0.5 hectares (about one acre), measuring roughly 41 meters by 122 meters; it is about 6 meters deep. The pit was used for disposal of transuranic waste for only a few months - from May 1968 through September 1968, and was closed in June 1969.[248] The waste characteristics, so far as they are known, are described in the Record

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[246] Lockheed Martin Idaho Technologies Company has managed the Idaho Lab -- including the Pit 9 project -- for DOE since October 1994. Lockheed Martin Advanced Environmental Systems was awarded a contract for the Pit 9 project in August 1994. Both subsidiaries of the same company, Lockheed Martin.
[247] INEL, 1993, page II-4.
[248] Card, 1977, p.23.

of Decision. The pit contains approximately 4,000 cubic meters of waste, 10,000 cubic meters of soil between and below the buried waste, and 7,000 cubic meters of soil "overburden" (soil used to cover the pit once it was filled with waste). Site records indicate burial of 3,937 drums and 2,452 boxes of waste, as well as 72 "unspecified containers." The Record of Decision notes that "the boxes were generally disposed of at the north end of the pit, and the drums were generally dumped in the south end, although intermixing of containers in the pit did occur as a result of pit flooding in 1969." Waste identified as "atypical" includes a 100,000 kilogram (220,000 pound) carbon steel reactor vessel sized into 12 pieces.[249]

Remediation alternatives evaluated in the Record of Decision included (i) a "no-action" alternative, (ii) vitrification of the waste *in-situ*, (iii) vitrification without physical separation or chemical extraction, (iv) physical separation, chemical extraction, and stabilization[250], and (v) complete removal, repackaging, and interim storage on-site (pending identification of an off-site disposal location) of all waste in the pit.

DOE did not consider another alternative -- complete removal and treatment of all wastes. This alternative was suggested to DOE, but rejected simply on the grounds that the cost was "substantially higher" than DOE's proposed alternative of physical separation, chemical extraction, and vitrification.[251]

As discussed above in the section on *in-situ* vitrification of TRU soil at Oak Ridge, *in-situ* vitrification is an inappropriate and inadequate technology. The Record of Decision noted several concerns in applying this technology to a disposal pit containing the wide range of materials such as occur in Pit 9:

- gases generated from combustible materials may overwhelm the off-gas system
- metals such as mercury and cadmium may not incorporate into the melt or may reduce the quality of the melt
- contaminants may migrate into surrounding soil prior to vitrification
- metals in the pit may cause an electrical short between electrodes.[252]

Table 24 presents a summary of the three other alternatives that were considered in the Pit 9 Record of Decision (not including the "no action" alternative).

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[249] INEL, 1993, pages 7-12.
[250] Vitrification was eventually chosen as the means of stabilization. We use "vitrification" instead of "stablization" in the remainder of this discussion, to reflect this, even though the Record of Decision does not specify what type of stabilization is required.
[251] INEL, 1993, page I-9.
[252] Ibid, page 32.

Table 24: Comparison of Alternatives in Pit 9 Record of Decision

	Physical separation, chemical extraction, vitrification	Vitrification (no separation or extraction)	Complete removal (no treatment)
Excavated volume[1]	7,000 cubic meters	7,000 cubic meters	14,000 cubic meters
Volume remaining in pit[1]	7,000 cubic meters (this material would contain non-radioactive toxic chemicals and metals, as well as less than 10 nanocuries per gram of TRU)	7,000 cubic meters	0 cubic meters
Final volume to be managed as TRU waste	700 cubic meters	3,500 cubic meters	14,000 cubic meters
Excavated material returned to pit[2]	Materials less than 10 nanocuries per gram	None	None
Cost for Treatability Study	$16,000,000	5,000,000	0
Cost to Implement			
Op.&Maint.	*$29,102,000*	*4,063,000*	*59,660,000*
Capital	*$20,661,000*	*25,337,000*	*26,768,000*
Subtotal	$49,763,000	29,400,000	86,428,000
Cost for Management of TRU waste[3]	$61,950,000	130,815,000	261,623,000
Total estimated cost	$127,713,000	165,215,000	348,051,000

Source: INEL, 1993, Section 7.

Note: The Record of Decision does not state what year the dollars are in. A document published in October 1992 used the same figures (INEL, 1992), which were updated estimates of figures published in a December 1991 document (INEL, 1991). Presumably, then, the figures in the table are 1992 dollars.

[1] Does not include soil overburden (7,000 cubic meters), some of which is contaminated.

[2] This is in addition to material that is not to be removed from the pit (i.e., the volumes listed in Row 2).

[3] Includes cost estimates for interim storage, transport, and long-term disposal.

The complete removal (no treatment) alternative shown in Table 24 had the highest costs, which were were driven by the large volume of waste that would need interim storage, transport, and disposal. DOE rejected the need for complete removal on the grounds waste containing less than 10 nanocuries per gram of TRU elements was consistent with "low-level" waste management practices at the Idaho Lab. As a result, DOE estimated that it could leave half of the 14,000 cubic meters of waste and soil (not counting the overburden) in the pit. Moreover, it would then put waste containing less than 10 nanocuries per gram back into the pit. Thus, the complete removal (no treament) alternative was ruled out.

The two other alternatives shown in Table 24 differed by whether or not retrieved waste would be subject to pretreatment -- separation and extraction -- before the vitrification step. The pretreatment alternative was estimated to have lower overall costs, due to the fact that a lower volume of TRU waste was anticipated, 700 cubic meters versus 3,500 cubic meters. DOE also expected that the pretreatment steps would increase the efficiency of vitrification of the pretreated waste stream.[253]

These arguments are all now moot because estimated costs have increased to over $400 million -- greater than costs for any of the alternatives considered in Table 24. Crucial assumptions made by DOE regarding the total transuranic content of the pit, the maturity of the pretreatment technology, and the cost have been proven wrong. The project has been halted until DOE and its contractors can resolve their disputes (see below).

2. Selected Alternative - Physical Separation, Chemical Extraction, Vitrification

In selecting the alternative involving physical separation, chemical extraction, and vitrification, DOE chose an "interim action" that was only a partial solution. As such, after the Pit 9 project is complete, the pit would still contain transuranic radionuclides as well as non-radioactive hazardous materials. Thus, the contents of the pit could require further treatment. DOE did state that it would consider such wastes in a future risk analysis to be completed for the entire Idaho Lab disposal area.[254]

DOE's claims about the safety of materials left in or returned to the pit does not seem to be based on a conservative analysis. The Record of Decision does not indicate that transport modeling was carried out for radiological contaminants other than transuranics or for non-radiological contaminants such as chemicals and heavy metals.[255] Moreover, the analysis was made prior to completion of a 1995 study that estimated the radioactivity of TRU elements in Idaho Lab disposal area to be nine to twelve times

[253] Ibid, page 32.
[254] Ibid, page 14.
[255] Ibid, page 42.

higher than previously thought.[256] Also, we have not seen evidence that DOE has systematically corrected its past serious miscalculations regarding the mobility of TRU elements in the environment.

The remediation chosen in the Pit 9 Record of Decision was to involve two major components -- the retrieval system and the treatment system. The retrieval of the pit contents was to have several features to minimize the escape of contaminated dust and reduce worker exposure. Waste and soil would be removed using a remotely-controlled excavation system. The excavation would be performed in a building that would span the width of the pit and be designed to travel along the length of the pit. The retrieval building was to have a double confined structure.[257] The space in between the two structures was to be controlled by a pressure regulation system that would filter the air and keep the space between the two structures at negative pressure.

The excavated waste would be sent to the treatment building, located next to the pit. Retrieved waste would undergo physical separation and/or chemical extraction. Two waste streams would result from the physical separation / chemical extraction steps: one would contain less than 10 nanocuries per gram of TRU radioactivity and would be returned to the pit; the other would contain greater than 10 nanocuries per gram and be managed as TRU waste.[258] The TRU waste would be then be stabilized -- plasma arc vitrification was eventually chosen as the stabilization technology -- and then stored in the Transuranic Storage Area at the Idaho Lab. In the contract awarded for the Pit 9 project, the final volume managed as TRU waste was required to be less than 10 percent (approximately) of the volume retrieved from the pit.[259]

Although the Record of Decision states that TRU waste was to be disposed of off-site, no location was identified and no date for removal from the Idaho Lab was set. The Record of Decision stated that it was not eligible for DOE's planned TRU waste repository, the Waste Isolation Pilot Plant in New Mexico, because the Waste Acceptance Criteria for WIPP prevent disposal of any wastes that have been previously buried.[260] More recently, however, site officials now claim that these wastes would be eligible for WIPP because after treatment they are considered "post-1970" TRU waste.[261]

The contractor would be selected from two competing teams that would participate in a Proof-of-Process phase. The winning contractor would then have to pass a Limited Production Test prior to full-scale remediation. The remedial activity itself (i.e., retrieval and treatment) was estimated to cost $50 million dollars, as shown in Table

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[256] See Table 14.
[257] INEL, 1993, page 23.
[258] Ibid, pages 14-16.
[259] EG&G, 1994, page 15.
[260] INEL, 1993, page II-6.
[261] Jackson, 1996.

24. It was estimated that an additional $62 million would be required for long-term storage and off-site disposal, for a total project cost of $128 million.[262]

The initial schedule estimated completion of the treatment facility design by March 1996, to be followed by a Limited Production Test from August through December 1996. Following a successful Limited Production Test, full-scale remediation would take place for about one year, finishing in February 1998.[263]

3. Initial Bids on Project and Proof-of-Process Testing Results

The Proof-of-Process phase of the project provided $16 million for two competing contractors to conduct tests to demonstrate the ability of the technology to meet certain performance criteria.[264] One of the teams to be awarded the contracts for the Proof-of-Process was led by a Lockheed subsidiary and the other was led by Rust Federal Services.[265] The Proof-of Process phase did not involve a comprehensive test of the entire process, but only tested key aspects of crucial components of each team's technology. The Proof-of-Process phase was completed in December 1993 and both of the teams that participated passed the tests and received payment for doing so.[266]

Although DOE had intended to make no payments until remediation began, the GAO report notes that DOE decided that it would make some payments in order to keep financing costs low for the contractor. These would be awarded as design and construction milestones were met. Thus, contrary to DOE statements and popular perception, fixed-price and privatization contracts do not necessarily mean that DOE does not put money up front.[267] Because it was making the payments, however, DOE required that the contractor guarantee that if it did not pass the Limited Production Test, it would be required to return all payments.[268] The General Accounting Office report noted that the Rust team did not provide this guarantee, and was therefore disqualified from the contract.

This left the Lockheed team as the final participant; it was awarded the contract in October 1994.[269] It is interesting that DOE had to conduct the contract negotiations instead of the site contractor. During 1994, another Lockheed subsidiary, Lockheed

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[262] INEL, 1993, page 19.
[263] INEL, 1995a, page 2.
[264] The criteria are summarized in INEL, 1993, pages 34-35.
[265] The Lockheed subsidiary was originally named Lockheed-AWC, which then changed its name to Lockheed Environmental Systems and Technologies, and finally, after the merger between its parent company, Lockheed, and Martin Marietta, the subsidiary became known as Lockheed Martin Advanced Environmental Systems, which we refer to as Lockheed Martin AES (GAO, 1997c, page 8).
[266] GAO, 1997c, pages 9-10.
[267] For example, in the *Accelerating Cleanup* Discussion Draft, DOE states that privatization "helps to accelerate cleanup despite budget constraints because budget outlays are deferred until products and services that meet performance specifications are delivered" (DOE, 1997c, page 5-3).
[268] GAO, 1997c, page 10.
[269] The contract states that it is effective as of a few months prior -- August 1994 (Lockheed, 1994).

Martin Idaho Technologies Company, had been awarded the Management and Operating (M&O) contract at the site. In order to avoid potential conflict of interest between the two Lockheed subsidiaries, DOE conducted the final negotiations. The General Accounting Office notes that to address potential conflict of interest during oversight of the contract, managers from the Lockheed Martin Idaho Technologies Company responsible for the Pit 9 project were sequestered from the rest of the organization and an oversight board was set up to monitor communications between the two subsidiaries.[270]

4. Award of Fixed Price Contract; Retrieval and Treatment Cost Increases from $50 Million to $179 Million

The contract awarded to the Lockheed team, effective August 1994, included a cost increase for retrieval and treatment from $50 million (estimated in the October 1993 Record of Decision) to $179 million -- nearly a quadrupling in just over one year.[271] Because of the large increase in the cost of the project, DOE issued an "Explanation of Significant Differences" in January 1995 in which it explained that

> The costs in the negotiated fixed-price subcontract significantly exceeded estimated project costs in the ROD... Since this Pit 9 operation is a first of a kind facility and operation, much uncertainty existed when the initial estimate was prepared. The Pit 9 ROD cost estimates did not include allowances for project management, contingency, profit, or escalation, and underestimated the capital as well as operation and maintenance costs.[272]

This list of omitted and underestimated costs essentially covers all project cost categories. If such gross misestimations were discovered within a year of the Record of Decision, why were they not discovered earlier? The failure to discover any of the major elements of cost underestimation during the bidding and Record of Decision process raises a host of questions regarding the integrity of the bidding and contracting process that we cannot address, much less resolve, within the scope of this report. But it is evident that it is part of a pattern of DOE misestimating costs and then allowing huge cost increases without careful consideration of the basis for its escalation.

The Explanation of Significant Differences goes on to state that since the contract was a fixed-price contract, the cost could not change again unless "major project

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[270] GAO, 1997c, page 11.

[271] According to the General Accounting Office, Lockheed Martin AES' "Best and Final Offer" was $206 million, but DOE did not want to allocate more than $180 million to the project. During final negotiations, the costs were reduced by $6 million because DOE agreed to assume some of the financing costs. Additionally, DOE allowed the contractor to allocate $21 million in equipment to future work. If the contractor proceeded with this work, it would receive the $21 million. If it did not, DOE would be required to pay the $21 million anyway. Thus, the GAO refers to cost of the *contract* as $200 million since the $21 million would be paid to the contractor regardless of whether or not it performs additional work (GAO, 1997c, page 11). The total cost for the *project*, as stated in the Explanation of Significant Differences, was estimated at $264 million: $179 million payable to Lockheed Martin AES plus $6 million in financing covered by DOE plus $16 million for the proof-of-process testing plus $62 million for long-term storage and disposal.

[272] INEL, 1995b, page 4.

assumptions change."[273] Also, the Explanation of Significant Differences notes that the cost estimates "have been considerably refined from the original estimates which were based on conceptual design information; therefore, costs are now better defined."[274] As it has turned out, "better defined" costs are still subject to increases of more than a factor of two -- in March 1997 Lockeed Martin AES claimed that over $200 million dollars is needed in addition to the cost increase explained in the Explanation of Significant Differences.

5. Performance of Lockheed Martin AES under the "Fixed Price" contract

Under the fixed-price contract, Lockheed Martin AES became solely responsible for the technical success of the project; DOE was removed from direct management and implementation of the project. The Defense Nuclear Facility Safety Board noted that "The contract for Pit 9 essentially privatizes the project such that DOE will pay [the Lockheed team] for its waste processing services and [the Lockheed team] will have full ownership and responsibility for the treatement facility."[275] However, DOE still retained responsibility for approving the safety analysis and startup.

The fixed-price contract required successful completion of the project in order for Lockheed Martin AES to receive full payment. The General Accounting Office noted the contract was awarded based on "a guarantee of performance under which the company would return all payments received if its treatment system failed to work properly."[276] According to the GAO, $54 million has been paid to Lockheed Martin AES through May 31, 1997.[277] Moreover, Lockheed Martin AES has already exceeded the $200 million dollar contract -- it has requested $257 million for its work through June 30, 1997.[278]

The GAO noted that senior DOE officials proceeded with this type of contract because "private industry was confident that it had the technology to clean up the wastes."[279]

Indeed, Lockheed Martin AES touted the capabilities of its treatment system. In the Technical Proposal of its "Best and Final Offer," Lockheed Martin AES claimed

> The treatment system is very robust, in that any chemical, radiological, or physical characteristic of waste in Pit 9 can successfully be processed. No comprehensive pre-processing characterization is required, so costs and the potential for personnel exposure and contamination release (either chemical or radiological) are dramatically reduced. [page 1-3 of Best and Final Offer]

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[273] Ibid, page 5.
[274] Ibid, page 6.
[275] DNFSB, 1995b.
[276] GAO, 1997c, page 2.
[277] Ibid, page 26.
[278] Ibid, page 2.
[279] Ibid, page 6.

> Our mixed waste remediation process has very **high performance.** From contaminated buried waste and surrounding soil, our process produces only clean material and highly stable TRU waste.
>
> Lockheed's remediation is **comprehensive and integrated.** We have identified, defined, and managed all material streams in our design. We have selected remediation unit processes that are compatible with natural matching of inputs and outputs among the unit processes. [Section 2.1.1 of Best and Final Offer. Emphasis in original] [280]

The fixed-price contract made the Pit 9 project a financial experiment. It was a test of DOE's "privatization" program under which DOE is seeking to transfer the risk of technical success to its contractors.

Despite assurances that it already had a "robust," "high performance," and "comprehensive and integrated" remediation technology, Lockheed Martin AES began informing DOE of major changes to the chemical treatment system in April 1995. These changes were made despite the fact that the chemical treatment system was an integral part of the original design and key aspects of the chemical treatment system had passed the Proof-of-Process testing.

Some of the changes included introduction of additional untested chemical steps, and elimination of ion-exchange columns that were designed to trap radionuclides.[281] Additionally, redesigns of the chemical treatment system, including elimination of a calciner, would have resulted in disposal of secondary waste streams in the pit, contrary to Lockheed Martin AES' claim in its Best and Final Offer that "virtually no process-generated wastes result" from their process.[282]

Since Lockheed Martin AES had committed to an "Engineering Scale Test" of the final chemical treatment system design, DOE's site contractor did not take any actions to halt or stop the changes.[283] The site contractor and regulators did, however, provide extensive comments to Lockheed Martin AES stating their serious concerns about the changes. Between January 1995 and July 1996, DOE submitted some 7,000 detailed review comments on the design of various aspects of the project.[284]

Lockheed Martin AES was supposed to perform the Engineering Scale Test of the chemical treatment system in July 1995, but assembly of the test bed did not begin until December 1995. The testing done at the test bed facility revealed serious flaws in the design of the new chemical treatment system. Pumps used in the system degraded so fast

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[280] As quoted in Longhurst, 1997, Attachment A, pages 18,19, and 30.
[281] Schwartz, 1997.
[282] Schwartz, 1997 and Longhurst, 1997, Attachment A, pages 46-49.
[283] The Engineering Scale Test of the chemical treatment system is different from the Limited Production Test described above.
[284] GAO, 1997c, page 14.

that they had to be replaced as often as every 24 hours.[285] This would have created serious worker exposure concerns had radioactive materials been involved. DOE and Lockheed Martin Idaho Technologies Company observed that, in effect

> LMAES had assembled a standard piping system without consideration of the nuclear environment at Pit 9. The piping was subject to many leaks at the joints and was so complex that the area would have been a safety hazard and prohibitive to decontaminate if leaks occurred. More significantly, the system as designed was potentially susceptible to "criticality" -- that is, to the potential that radioactive materials could be brought together in sufficient concentrations to sustain a nuclear chain reaction. In addition, the system lacked an adequate mechanism for tracking the radioactive materials that were moving through the chemical treatment process.[286]

In May 1996, Lockheed Martin AES declared that the redesigned chemical treatment system did not work, and proposed replacing it with a physical soil separation process -- abandoning the chemical leaching system altogether.[287]

To our knowledge, Lockheed Martin AES has not completed a summary of the results of the test bed performance. We have not been able to obtain the limited information related to the test that has been submitted to DOE's site contractor because we understand it has been submitted under procurement procedures.[288]

DOE's site contractor, Lockheed Martin Idaho Technologies Company, also claims other aspects of the project besides the chemical treatment system have not been properly implemented by Lockheed Martin AES. For example, the Record of Decision and the Best and Final Offer made by Lockheed Martin AES stated that the retrieval system would use double confinement, but the retrieval facility that has been built does not have double confinement. In June 1997, Lockeed Martin Idaho Technologies stated that Lockheed Martin AES "asserts the current design meets the performance requirements; however, it is not a 'traditional' double confinement."[289] Lockheed Martin Idaho Technologies Company stated that, in fact, Lockheed Martin AES' "entire process ... was predicated on double containment" and that the "current facility does not meet the nuclear facility design and safety requirements"of the contract.[290]

According to the General Accounting Office, DOE, its site contractor, and its regulators claim that the failures were at least partly due to the fact that "initially LMAES personnel seemed particularly limited in their knowledge about necessary regulatory requirements, including those dealing with nuclear materials, and, as a result, submitted inadequate designs."[291] This project is a wasteful failure and typifies the kinds of problems that are all too common in DOE programs.

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[285] Schwartz, 1997.
[286] GAO, 1997c, pages 17-18.
[287] Schwartz, 1997.
[288] Ibid.
[289] Longhurst, 1997, Attachment A, page 10.
[290] Ibid, pages 10-13.
[291] GAO, 1997c, page 17.

6. March 1997: Lockheed Martin AES Requests Contract "Adjustment"

The inadequacies of Lockheed Martin AES' treatment system created a major setback to the project. In September 1996, a Lockheed spokesperson was quoted as saying "it's highly likely we will be over a year past schedule."[292] As the questions continued remained unanswered, the spotlight focused on Lockheed Martin AES. In February 1997, the *Times-News* quoted Lockheed Martin AES company spokesman Steve Harry as saying "backing out of the project is not in the mix of options at this time" and indicated that the company was commited to the project and would have a new proposal ready by March or April 1997.[293]

On March 28, 1997, Lockheed Martin AES submitted a "Request for Equitable Adjustment" to Lockheed Martin Idaho Technologies Company. According to the Associated Press, Lockheed Martin AES stated that "substantial and intrusive government oversight and involvement in virtually every aspect" of the project caused delays and cost overruns. Lockheed Martin AES asked for additional funding and for all future costs to be covered under a traditional cost-plus-reimbursement contract -- thereby ending one of DOE's showcase fixed-price contracts.[294] Moreover, Lockheed Martin AES stated that it would not be able to complete the project until April 2001.[295] This is more than a 3-year delay from the schedule DOE had published in 1995.[296]

The cost increases that Lockheed Martin AES has asked for are significant. A report by the General Accounting Office stated that Lockheed Martin AES has requested $257 million for its work through June 30, 1997 - already $57 million higher than the total cost of the contract without having even completed the design phase. Moreover, Lockheed Martin AES estimated the cost to complete the project at over $400 million - more than doubling the $200 million fixed-price contract it had signed in December 1994. The General Accounting Office report noted that DOE has asked the Defense Contract Audit Agency to audit Lockheed Martin AES' cost records.[297]

Meanwhile, DOE was fined $940,000 by its regulators - the State of Idaho and the U.S. Environmental Protection Agency - for failing to meet deadlines for submitting acceptable design documents. DOE is required to pay the fines, but it is not clear whether or not it will be able to recover the costs from its site contractor, Lockheed Martin Idaho Technologies Company, or from the Pit 9 project subcontractor, Lockheed Martin AES.[298]

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[292] Associated Press, 1996.
[293] Nokkentved, 1997.
[294] Gullo, 1997.
[295] GAO, 1997c, page 12.
[296] INEL, 1995a, page 2.
[297] Ibid, pages 2 and 12.
[298] Ibid, page 13.

Lockheed Martin AES contends that its requests are justified on two main grounds[299]:

1. *DOE and Lockheed Martin Idaho Technologies Company improperly administered the fixed-price contract and had too much interference into how Lockheed Martin AES ran the project.*
   Lockheed Martin AES claims that its expectations were that it would have more freedom on the fixed-price contract than on other types of DOE contracts, in return for accepting more risk if it failed. It expected that it would be able to make significant changes based on its commercial judgement, without requiring specific DOE approval. However, Lockheed Martin AES claims that DOE's oversight was such that it had to spend time responding to DOE's comments rather than moving forward with the project. According to Lockheed Martin AES, this work was out of the scope of the project.

2. *DOE and Lockheed Martin Idaho Technologies Company revised the estimated quantities and types of material in the pit, and these changes would have a significant impact on Lockheed Martin AES' process.*
   DOE and Lockheed Martin Idaho Technologies Company provided Lockheed Martin AES with information indicating that estimates of the contents of the pit have changed in several key ways. Lockheed Martin AES contends that information it received after being awarded the contract indicate the presence of plutonium in chemical forms that were unanticipated. It also asserts that it was unaware of the possible presence of drums with high fissile content (greater than 200 grams of plutonium). Additionally, Lockheed Martin AES contends that the estimates of the pit provided by DOE and Lockheed Martin Idaho Technologies Company indicate substantially greater quantities of gamma emitters in the pit than noted at the time the subcontract was signed. These revisions would require major changes to Lockheed Martin AES' system, including different chemical treatment to deal with unanticipated forms of plutonium, more controls to prevent nuclear criticality, and greater shielding throughout the retrieval and treatment facilities.[300]

For these, reasons, Lockheed Martin AES believes that its guarantee of performance, which stipulated it would not get paid unless the project were successful, is now invalid. Moreover, it believes that it is entitled to reimbursement for the costs it has incurred to date.

DOE counters that its oversight was justified, based on Lockheed Martin AES' major changes to key components, such as the chemical treatment system. In addition, DOE argues that its comments regarding nuclear safety and criticality issues were consistent with the scope of the contract because DOE retained the responsibility for safety analysis and startup.

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[299] Ibid, pages13-17.
[300] Longhurst, 1997, Attachment A, pages 17-19, 34-38.

DOE's site contractor, Lockheed Martin Idaho Technologies Company, also counters that the extent of uncertainty regarding the pit contents was made clear to Lockheed Martin AES, citing information presented in the Request for Pricing Proposal and the subcontract. DOE's site contractor also points out that the Best and Final Offer made by Lockheed Martin AES indicates that it was aware of possible contents of the pit. Specifically, DOE's site contractor cites the following:

1. *Chemical form of plutonium*[301]
   • No exceptions were made for the chemical form of plutonium in the subcontract.
   • Lockheed Martin AES' Best and Final Offer claimed a "very robust" process that can "treat most any TRU waste feed material."
   • Lockheed Martin AES' Best and Final Offer states that its treatment process is the "only practical process that rapidly dissolves the aged plutonium oxide polymer which is expected to be found in Pit 9."
2. *High fissile content drums*[302]
   • The Request for Pricing Proposal stated "the data should be considered as a basis... to suspect that Pit 9 may have some RFP [Rocky Flats Plant] containers with more than 200 g of plutonium."
   • Lockheed Martin AES' Best and Final Offer states "as part of criticality control... monitors... detect sources greater than 200-gram equivalent. These sources are retrieved only after careful review and planning, and are then set aside for more detailed assay."
3. *High quantities of gamma emitters*[303]
   • The Request for Pricing Proposal states that "shipping records show radiation levels measured at the surface of the waste containers at the time of pit placement ranged from 0 to 2500 mrem per hour."

In sum, DOE's contention is that Lockheed Martin AES' proposal was not dependent on a precise inventory of the pit. Indeed, as we have noted, Lockheed Martin AES' proposal indicated that its process was robust ("any chemical, radiological, or physical characteristic of waste in Pit 9 can be successfully processed") and could proceed without extensive "pre-processing characterization."

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[301] Ibid, Attachment A, pages 34-36.
[302] Ibid, Attachment A, pages 37-38.
[303] Ibid, Attachment A, pages 17-19.

7. Conclusions Regarding the Pit 9 Project

The Pit 9 project stalled soon after Lockheed Martin AES submitted its revised proposal in March 1997. The disputes in which this project is mired bode ill not only for Pit 9 waste retrieval, but for retrieval and treatment of far larger quantities of buried TRU waste at the Idaho Lab and at other sites in the DOE complex. A careful analysis of the managerial, programmatic, financial, and technical aspects of this costly failure and the application of the lessons to other DOE projects could still allow taxpayers to salvage some value from it. Such an evaluation should be done before other large, first-of-a-kind projects, such as Hanford tank waste treatment, or the Advanced Mixed Waste Treatment Facility at the Idaho Lab, are "privatized."

Despite the fact that Lockheed Martin AES was awarded the contract based on its successful completion of a "proof-of-process" test, the technology was not ready to be scaled up. It is one more example of DOE and its contractors rushing into large-scale projects without adequate preparation. This project is a showcase for the pitfalls of "monumentalism." The bidder made tall claims and DOE accepted them without enquiring too closely.

The uncertainties associated with the project were made known to Lockheed Martin AES, who clearly placed confidence in its treatment system. It strains credibility that a major corporation could be responsible for such tall claims that it could not follow through on and that DOE still considers the company qualified to do major work. It is, moreover, extraordinary that such contractual, estimating, and technological lapses would occur from a contractor that was responsible for major portions of a dramatically successful "first of a kind facility and operation" - the Mars pathfinder mission or that the government agency responsible for overseeing the human genome project could preside over such a failure.

Perhaps the only success of the Pit 9 has been the development of remote retrieval technologies that can reduce risk to workers from radionuclides, chemicals, and explosives. However, even this success has a major flaw in that Lockheed Martin AES did not build a double-confined structure as required by the Record of Decision and as described in Lockheed Martin AES' own Best and Final Offer.

One of the remarkable indicators of a lack of coordination and disarray in DOE's Environmental Management program is its failure to coordinate extraction and treatment of buried waste in Pit 9 with the Advanced Mixed Waste Treatment Facility that is supposed to treat the "retrievably stored" TRU waste at the Idaho Lab; treatment of the "retrievably stored" wastes is estimated to cost $880 million dollars.[304] The buried and stored wastes contain similar kinds of wastes and it is likely that a large percentage will

[304] DOE, 1996c, page Idaho-51.

require similar treatment technologies.[305] Whether or not they are stored under a few feet of dirt is relevant only to extraction and not to treatment technologies. Yet, DOE is proceeding with the Advanced Mixed Waste Treatment Facility as a privatized project without yet having absorbed the lessons of the Pit 9 failure.

DOE's managerial and financial experience with a fixed-price contract for Pit 9 included

- significant cost increases over those quoted in the Record of Decision, notably those for "profit"[306]
- technologies that were supposed to be "robust" that did not work
- DOE's loss of control over key aspects of the project
- disputes such as who is responsible for the $940,000 in fines
- a "fixed-price" contractor now wants a non-fixed-price contract

The fixed price contract for this project was claimed to provide several advantages, "including cost savings, demonstrating technologies that may be applicable to other DOE sites and achieving more rapid cleanup of waste sites."[307] Unfortunately, these benefits are not evident at Pit 9. The General Accounting Office notes that

> Limited guidance exists on selecting a contract type; however, the Federal Acquisition Regulation (FAR) suggests that a firm fixed-price contract, which best utilizes the basic profit motive of the private sector, should be used when the risk involved is minimal or can be predicted with an acceptable degree of certainty.[308]

Certainly, for the Pit 9 project, as well as for the Hanford high-level waste tanks (also slated to become a "privatization" project), the risk involved cannot be characterized as "minimal" or "predictable." In fact, it is quite the opposite. Privatization would not be suitable for any of the problems we have detailed in the case studies.

Another major flaw in DOE's implementation of the privatization program was described by a coordinator-manager from the State of Idaho in Congressional testimony in 1997:

> Consistent dialogue with regulators has been a key to the success of other activities under our cleanup program. At other INEEL projects, EPA and Idaho have been kept apprised of proposed project changes so we can resolve concerns in a timely manner and ensure that changes are consistent with the agencies' Records of Decision...
> The nature of the Pit 9 subcontract allowed DOE's subcontractor Lockheed Martin Advanced Environmental Systems (LMAES) to make design changes without consulting with the agencies, thus preventing the agencies from identifying and resolving concerns in a timely manner. In

[305] Some wastes in the pits and trenches, for example the carbon steel reactor in Pit 9, will require special management.
[306] INEL, 1995b, page
[307] INEL, 1994, page 1.
[308] GAO, 1997c, page 5.

> addition, EPA and Idaho were not even officially informed of the extent of cost overruns and schedule delays until October 1996, months after project deadlines had already been missed.[309]

William Weida, of Global Resources Action Center for the Environment and an economics professor at Colorado College, discusses another disadvantage of privatization: an increase in secrecy.

> Privatization, as implemented by the DOE at the Portsmouth and Paducah gaseous diffusion plants, has been used to thwart citizen oversight by allowing the privatized operators to claim that most information about their operations is proprietary in nature and not subject to citizen oversight.[310]

Such practices threaten a return to the kind of secrecy that enveloped the nuclear weapons production complex in earlier years, this time under the guise of "privatization." However, as in the past, greater secrecy is likely to adversely affect the soundness of environmental decision-making. It is a recipe for continued frustration, failure, and waste of taxpayer dollers.

In Chapter 5, we present our recommendations for DOE's TRU management program.

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[309] Trever, 1997, page 2.
[310] Weida, 1997, page 1.

Chapter Three: High-level Waste Tank Farms at Hanford Reservation

Hanford High-Level Waste: Background

The Hanford Reservation, in south-central Washington state along the Columbia River (see), is the site of the world's first large-scale plutonium production facility. The plutonium for the Nagasaki bomb was made there. In all, nine plutonium production reactors and five chemical processing plants (called reprocessing plants) that separate plutonium from uranium and fission products were built at Hanford between 1943 and 1963. In addition, other facilities were constructed to support various missions at the Hanford site through the years.

One of the legacies of the reprocessing facilities is highly radioactive liquid waste, containing fission products (such as technetium-99, cesium-137, and strontium-90) and residuals of plutonium, uranium, and other heavy radioactive elements. This waste is classified as high-level waste under the Nuclear Waste Policy Act. Liquid high-level wastes are also stored at the Savannah River Site, the Idaho National Engineering and Environmental Laboratory, and at West Valley, New York.[311] The largest volume of waste is in the Hanford tanks (roughly sixty percent of the total), while the Savannah River tanks contain the largest amount of radioactivity (about two-thirds of the total).

At Hanford, the high-level waste is in 177 tanks with a total capacity of over 125 million gallons (475,000 cubic meters). The total amount of waste is approximately 54 million gallons (206,000 cubic meters)[312], with roughly 200 million curies of radioactivity.[313]

In addition to having the most liquid high-level waste, Hanford's wastes are the most varied and the most intractable to treat. Years of neglectful and dangerous waste management practices at Hanford have created what will likely be the costliest item in the Department of Energy's Environmental Management program.

According to the most recent estimates, removal and treatment of the wastes that are in the tanks will cost about $15 billion.[314] The current goal of the Tri-Party In addition, billions of dollars will be required just for operational and maintenance expenditures in the near-term. Additional costs will also be incurred for disposal of treated waste in a geologic repository. Finally, an additional unknown amount will be

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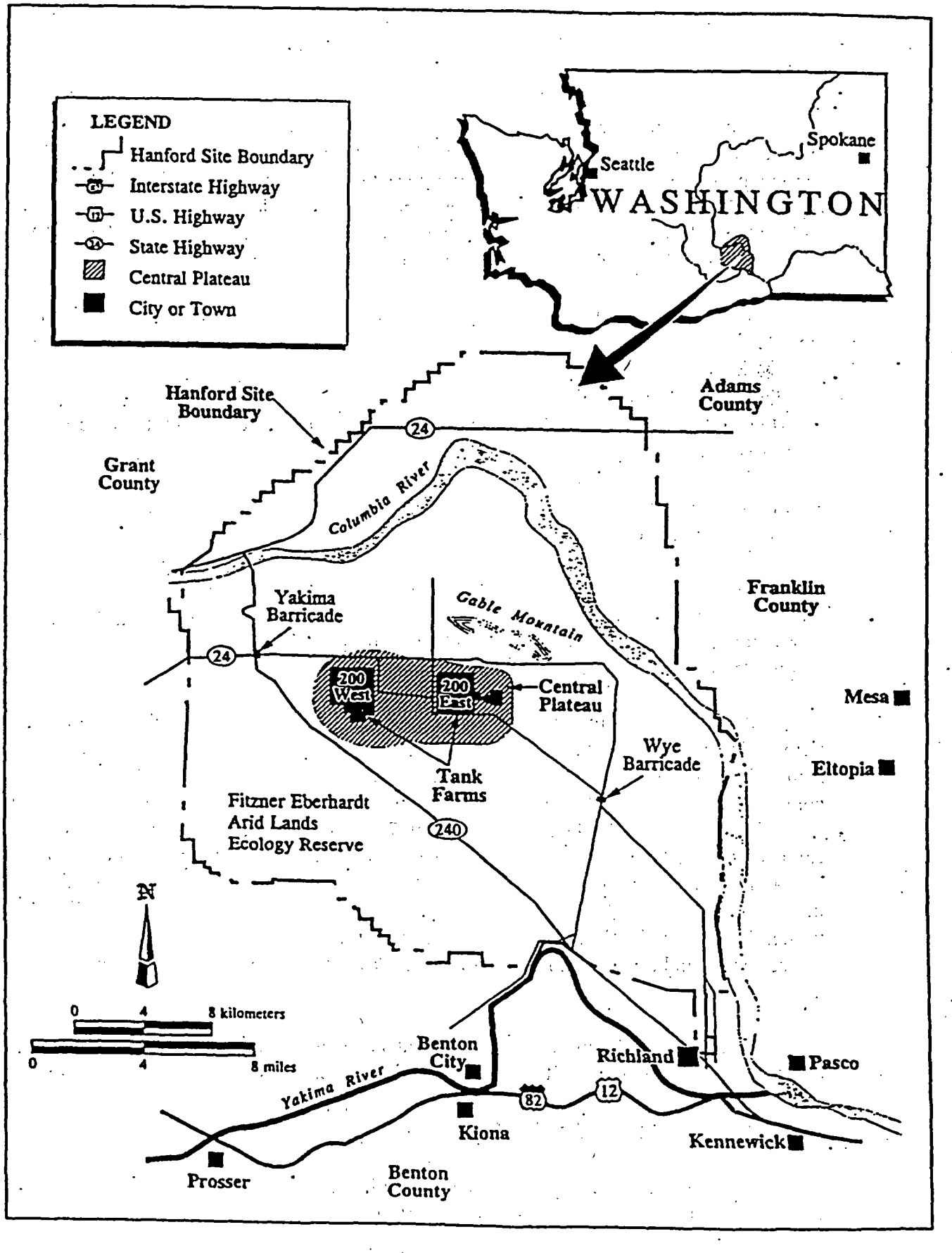
[311] The reprocessing waste at West Valley, New York, generated from 1966 to 1972, is partly due to civilian reprocessing.
[312] Hanlon, 6/97, page E-2.
[313] Gephart and Lundgren, 1996, page 12, report 215 million curies "decayed as of 1996"; IDB, 1996, page 53, reports 194 million curies, decayed to December 31, 1995.
[314] DOE, 1996c, page Washington-36.

Figure 9: Location of Hanford Reservation



Source: DOE Richland, 1996b, p. 1-2.

required to deal with the tanks themselves, the contaminated soil around the tanks due to direct discharges and leaks, and the contaminated groundwater.

Environmental management activities at the Hanford Reservation, including the high-level waste tanks, are governed by the Tri-Party Agreement, a legally-enforceable agreement between the Department of Energy (DOE), the Environmental Protection Agency (EPA), and the Washington State Department of Ecology. This agreement defines the milestones according to which activities occur. Since it was signed in 1989, there have been four major revisions of the Tri-Party Agreement.

The current and planned major activities for management of high-level tank waste include

- Characterization of tank contents
- Management of the tanks to reduce safety and environmental risks in the period prior to treatment
- Retrieval of the tank wastes
- Pretreatment of the tank wastes
- Immobilization of the tank wastes.

In addition, soil and groundwater contaminated by leaks and other activities relating to the tanks will need to be remediated. The current requirements in the Tri-Party Agreement include removal of 99% of waste from "single-shell" tanks by 2018, and completion of treatment of retrieved tank waste by 2028.

A succession of private contractors have run the site for the federal government, with rapid changes occurring since the mid-1980's. In October 1996, Fluor Daniel Hanford was named head of the "Project Hanford Team" - which includes 12 other contractors - responsible for management of the Hanford Reservation. Hanford formalized a new plan for tank wastes in a 1997 Record of Decision for the Tank Waste Remediation System (TWRS). Contracts were awarded to two companies, Lockheed Martin Advanced Environmental Systems and British Nuclear Fuels Limited Inc., to define what it would take for them to set up the first facilities to treat and immobilize the waste. DOE plans for these two contractors to eventually take over the retrieval, pretreatment, and treatment of the high-level tank waste in a "privatized" contracting arrangement.

This case study summarizes the current status of the high-level wastes at Hanford, examines DOE's management plans, and provides recommendations for the program.

Overview of Tank Contents

The waste in the Hanford tanks is a complex mixture of chemical and radioactive constituents. Figure 10 shows a schematic arrangement of a tank. The vapor space in the

tanks contains gases such as hydrogen, nitrous oxide, and ammonia. The wastes range from dilute, easily pumpable liquids to sludges, hardened salts, and waste solidified by the addition of cement (added to solidify waste in some leaking tanks). A broad categorization of the different physical states of the waste is as follows:[315]

- **Supernatant Liquid:** The topmost layer of waste consisting of a dilute liquid that can be relatively easily pumped from the tanks.
- **Slurry:** A mixture of solid particles suspended in a liquid. While slurry can be pumped, changes in pH (a number that describes how acidic or basic a liquid is), temperature or chemical composition can cause it to turn into a thick paste capable of plugging pipes and filters.
- **Saltcake:** A material created from the crystallization and precipitation of chemicals after the supernatant liquid was evaporated; usually made of water-soluble chemicals.
- **Sludge:** A thick layer containing water insoluble chemicals precipitated or settled to the bottom of a tank. Sludge layers in the tank can have varying degrees of hardness.
- **Interstitial Liquid:** A liquid found within the pore spaces of sludges and saltcake.
- **Hard-heel:** The hardest wastes, at the very bottom of the tanks; this heel is in some cases the result of addition of cement or diatomaceous earth to the waste.

Activities at Hanford generated some 1.4 billion liters of high-level waste between 1944 and 1980.[316] From 1944 to 1966, about 450 million liters (120 million gallons) of liquid wastes was intentionally discharged from Hanford tanks directly to the ground. Further, some wastes were evaporated and smaller quantities leaked into the ground. The net result of all these processes is that the waste volume currently in the tanks is approximately 206 million liters (54 million gallons). The mass of the radioactive materials in the tanks is actually a tiny fraction of the total. Most of the mass is non-radioactive and consists of water, sodium nitrate, organic compounds, and metals.

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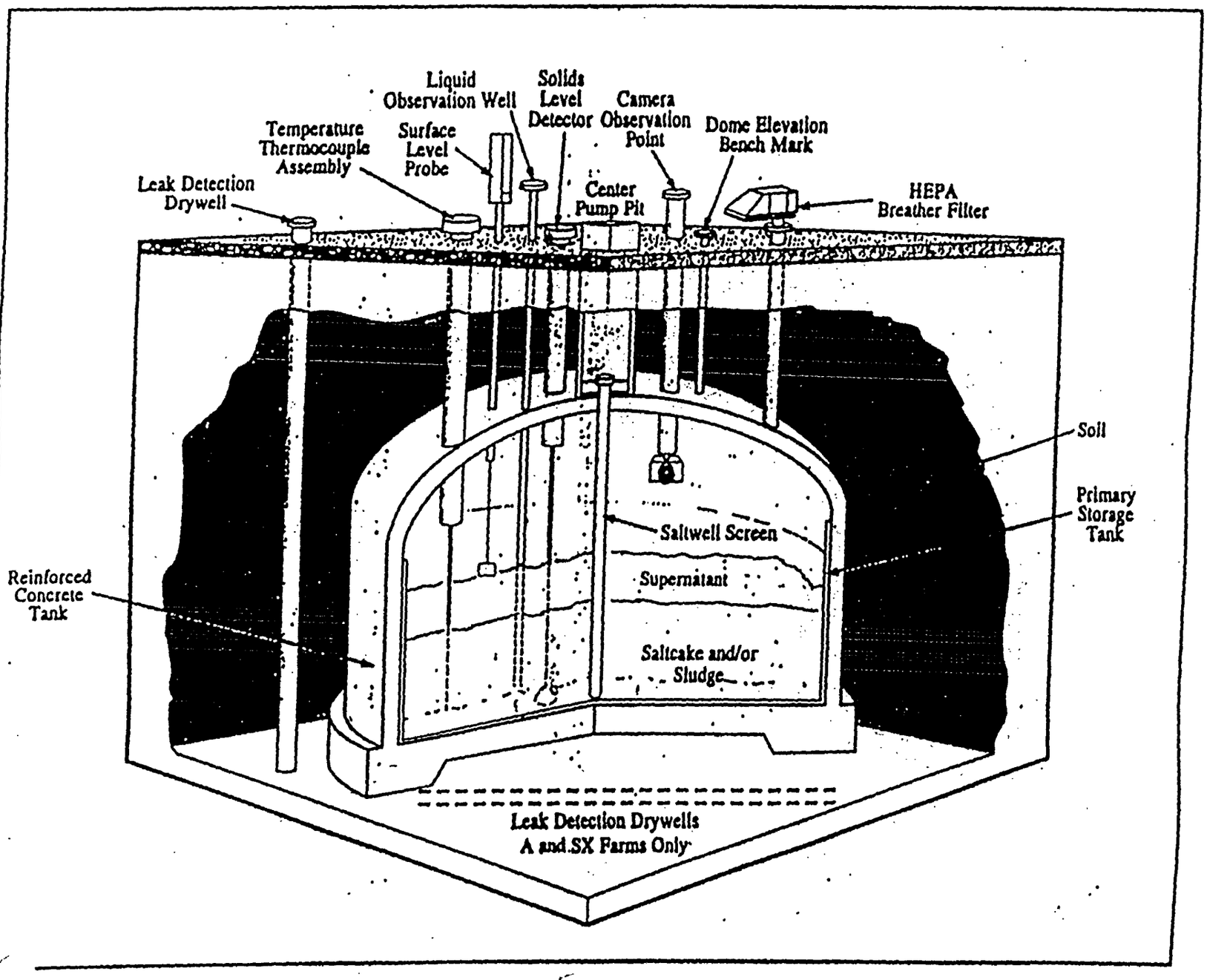
[315] Gephart and Lundgren, 1996, pages 19-20.
[316] Slankas, 1995, page B-12.

FIGURE 10: Schematic of a High-Level Waste Tank



Source: DOE Richland, 1996b, p. 3-3.

A. Storage of Waste in Tanks

During the Manhattan Project storing the waste in tanks was an "interim emergency method" until long-term solutions could be found.[317] Because stainless steel was then in short supply, officials decided to use carbon-steel tanks. But reprocessing wastes are acidic: this meant they had to be neutralized (made alkaline) so they would not dissolve the carbon steel. The neutralization process involves adding lye (sodium hydroxide, chemical formula: NaOH) and water to the wastes. Neutralization of the waste has two main effects:

- it greatly increases the volume of wastes
- it creates chemical reactions that cause most radioactive elements, with the major exception of cesium isotopes, to precipitate out as sludge.

Unfortunately, this decision to neutralize wastes for storage in carbon steel tanks was not revisited after World War II. Switching to stainless steel tanks would have allowed storage of the wastes as acids, resulting in a much lower waste volume. Additionally, acidic wastes can be maintained in homogeneous forms and are, partly for this reason, less difficult to put in solid, non-explosive forms. Acidic storage was used for high-level wastes at the Idaho National Engineering and Environmental Laboratory, and is standard practice in other countries, such as France and Britain.

Continued waste neutralization created problems that affect a wide range of current and future activities at the site, including safe storage of the wastes, retrieval of wastes from the tanks, and treatment of the wastes. Larger volumes of waste necessitated the building of more and larger tanks, discharging liquids containing chemicals and radionuclides to the ground, and evaporating waste in evaporator facilities. Concentration of radioactivity at the bottom of the tanks led to heat buildup and caused some of them to crack. And, finally, formation of sludges and solids has made the wastes more difficult to retrieve from the tanks.

The problems created by waste neutralization are common to both the Hanford and Savannah River Sites. However, at Hanford, the situation has been rendered vastly more complex by three other factors:

- a variety of reprocessing techniques were used, creating wastes with many different chemical compositions,
- many different chemicals and waste materials were added to the tanks over the decades, aggravating problems of management and retrieval, and
- inter-tank waste transfers were made without due regard to the long-term waste management problems that they might create.

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[317] Alvarez and Makhijani, 1988

B. The Tank Farms

The high-level waste tanks are located in the 200 East and 200 West areas of the Hanford Reservation. The tanks were built underground in 18 groups, called "tank farms." They were generally built near processing facilities, and wastes were transferred to them by underground piping. The tops of the tanks lie six to eleven feet below the ground surface, and are covered with soil and gravel. Ventilation and instrumentation ports rise to the surface (see Figure 10).

Table 25 gives some of the physical characteristics of the 177 tanks at Hanford. The tanks are constructed of carbon (also referred to as "mild") steel and are contained within an envelope of concrete. The most important difference between the tanks is that some have one carbon steel shell and some have two. The 149 "single shell" tanks were the first tanks built, between 1943 and 1964. Sixty-seven of these are known or suspected leakers. Beginning in 1968, tanks were built with a "double shell" of steel to provide greater protection against leaks. The change to double shell tanks was successful in that none of them have leaked to date. Other design changes over the years have included (i) added equipment to allow the tanks to handle waste that is boiling as it comes from the processing facilities, (ii) larger size, and (iii) changed shape of the bottom of the tanks from a flat surface to a bowl shape.[318]

Table 25: Number and Dimensions of Tanks

Tank Capacity (gallons)	Tank Farm Name	Number of Tanks	Tank Diameter (feet)	Approximate Height (feet)
Single Shell Tanks				
55,000	B, C, T, U	16	20	26
530,000	B, BX, C, T, U	60	75	30
758,000	BY, S, TX, TY	48	75	39
1,000,000	A, AX, SX	25	75	44
Double Shell Tanks				
1,000,000 to 1,160,000	AN, AP, AW, AY, AZ, SY	28	75	48

Source: Gephart and Lundgren, 1996, pages 12-18.

The tank farm areas also contain numerous support facilities and an extensive infrastructure. The high-level waste tanks and processing facilities are interconnected by miles of underground pipes. The support infrastructure for the tanks and the piping system also includes diversion boxes and valve pits that allow for inter-tank transfers. Many of the pipes have leaked, become clogged, and otherwise deteriorated over

[318] Gephart and Lundgren, 1996, page 12.

theyears. Extensive operations involving pumping of wastes into the tanks, out of the tanks, inter-tank transfers, have undoubtedly caused a substantial amount of radionuclide contamination to build up in this infrastructure. To date, the characterization of the tank transfer infrastructure radioactive contamination problem has taken a back seat to the characterization of the high-level waste tanks, which present the more serious problem. But given the scope of the potential remediation, it is important to begin a serious characterization effort.

The tank farm infrastructure also includes some sixty "miscellaneous underground storage tanks" that contain unknown amounts of chemicals and radionuclides. Forty of these tanks are "inactive" while 20 are still active. Many of the abandoned tanks contain thousands and even tens of thousands of gallons of solid and liquid wastes. The radionuclide composition of these wastes is largely a mystery, or least not reported by the DOE.[319]

Some of the problems posed by miscellaneous tanks were noted by the Defense Nuclear Facilities Safety Board as the result of a 1996 investigation. Its report expressed concern about "several inactive facilities that were abandoned without proper equipment cleanout and inventory removal." The investigation report further noted that:

> Hazards posed by this situation include hydrogen generation, spread of contamination, and loss of radioactive material containment.
> ....The facility [244-AR Vault] contains four tanks in underground cells. One of these tanks contains 23,000 gallons of waste including 600 gallons of neutralized current acid waste (NCAW) from PUREX. The estimated source term for this tank is 120,000 curies. While actual configuration of the tank is uncertain, WHC [Westinghouse Hanford Company] stated that it is isolated from the ventilation system.[320]

Even after billions of dollars have been spent on waste management at Hanford the scope of the problem posed by such "miscellaneous" tanks is not well understood.

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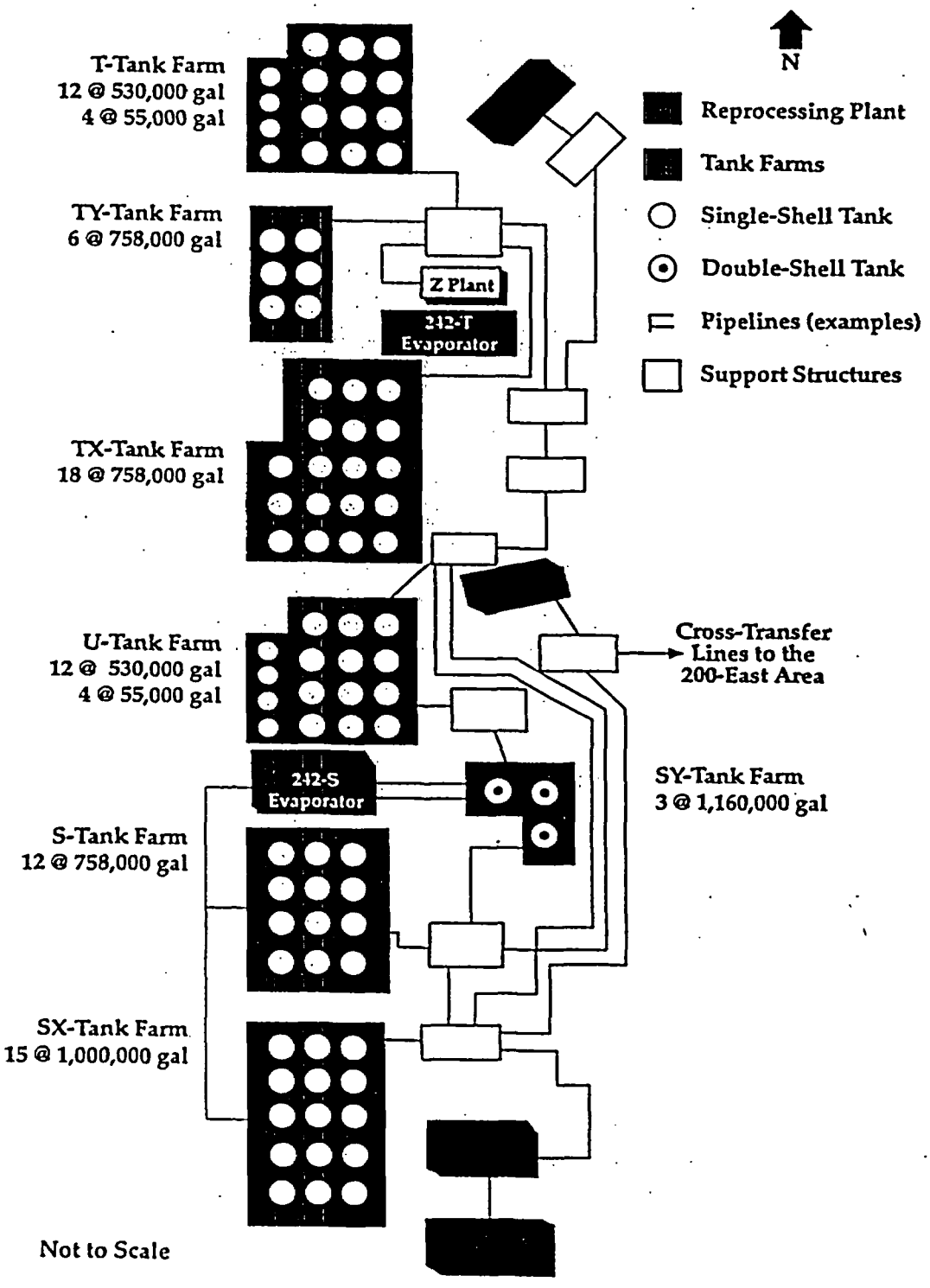
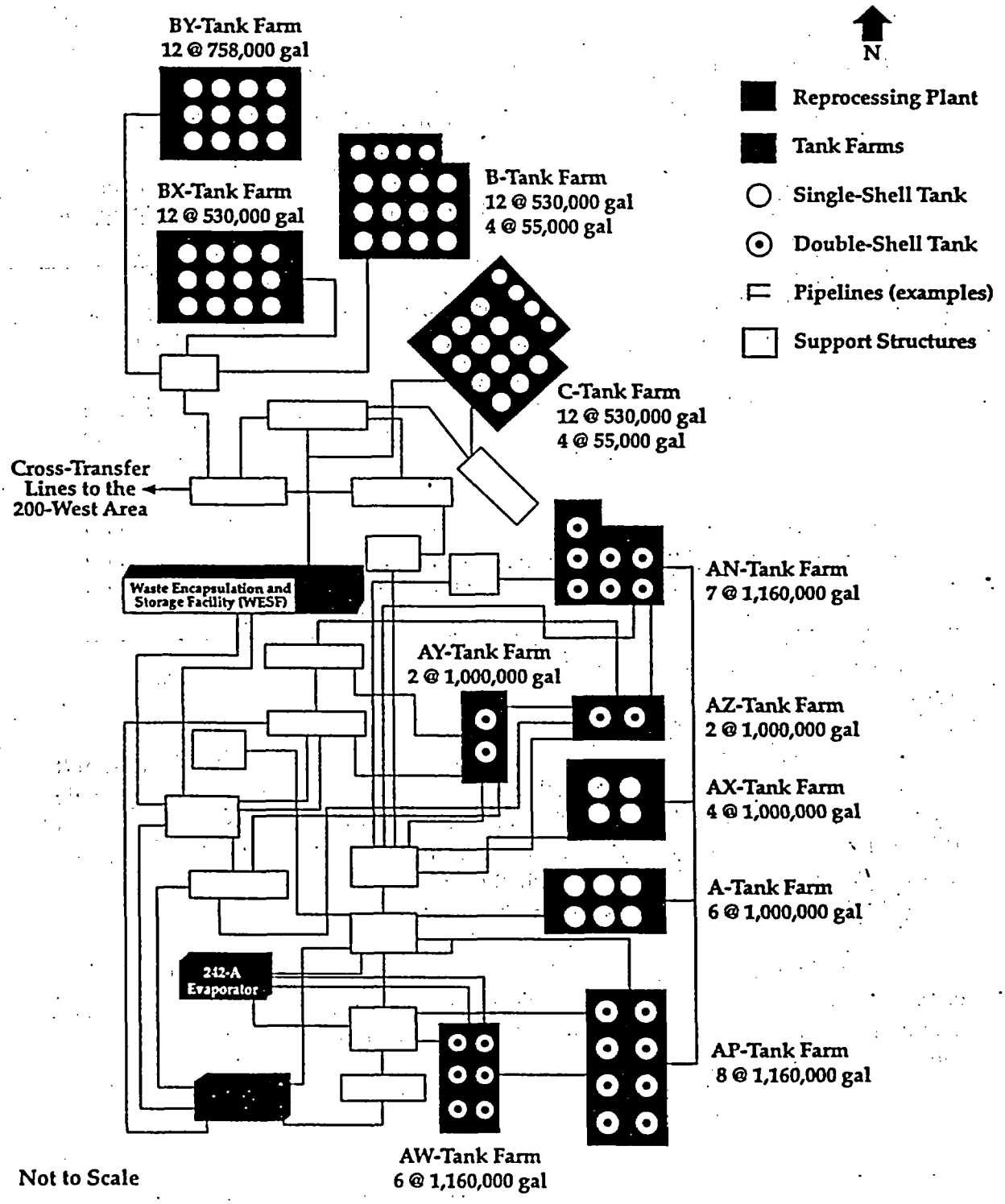
[319] DOE Richland 1996b, pages 1-1, 3-4, pages, A-3, A-25, A-26.
[320] DNFSB, 1996b.

Figure 11: Hanford East and West Tank Farms



The 200-West Area (shown here simplified to show relationships and not to scale) contains six single-shell tank farms and one double-shell tank farm. These farms received waste from reprocessing plants and other facilities, including Plutonium Finishing Plant (Z Plant), T Plant, U Plant, 242-S and 242-T Evaporators, REDOX Plant, and 222-S Laboratory. Cross-transfer lines were used to pump tank waste between the 200 West and 200 East Areas.

Source: Gephart and Lundgren, 1996, pp. 13-14.



The 200-East Area (shown here simplified to show relationships and not to scale) contains six single-shell tank farms and five double-shell tank farms. These farms received waste from reprocessing plants and other facilities, including B Plant, Waste Encapsulation and Storage Facility, 242-A Evaporator, and PUREX Plant. Cross-transfer lines were used to pump tank waste between the 200 East and 200 West Areas.

C. Types of Waste in Tanks

There are approximately 36 million gallons of waste in the 149 single shell tanks and approximately 19 million gallons of waste in the 28 double shell tanks.[321] Table 26 gives an overview of the contents of the single shell and double shell tanks.

Table 26: Volume of Waste in Single and Double Shell Tanks

Waste Type	Volume in Single Shell Tanks (gallons)	Volume in Double Shell Tanks (gallons)
Supernatant	548,000	14,750,000
Slurry	0	410,000
Sludge	12,034,000	3,596,000
Saltcake	22,974,000	115,000
Total	35,600,000	18,900,000
Estimated Total Liquid [1]	6,396,000	15,059,000
Estimated Total Solids	29,160,000	3,812,000
Total	35,600,000	18,900,000

Source: Hanlon, 6/97, page E-2. Waste volumes as of April 1997.
[1] Includes liquids occurring in the pore spaces of sludge and saltcake that is referred to as "drainable liquid."

Most of the supernatant liquid is now in the double shell tanks, while most of the sludge and saltcake are in the single shell tanks. The DOE has been transferring single shell supernatant waste to the double shell tanks to minimize the risk of leaks. As of July 1997, some 31 single shell tanks still contain significant amounts of liquids.[322] The transfer of most of the liquids to double shell tanks was scheduled to be completed by the end of 1999, but the deadlines are being renegotiated.[323]

A brief review of waste generation and tank management is essential to understanding the nature of the high-level waste management issues at Hanford because the mixing of various wastes, addition of chemicals, and other actions have created a very complex set of problems.

[321] Hanlon, 6/97, page E-2. The total adds to greater than the 54 million gallons cited elsewhere in this chapter due to rounding.
[322] Hanlon, 9/97, page I-2.
[323] Hanlon, 9/96, page I-4 and Hanlon, 9/97, page 3.

An estimated forty-eight types of waste were generated at Hanford.[324] DOE notes that "these processes have resulted in a collage of tank materials in a variety of combinations and configurations. The material was regarded as waste and there was little perceived need to understand the details of the combinations and configurations."[325]

Some of the major waste generation activities are discussed below and are summarized in Table 27.

Table 27: Summary of Major Waste Generating Processes at Hanford (1944-1980)

Process or Facility	High-Level Waste Generation (cubic meters)
Bismuth Phosphate	369,000
Tributyl Phosphate Uranium Recovery	215,000
REDOX	155,000
PUREX	316,000
Ferrocyanide Scavenging (cesium precipitation)	168,000
B Plant Fractionation (cesium and strontium recovery)	197,000
Plutonium Finishing Plant	6,060 [1]
Strontium Semiworks	3,030

Source: Slankas, 1995, page B-12.
[1] Waste volume is through 1988.

1. Reprocessing Wastes

Plutonium was recovered during a series of aqueous processes that dissolved uranium-based irradiated reactor fuel. A total of five reprocessing plants were built at Hanford - the three original plants (U, T, and B) were built between 1943 and 1945; two additional plants were completed in the 1950's (REDOX (1951) and PUREX (1956)).

The T, B, and U reprocessing plants used the Bismuth-Phosphate ($BiPO_4$) process in order to recover plutonium. The $BiPO_4$ process was inefficient -- it allowed relatively high amounts of plutonium to end up in the waste streams, it had no provisions for recovering uranium, and it produced large volumes of waste.[326] These inefficiencies drove the development of other reprocessing technologies. All three reprocessing plants were shut down or closed by 1958.[327]

The REDOX (REDuction OXidation) plant improved the efficiency of plutonium recovery, reduced the amount of waste generated, and added the ability to recover uranium from the irradiated fuel.[328] The REDOX plant was last operated in 1966. The

[324] DNFSB, 1996a.
[325] DOE Richland, 1996e, page 3.
[326] Ibid, page 3.
[327] Makhijani, Hu, Yih, eds., 1995, page 217.
[328] Ibid, page 218.

PUREX (Plutonium URanium EXtraction) plant was Hanford's longest-operating reprocessing plant. The PUREX process uses nitric acid to dissolve irradiated fuel and then employs organic solvents to recover plutonium, uranium, and neptunium from irradiated fuel. It was more efficient than either of the earlier reprocessing plants. PUREX operated from 1956 until 1972, then was upgraded and restarted in 1983. It reprocessed fuel from the N-Reactor through 1988.[329] It was deactivated in 1997.

2. Uranium Recovery Wastes

In the 1950s, uranium was in short supply.[330] Because uranium was not recovered in the early reprocessing plants, the contents of some tanks were sluiced (jets of water were sprayed into the tanks in order to mobilize the solids) to obtain uranium. The slurry from sluicing was piped to U-Plant, which was converted from its original design as a plutonium recovery plant so it could recover uranium. Uranium was extracted by dissolving the waste in nitric acid followed by a solvent extraction process that used tributyl phosphate mixed with kerosene. The acidic wastes from this process were made basic and returned to the tanks. Uranium recovery was done in U-Plant from 1952 to 1958.

3. Cesium Precipitation Wastes

Attempts to remove cesium-137 from the supernate and precipitate it into the sludge layer added 168,000 cubic meters (44 million gallons) of waste to the tanks.[331] The main reason for this effort was to free up tank space. By removing cesium out of the liquid fraction, it was felt that the resulting waste would then be safe to discharge directly into the soil, via "liquid waste disposal units," such as "cribs" and "trenches."

Cesium precipitation involved adding sodium ferrocyanide and nickel sulfate to the high-level waste. Chemical reactions caused most of the cesium to bind with nickel and ferrocyanide and form a solid. This led to the formation of more complex sludge and solid layers at the bottom of the tanks.

The precipitation of cesium made the upper liquid layer of the tanks less radioactive. This supernate was then dumped into the soil. Because not all of the cesium was removed and because chemicals were present in the liquid layers, these cribs and trenches have contaminated the soil and groundwater in the tank farm area.

Another side effect of the decision to precipitate cesium was that the presence of ferrocyanide in the tanks created a new safety concern. The combination of ferrocyanide and an oxidizing material, such as sodium nitrate, at a high enough temperature, can result in an accidental explosion. Realization of this problem resulted in the scrapping of

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[329] Gephart and Lundgren, 1996, page B.3.
[330] DOE Richland, 1996e, page 3.
[331] Slankas, 1995, page B-12. Values for 1944 to 1980.

the cesium precipitation program in 1957 but DOE did not publicly admit that there were potential safety concerns involving explosions until 1989, partly as a result of congressional and public pressure. Subsequently, a "Ferrocyanide watch list" of eighteen tanks was created to evaluate potential safety issues resulting from the cesium precipitation effort (see below for a discussion of safety issues).

4. Cesium and Strontium Recovery Wastes

Two factors resulted in a decision to remove cesium-137 and strontium-90 from the tanks. In the late 1960s and 1970s, cesium-137 and strontium-90 created very high heat loads in many of the tanks. This created stresses in the single shell tanks, most of which were already beyond their 10- to 20-year design life. Additionally, since some tanks had already leaked, putting the two most problematic fission products into solid form was seen as an appropriate safety measure.

The processing from cesium and strontium removal resulted in an additional 197,000 cubic meters (52 million gallons) of waste.[332] Two main techniques were used for wastes removed from the tanks:

- Supernates containing cesium were pumped from the tanks and passed through ion exchange columns that bound the cesium ions.
- Sludges containing strontium from the A and AX tank farms were sluiced from the tanks, acidified, and sent through a solvent extraction process in B plant to remove the strontium.[333]

The wastes from solvent extraction at the B plant produced a waste known as "concentrated complexant" - a waste containing high concentrations of organic compounds (known as complexants) that retain transuranic elements (e.g., plutonium) in solution. There is approximately 4 million gallons of concentrated complexant waste in the double shell tanks, mostly from cesium and strontium recovery at B plant. In the 1970s, Hanford began directly sending acid wastes from the PUREX plant to B Plant for solvent extraction to remove the cesium and strontium before the rest of the wastes were neutralized and sent to the tanks.[334]

5. Plutonium Finishing Plant Wastes

Another source of waste to the tanks was the Plutonium Finishing Plant (also called the "Z plant"). The Plutonium Finishing Plant created plutonium metal from the

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[332] Ibid, page B-12. Values for 1944 to 1980.

[333] Separated cesium and strontium were calcined and are stored in water-filled pools at Hanford's Waste Encapsulation and Storage Facility in 1,929 double-walled metal alloy tubes, or "capsules." These capsules generate large quantities of heat from radioactive decay. The capsules are managed as high-level waste.

[334] Gephart and Lundgren, 1996, pages B-4 and C-1..

plutonium nitrate produced by the PUREX plant. Waste from the Plutonium Finishing Plant included fission products, plutonium and other transuranic elements, and high concentrations of metallic nitrates. About 6 million liters (1.6 million gallons) of high-level waste were generated from Plutonium Finishing Plant operations.[335]

From 1949 until 1973, Z plant waste was discharged to the soil in trenches. One trench used from 1955 until 1962, known as "Z-9", received an estimated 100 kilograms of plutonium in the liquid waste.[336] In 1972, this trench was considered dangerous enough that soil was removed and processed to extract some of the plutonium. DOE now reports 38 kilograms of plutonium in the Z-9 trench.[337] Beginning in 1973, waste from the Plutonium Finishing Plant was sent to the tanks, a decision triggered by the finding of concentrations of plutonium high enough to pose the risk of an accidental criticality and by implementation of the Atomic Energy Commission's 1970 directive requiring "retrievable storage" of transuranic waste.[338]

D. Characterization

Characterization of the wastes in the tanks is crucial to formulating a rational plan for dealing with the waste in the tanks, including

- mitigating the safety issues in the tanks
- removal and treatment of the wastes in the tanks.

1. Tank Contents

Since 1989, there has been substantial work and progress in understanding the contents of the Hanford tanks. However, large uncertainties persist. The data available are insufficient to track the waste through more than 50 years during which they have undergone inter-tank transfers, chemical transformations inside the tanks, radiolytic decomposition (that is, chemical decomposition due to the action of radiation), radioactive decay, and processing in various facilities. Another set of uncertainties relates to the distribution of chemicals and radionuclides within each tank since wastes are not uniformly distributed and are present in different phases such as vapors, liquids, sludges, and saltcake. Due to such uncertainties, the contents of individual tanks have been described by Hanford as "something of a mystery."[339]

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[335] Slankas, 1995, page B-12. Values for 1944 to 1980.
[336] AEC, 1972, page 1.
[337] DOE Richland, 1987, page A-22. Other sites are reported as having higher concentrations of plutonium in the soil, as well as higher total amounts of plutonium.
[338] See the case study in this report on TRU waste for more information. From 1970 until the waste was sent to the tanks in 1973, the Hanford site was not in compliance with the AEC's directive that required, beginning in 1970, retrievable storage of all TRU waste.
[339] Gephart and Lundgren, 1996, page 18.

The actual amounts of materials involved in such uncertainties varies a good deal from one chemical to the next, as attested to by two examples from efforts by Los Alamos National Laboratory to model the contents of Hanford tanks[340]:

- Total sodium in the tanks is estimated by Los Alamos to be 40,000 metric tons, which is 20,000 metric tons less than previous estimates.[341] Since sodium is a limiting factor in the percentage of waste that can be loaded into a certain volume of glass, if the new estimate is correct, a smaller volume of "low-level" waste glass may be produced.[342]

- Total iron in the tanks is estimated by Los Alamos to be 1,800 metric tons, which is greater than previous estimates of 700 metric tons.[343] If the new estimates are correct, then iron could become a limiting factor for the production of "high-level" glass -- this could increase the quantity of "high-level" waste glass that is produced.

2. Beginnings of the Characterization Program

DOE notes that a mind set evolved that disposing of waste in the tanks was safe and that "except for maintaining certain operational tank parameters to prevent release of radioactive materials, there was no comprehensive plan to understand the nature and composition of the tank waste."[344] In 1989, after decades of storing high-level wastes in the tanks, the Tank Waste Remediation System (TWRS) initiated a Characterization Program to address such deficiencies.

The Characterization Program was immediately beset by many logistical and physical constraints. Due to the deadly level of radiation inside the tanks, samples have to be taken remotely. Toxic and radiological gases in the headspace of tanks also complicate sampling. Even with precautions, intrusions into the tanks pose risks to workers operating sampling equipment.

The Characterization Program also needed to develop special equipment that could fit through small openings and operate in intense radiation fields. Sampling hardened wastes required the development of sampling equipment that did not generate heat and sparks, which could ignite flammable gases in the tank or initiate chemical reactions. New laboratory and analytical capabilities needed to be developed that could

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[340] DNFSB, 1996a.

[341] Where do you put 20,000 tons of sodium? The new estimates incorporate evidence that this amount of sodium was disposed of in the cribs along with the liquids that were drained off of the top of the tanks.

[342] See below for DOE's plans to separate the tank waste into "high-level" and "low-level" waste streams. Both will be vitrified, but the "low-level" waste will be disposed of on-site in shallow land burial, while the "high-level" waste will be disposed of in a geologic repository.

[343] Where do you pick up 1,100 metric tons of iron? LANL's estimates include corrosion from process vessels.

[344] DOE Richland, 1996e, page 3.

handle radioactive waste and give results in a reasonable amount of time. Because of these and other challenges, obtaining a single sample of waste from one tank (typically a one inch diameter core) often took as long as a year.[345] Over the course of ten years, these difficulties have been addressed and the site has the analytical and technical capabilities in place to carry out characterization. Over the last decade, many issues have become clearer and what remains to be done is also better understood.

In addition to physical limitations on sampling the tank wastes, it soon became clear the program lacked a proper focus because safety concerns made the old sampling strategies obsolete. The original Characterization Program, developed in response to the original Tri-Party Agreement, was driven by regulations that required specific information in order to support a since-abandoned plan involving the disposal of the tank waste in situ.[346] However, several urgent safety issues needed to be addressed before the regulatory requirements for waste disposal could be met. The time frame and type of data necessary to address the safety issues were dramatically different from the original characterization plan.

In July 1993, the Defense Nuclear Facilities Safety Board (DNFSB) made several formal recommendations to the Department of Energy about Hanford's Characterization Program. The DNFSB recommended

> a comprehensive reexamination and restructuring of the characterization effort with the objectives of accelerating sampling schedules, strengthening technical management of the effort, and completing safety-related sampling and analysis of watch list tanks within a target period of two years, and the remainder of the tanks by a year later.[347]

Eighteen months later, in December 1994, a letter from the DNFSB again expressed concern "over what appears to be a badly faltering program."[348] The DNFSB noted that it could not determine whether or not the revisions to the program made by Hanford would be able to provide the information needed by the safety program, or how it would support the longer-term needs such as retrieval, treatment, and storage. A March 1995 DNFSB review noted that although the management contractor (at the time, Westinghouse Hanford Company) was continuing to develop a new approach for safety-related characterization, deficiencies remained -- the DNFSB noted that "significant portions" of a new safety-related characterization strategy were "based on simplified models and simulants that may not adequately represent tank wastes."[349]

3. Tank Waste Remediation System Characterization Program, 1997

[345] Blush, 1995, page A-10.
[346] Blush, 1995, page A-9
[347] DNFSB, 1993.
[348] DNFSB, 1994.
[349] DNFSB, 1995a.

In response to the DNFSB concerns, DOE overhauled its tank sampling program. The new approach involves a process where "high priority" tanks are identified, based on their ability to contribute information to different parts of the Tank Waste program. The list of activities for which data is needed include[350]:

Flammable gas	Historical model evaluation
Organic fuel phenomenology	Process testing - sludge washing
Safety screening	Process testing - supernatant pretreatment
Vapor screening	Retrieval
Vapor space phenomenology	Privatization
Waste compatibility	Evaporator

For each issue, Tank Waste programs, DOE, and the Washington Department of Ecology have established and weighted criteria and assigned priorities. The idea is to provide a list of tanks "recommended for sampling to obtain the maximum information about the waste in a cost-effective manner."[351] For example, the working list of "high priority" tanks for sampling is composed of 27 tanks.[352] This prioritization represents a significant improvement over Hanford's initial strategy, and it is targeted to provide useful information to the various programs.

Through July 1997, 27 tanks have been sampled and had all required analyses completed (not all of these are the "high priority" tanks). Twenty-five tanks have had no sampling.[353]

Major Safety and Environmental Issues

A. Safety

Hanford tank safety issues represent some of the most serious concerns in the entire DOE weapons complex. The potential exists for fires in the tanks, chemical explosions, and nuclear criticality. DOE describes the situation as follows.

> There is an incomplete picture of the status of the waste in the tanks... There are analytical measurements that indicate the presence of materials in the tanks that did not come from known processing chemicals. The historical record, by itself, is not sufficiently accurate to authoritatively establish a basis for safety decisions. It does provide a reasonable framework to guide the sampling program and clarify the interpretation of the results.[354]

The serious nature of safety concerns are illustrated by a 1957 explosion in a Soviet high-level waste tank. While there are many differences between the chemistry

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350 Brown, 1996.
351 Ibid, p.2-3.
352 Ibid, chapter 7
353 Hanlon, 9/97, Appendix J.
354 DOE Richland, 1996e, page 4.

and other aspects of Soviet and U.S. tanks, a brief recounting of the 1957 accident is nonetheless instructive, especially as a lack of accurate knowledge about tank conditions was a crucial factor in the accident.

On September 29, 1957, a high-level waste tank exploded in Chelyabinsk-65, the former Soviet Union's oldest and largest plutonium production site.[355] The tank was one of a group of 20 stainless steel tanks, each with a capacity of 300 cubic meters (about 79,000 gallons), that were located in a concrete canyon 8 meters underground. Due to high radiation fields, poor design, and deterioration of monitoring equipment, there was little information about the temperature and water content of the tanks.

The tanks contained liquid radioactive wastes from reprocessing which gradually dried out due to the heat generated by radioactive elements in the tanks. Although it is possible that a brief nuclear criticality may have been a factor in initiating the explosion, the explosion was mostly, if not entirely, chemical in nature. High concentrations of sodium nitrate (up to 100 grams per liter) and sodium acetate (up to 80 grams per liter) were present in the waste. This mixture may have ignited spontaneously as the wastes dried out and heated up, or a spark or friction may have caused the explosion. The tank explosion released an estimated 20 million curies of radioactivity, ninety percent into the soil and ten percent to the atmosphere in a plume that was carried in a northeasterly direction from the plant.

Over 10,000 people were evacuated from more than thirty towns and villages. More than 15,000 square kilometers of land was contaminated to levels more than 0.1 curie per square kilometer of strontium-90. According to one estimate, 20,000 people were exposed to 5 rem or more of radiation. Clean-up worker exposures have not been made public. Some 20,000 hectares (200 square kilometers) were ploughed under to reduce further dispersion of radioactivity by wind. Controls were only partly effective, resulting in consumption of contaminated food; milk contaminated with strontium-90 was a significant source of exposure.

There have been no catastrophic accidents from U.S. high-level waste tanks, but numerous safety concerns exist. In response to a law passed in 1990, a program was initiated at Hanford to identify tanks with potential safety problems.[356] A "watch list" of tanks was created to establish a formal review of tank safety issues. Four lists were created - flammable gas, organic content, ferrocyanide, and high heat. The tanks on these lists were judged to have the potential for uncontrolled releases of radioactivity. The flammable gas watch list has included as many as 25 tanks, the organic list 20, the ferrocyanide list 24, and the high heat list 1.[357]

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[355] This discussion of the 1957 tank explosion is based on Makhijani, Hu, Yih, eds.,1995, pages 333-337 and 384-388 as well as IPPNW and IEER, 1992, Chapter 4.
[356] Public Law 101-510, Section 3137, "Safety Measures for Waste Tanks at Nuclear Reservation."
[357] Hanlon, 3/97, page A-3.

Currently, there are three watch lists, with 38 tanks on one or more lists.[358] The ferrocyanide watch list has been closed because recent work has eliminated official concern about the issue (see below).

As noted above in the discussion on characterization, in July 1993, the Defense Nuclear Facility Safety Board issued a formal recommendation that safety-related characterization be completed in watch list tanks within two years, and the remainder of the tanks a year later. Four years after this recommendation, twenty-five tanks have had no sampling, including five watch list tanks.[359] In addition, although the ferrocyanide safety issue has been declared resolved, not all tanks that were on the list were sampled. Moreover, crucial efforts, such as sampling to resolve the organic safety issue, are forecast to drag on until 2001.

Five safety issues are among the urgent concerns in Hanford tank farm management. They are

- Ferrocyanide
- Organics
- Flammable gas buildup
- High heat
- Criticality.

We discuss each of these below.

1. Ferrocyanide Safety Issues

Twenty-four tanks have been on the ferrocyanide watch list at some point between 1991 and 1996.[360] As discussed above, ferrocyanide was used as a way to remove cesium from the liquid portion of the high-level waste.

Ferrocyanide in the tanks was recognized as a safety issue in 1957 during the program of cesium precipitation. Pumping liquids out of these tanks raised the possibility that tank temperatures would rise, creating a risk that the waste might become hot enough to start a fire or explosion. A necessary condition for fires or explosions is the presence of an oxidizing material which the tanks contain, mainly in the form of nitrates.

The Defense Nuclear Facilities Safety Board made two recommendations in 1990 that reflected a sense of urgency about the issue.[361] One of the specific recommendations was that:

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[358] Ibid, page A-3.
[359] Hanlon, 9/97, Appendix J.
[360] Hanlon, 3/97, page A-3.
[361] DNFSB, 1990a and 1990b.

> immediate steps should be taken to add instrumentation as necessary to the single shell tanks containing ferrocyanide that will establish whether hot spots exist or may develop in the future in the stored waste. The instrumentation should include as a minimum additional thermocouple trees.[362] Trees should be introduced at several radial locations in all tanks containing substantial amounts of ferrocyanide, to measure the temperature as a function of elevation at these radii. The use of infra-red techniques to survey the surface of waste in the tanks should continue to be investigated as a priority matter, and on the assumption that this method will be found valuable, monitors based on it should be installed now in the ferrocyanide bearing tanks.[363]

The stress on thermocouples and infra-red techniques related to the lack of knowledge of temperature distribution especially in the solid layers of the tanks.

It is interesting to note similarities between this recommendation and one made in a report as far back as June 1967:

> The thermocouple probes will provide satisfactory temperature measurements in an area adjacent to the thermocouple but because of poor conductivity of the [salt]cake and the potential of non-uniform heat distribution, hot spots a few inches away would not be detected. Since the thermocouple probes are spaced 40 to 60 feet apart, the thermocouple probes are not considered a good monitoring system with respect to localized hotspots. The number required for a satisfactory system is impractical. In addition, the maintenance problems associated with maintaining a thermocouple system for 25 to 50 years are staggering. The infrared scanning system which can determine the maximum temperature of a 25 square inch area and is capable of scanning the floor of the tank in a six-minute period would provide an excellent monitoring system.[364]

The failure of DOE and its contractors to address this issue carefully, in the full knowledge of the possible dangers, illustrates dramatically the risky neglect of safety and waste management issues at Hanford. Even as of February 1997 there were 13 tanks for which temperatures have not been measured in several years.[365]

To respond to the 1993 DNFSB recommendation, DOE carried out laboratory tests. These tests showed that ferrocyanide can decompose over time.[366] Subsequently, sampling of nine of the ferrocyanide tanks that were believed to have received the highest amounts of ferrocyanide led to the conclusion that ferrocyanide has decomposed over the years, and is present in low concentrations - 10 to 40 times lower than those concentrations needed to create an explosion.[367]

Although measurements were not directly made in the other ferrocyanide tanks, in October 1996, the Department of Energy declared the issue resolved. The Defense Nuclear Facilities Safety Board and the Washington Department of Ecology have

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[362] A thermocouple is a device used to measure temperature. A probe with more than one thermocouple on a probe is referred to as a "tree."
[363] DNFSB Recommendation 90-7.
[364] As quoted in Alvarez, 1993, page 7.
[365] Hanlon, 4/97, page A-6.
[366] DOE Richland, 1996e.
[367] Ibid, page 23, and Sohn, 1997.

concurred.[368] Resolution of this safety issue was cited by the Washington Department of Ecology as one of the major accomplishments in 1996 at Hanford.[369]

While we concur that measurements on the nine tanks have alleviated the ferrocyanide concern substantially, we believe that a careful program of measurements on other tanks should be carried out before the issue is closed. Such measurements will reduce the risk of problems arising from dry wastes - since water in the tanks has been judged to be a principal factor in reducing the risk of ferrocyanide explosions. The continuation of an evaluation program is also important for tank waste processing since ferrocyanide and nitrates in the wastes may pose risks for vitrification operations.

2. Organic Safety Issues

There are two different safety issues associated with organic materials in the tanks. One deals with organic-nitrate reactions and another with organic solvents.

Organic-nitrate reactions

Organic chemicals known as complexants were used to assist in chelating (a type of chemical bonding) metallic atoms. Examples include citrate and EDTA (ethylenediaminetetracetic acid). As with ferrocyanides, organic complexants and their decomposition products can serve as a fuel source for a chemical reaction. In the presence of an oxidizing material (such as nitrates), a high enough temperature, and an ignition source, oxidation of organic materials can create explosive reactions.[370] Nineteen tanks have been placed on the organic watch list because of concerns about complexants.

To address the organic-nitrate safety issue for the high-level waste tanks, DOE is analyzing potential ignition sources in the tanks, studying how moisture affects the potential for reactions, and establishing whether or not the concentrations of organics in the tanks are lower than that necessary to support a chemical reaction.[371] The organic safety issue will remain until the key parameters -- fuel, moisture, and ignition sources -- can be demonstrated to be within safe limits. However, sampling to support resolution of the potential for organic complexants to dry out and burn with an oxidizing material such as nitrate is not scheduled for completion until 2001.

Organic-nitrate reactions pose risks at other DOE facilities in addition to the 177 high-level waste tanks at Hanford. Serious accidents involving organic-nitrate reactions occurred within six months of each other at Hanford's Plutonium Finishing Plant (May 1997) and the Savannah River Site's F-canyon reprocessing facility (December 1996).

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[368] DOE Richland, 1996a.
[369] Washington Department of Ecology, 1997.
[370] DOE Richland, 1996e, page 17.
[371] Ibid, pages 24-28.

Although these accidents did not occur in large underground high-level waste tanks, they illustrate the destructive potential of chemicals that have been used and still are in use at DOE nuclear facilities.

At Hanford, a tank on the fourth floor of the Plutonium Finishing Plant exploded on May 14, 1997. The tank contained a mixture of hydroxylamine nitrate and nitric acid that dried out over the course of almost four years, which allowed for a spontaneous chemical reaction to occur. The reaction led to a rapid release of gases, which blew the lid off of the tank, severely damaged the room, and ruptured a small fire-suppression water line. The explosion damaged a wall and interior doors, as well as created a hole in the roof. A gaseous yellow-brown plume containing nitric acid and nitrogen oxides was released from the plant, and water flowed out of some exit doors. DOE reports that the tank did not contain radioactive materials and that it did not detect any airborne contamination. The water that flowed out of the plant, however, apparently picked up radioactive contaminants from flowing across contaminated walls and floors, leading to some contamination spilling outside of the building.[372]

An Investigation Board formed by DOE noted that the chemicals in the "makeup" tank in the Plutonium Finishing Plant had been prepared in July 1993. In December 1993, the part of the Plant containing the tank (the Plutonium Reclamation Facility) was directed to be shut down. Emptying the tanks was not included in the "short-term" shut down plan, but was deferred to an unspecified time in the future. The Investigation Board noted that emptying the tanks was not included in short-term shutdown procedures, that facility management did not adequately implement transition procedures that may have identified the potential hazards of leaving the chemicals in the tanks, and that the long-term shutdown procedure had not been implemented.[373] As a result, water in the tank slowly evaporated, concentrating the mixture of chemicals and allowing for the spontaneous reaction to occur.[374]

The Investigation Board concluded that

> Similar precursor events involving hydroxylamine nitrate and nitric acid have occurred within the DOE complex, including Hanford. However, the [Accident Investigation] Board found no evidence that information and lessons learned from these events and the associated hazards were incorporated into the current safety authorization documentation for Facility operations.[375]

The Investigation Board noted a failure to incorporate lessons learned from a 1989 accident in Hanford's PUREX plant, a failure to follow-up on a recommendation to inspect all chemical makeup tanks and verify contents that was made in DOE's 1994 *Chemical Safety and Vulnerability Assessment* ("the Board found no evidence that Facility line management ever inspected or verified the contents of the tanks"), and an

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[372] DOE Richland, 1997, Section 2.
[373] Ibid, Section 3.
[374] Ibid, Section 2.
[375] Ibid, Section 3.

incorrect judgement that the December 1996 accident at the Savannah River Site was not applicable at Hanford.[376]

The Savannah River Site accident, on December 28, 1996, involved an uncontrolled reaction involving hydroxylamine nitrate. The reaction resulted in a spill of 2,500 pounds of solution. After the Hanford accident, the Defense Nuclear Facility Board noted that "although SRS has experienced several uncontrolled reactions involving HAN [hydroxylamine nitrate]- nitric acid, there has always been sufficient venting to preclude the violence of the Hanford event."[377] In response to concerns over such explosive chemicals at nuclear facilities, several organizations, including IEER, sent a letter to Assistant Secretary of Energy Alvin Alm asking for a formal National Environmental Policy Act review of the implications of future use of hydroxylamine nitrate at the Savannah River Site.[378]

Although the explosions involving organic chemicals at Hanford and accidents at Savannah River did not occur in the high-level waste tanks that are the main subject of this case study, they should serve as a warning signal that DOE must place a far higher priority on organic-nitrate safety issues.

Organic Solvents

Various separation processes involving organic solvents were used at the Hanford Site. Some of these solvents were sent to the storage tanks. Given a sufficient ignition source, organic solvents in the waste tanks can ignite. DOE has identified one tank, C-103, as being especially problematic in this regard. It has a floating organic layer, making it particularly susceptible to ignition since the organic solvent is in contact with air. It has been placed on the organic watch list for this reason. Three of 63 tanks sampled had significant amounts of organic solvents.[379] We have not examined questions relating to thoroughness of the sampling or the representativeness of DOE's conclusions for the other 114 tanks.

Toxic gases escape from the tank, creating health risks to workers on the site.[380] DOE was required by its regulators to correct this health and safety concern. However, a report issued by the Government Accountability Project (GAP) has raised serious questions about how DOE and its contractor handled the issue. In order to meet a June 30, 1995 deadline for beginning operation of a "vapor treatment system" for Tank C-103, DOE's site contractor, Westinghouse Hanford Company, proposed the installation of an exhauster on the tank. The exhauster would simply involve diluting the concentration of gases in the headspace of the tank by blowing them into the environment.

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[376] Ibid, Section 3.
[377] DNFSB, 1997b.
[378] Costner, 1997.
[379] DOE Richland, 1996e, page 18.
[380] GAP, 1997, pages 4-5.

DOE scientists reviewed the contractor's proposal, and documented "numerous, serious questions." These were forwarded by DOE's Director of Tank Safety Analysis Division, Ron Gerton, to the President of Westinghouse Hanford Company in a letter dated May 31, 1995. One scientist noted that the exhauster was listed as a "non-treatment option" in an engineering evaluation of alternatives that was performed in June 1994 and therefore asked how the proposed installation of an exhauster could be reconciled with the fact that a "vapor treatment system" was required. This question was listed as a "hold point" -- meaning that it was a critical issue and had to be resolved before proceeding with the project. Other "hold points" included concerns that data on gases in the headspace was of questionable quality, that no diagram for the exhauster was provided, that there was no indication of whether dispersion modeling of contaminants was performed for the C tank farm area, that no calculations for contaminants around the stack were provided, and that proposed exhauster did not seem to have been "formally, quantitatively compared" to other alternatives. In all, there were 27 issues, 24 of which were hold points. The scientists concluded that "there is NO evidence that the personnel's chemical risk will be lowered."[381]

On June 8, 1995, DOE's Director of Tank Safety Analysis Division sent a letter to DOE's Director of Hanford's Tank Operations Division, Ami Sidpara, with a revised list of 15 "serious questions," including 13 hold points. The letter stated that resolution of all the comments were required, and that "it is Tank Safety Division recommendation that the Notice of Construction ... not be signed by RL [DOE's Richland Operations Office] and transmitted to [Washington State Department of] Ecology until all comments are addressed to the satisfaction of the commentors."[382]

On June 13, 1995, DOE's Ron Gerton informed the president of Westinghouse Hanford Company that the Washington State Department of Ecology coordinator for the tank farms, Toby Michelena, had stated that operation of the exhauster would be in violation of the Resource Conservation and Recovery Act (RCRA) and the Clean Air Act (CAA). Gerton wrote to the president of Westinghouse Hanford Company that

> Based on this determination by a regulatory person, Tank Safety Division has decided that work on the vapor exhauster project should immediately go "on hold" until the Westinghouse Hanford Company fully documents the fact that all RCRA, State Dangerous Waste, and CAA Regulations have been satisfied.
> RL [DOE's Richland Operations Office] will not support a potentially illegal activity.[383]

DOE soon reversed itself on its seemingly hard stand against the exhauster, however. The GAP report notes that in a third letter to the President of Westinghouse Hanford Company, DOE's Gerton wrote that the hold on the project had been removed

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[381] DOE Richland, 1995a.
[382] DOE Richland, 1995c.
[383] Gerton, 1995.

"as discussed in the meeting held between Westinghouse and [Hanford] management and staff at 9:30 am, June 15."[384]

DOE has yet to answer how the serious questions posed by its own scientists were resolved between Gerton's June 13 letter and the June 15 meeting. GAP charges that it was through intimidation: according to one of DOE's scientists that reviewed the proposal, "s/he had been harassed, belittled, and threatened with being fired if s/he did not concur with the letter" allowing the construction to proceed.[385] The GAP states that it could not find any official record of the meeting.

The GAP report notes that the exhauster was installed in time to meet the June 30 deadline. It operated from approximately the end of June 1995 until November 1995. GAP has called for an independent investigation to determine how the exhauster could have been installed despite the objections of DOE scientists. The GAP report raised concerns including

- possible violations of the Clean Air Act
- possible violations of the Resource Conservation and Recovery Act
- whether workers were "knowingly endangered"
- whether the Washington Department of Health properly investigated the issue before approving the project.

3. Flammable Gas Safety Issues

For several years, one of the most serious issues at Hanford was the buildup of flammable gas in tank SY-101. Flammable gases, most notably hydrogen and ammonia, are believed to be generated by radiochemical and thermochemical degradation reactions in the waste. In tank SY-101, these gases were trapped in a layer of slurry, and would build up over a period of months. When a sufficient amount of gas had accumulated, it would cause the slurry layer to rise to the top of the liquid layer in the tank. At the liquid surface, the layer would break up and release the gas. This phenomenon came to be known as "burping." DOE reports that this tank was known to exceed the lower flammability limit for hydrogen. Above this limit, a spark or heat source can ignite the gas and cause a fire or an explosion.[386]

After considerable study and analysis by a Technical Advisory Panel, the tank SY-101 burping problem was addressed in July 1993 by placing a mixer pump in the tank to mix the waste. This causes a more uniform release of gases and prevents them from building up to dangerous levels. The gases are continually vented from the tanks. This

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[384] GAP, 1997, page 8.
[385] Ibid, page 9.
[386] Gephart and Lundgren, 1996, p.28-31.

remediation measure has prevented the reoccurrence of high concentrations of flammable gases in the tank.[387]

The flammable gas safety issue is the most widespread safety issue at the Hanford site. Because of the uncertainties associated with how the gases are generated and how they are retained in certain layers within the tank, all 177 tanks at Hanford have had controls placed on them to minimize the potential to ignite flammable gases. These controls include sampling of the headspace before and during activities in the tanks.

Concerns about flammable gases have slowed work in the tanks, such as sampling, while new technologies have been developed to reduce the generation of heat and sparks. In some tanks, pumping of liquids was halted due to flammable gas safety issues.[388] Additionally, specific safety analyses are required for tanks on the flammable gas watch list before liquids can be pumped from them.[389]

DOE's safety guidelines are based on the National Fire Protection Association guidelines, which recommend that the concentration of a gas must remain below 25% of the lower flammability limit of that gas.[390] The lower flammability limit for hydrogen is four percent by volume. Thus, 25% of the lower flammability limit for hydrogen is a concentration of one percent hydrogen of the gas in the vapor space. Due to the presence of other flammable gases, DOE sets a guideline of 0.625 percent hydrogen.

Tank SY-101 was of significant concern because, several times, the hydrogen concentrations exceeded the lower flammability limit of hydrogen (i.e., one percent). Other tanks may require measures such as mixer pumps to prevent dangerous concentrations of hydrogen from occurring. In particular, Tanks AN-105 and AW-101 have had measured releases above the lower flammability limit of hydrogen.[391] In April 1997, the concentration of hydrogen in Tank AN-105 reached 0.7 percent hydrogen, above DOE's guideline of 0.625 percent and close to the Fire Protection guideline of one percent.[392] Tank SY-103 has also experienced "burps" that have resulted in elevated concentrations of hydrogen. After a "gas release event" on December 20, 1996, hydrogen concentrations in the tank vapor space peaked at 0.511 percent -- close to DOE's safety guideline.

Despite administrative controls, the possibility for human error must also be considered. For example, in 1995, the Defense Nuclear Facility Safety Board noted that a vapor sample was not taken on a tank that was on the flammable gas watch list. On another occasion, a flammable gas sample was taken from the wrong tank.[393]

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[387] Ibid, p.31.
[388] Hanlon, 9/96, page 6.
[389] Hanlon, 4/97, page 3.
[390] DOE Richland, 1996b, page E-6.
[391] DOE Richland, 1996e, page 19.
[392] Hanlon, 6/97, page 3.
[393] DNFSB, 1996c.

Since 1989, considerable improvements have been made on flammable gas issues with respect to some tanks and operational procedures, with SY-101 remediation being the most important. But significant issues, such as understanding what mechanisms are responsible for generating and releasing flammable gases, are still under investigation by DOE.[394]

4. High Heat Safety Issues

High heat loads (due to high concentrations of radioactivity) in the tanks can cause mechanical stress to the tanks, causing cracks and bulges. High heat can also provide sufficient energy to initiate a chemical reaction of fuels such as complexants and ferrocyanides. High heat contributed to the 1957 tank explosion at a Soviet nuclear weapons plant (Chelyabinsk-65), discussed above.

At Hanford, several tanks have had problems with high heat loads. Some tanks were supposed to be able to handle waste that was actually boiling when it was sent from the processing plants. However, these tanks fell short of their design capabilities. According to a 1993 memorandum by Robert Alvarez, then a staff member of the Senate Governmental Affairs Committee:

> *During the 1950's and 1960's, high-heat wastes were deliberately concentrated to allow boiling* as a form of waste volume reduction. This practice caused several steam explosions, known as "bumps" or "rollovers", to occur. Moreover, the high heat content of the wastes caused several tanks to crack and buckle. For example, in 1965, it is believed that the heat at the bottom of tank 105-A caused the moisture outside the tank to flash instantaneously, into steam -- causing the tank bottom to buckle and creating a hole about the size of a small automobile. A radioactive steam "geyser" blew out of the tank, some 50 feet high, for a half-hour.[395]

Ten tanks have been identified as having high heat loads. One analysis concluded that six of the ten have heat loads greater than 11.7 kilowatts (40,000 Btu per hour). The other four with heat loads less than 11.7 kilowatts were recommended to be managed along with the other six due to uncertainties involved with making estimates of the heat load in a tank. One of these tanks, C-106, is currently on the high heat watch list.[396]

Studies of tank C-106 indicate that if active cooling systems were lost for an extended time, waste temperatures could reach 260 degrees Celsius.[397] High temperatures in the tank could lead to structural failure of the tank and collapse of the

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[394] DOE Richland, 1996e, pages 33-35.

[395] Alvarez, 1993, page 4.

[396] Hanlon, 6/97, page A-6. A watt is a metric unit of power, equal to one joule per second. A kilowatt is equal to 1,000 watts, or 1,000 joules per second. "Btu per hour" is also a unit that measures power. "Btu" stands for "British thermal unit" - one Btu is equal to the amount of energy needed to raise one pound of water by 1 degree Fahrenheit.

[397] Bander, 1993, cited in DNFSB, 1996e, page 36. Note that the boiling point of water (at sea level) is 100 degrees Celsius.

dome. Safe management of the tank requires addition of water on a regular basis (22.7 cubic meters, or 6,000 gallons, per month) to promote heat transfer by evaporation; the tank also requires an active ventilation system.

The contents of tank C-106 include 746 cubic meters (197,000 gallons) of sludge and 121 cubic meters (32,000 gallons) of supernatant. The sludge is divided into two layers: 655 cubic meters of "soft" sludge that is believed to contain the strontium-rich wastes that are responsible for the high heat loads and 91 cubic meters of hardened sludge that is believed to emit low amounts of heat. The strontium-rich sludge gives off a heat load of 32 kilowatts (110,000 Btu per hour).[398]

Resolution of the high heat safety concern in tank C-106 involves emptying the supernatant and soft sludges from the tank because these layers are believed to contain most of the radioactivity and, hence, generate the most heat. Hanford plans to transfer the liquids to a double shell tank that can provide greater containment of the liquid waste. The soft sludge will be mobilized through high-volume, low-pressure sluicing.

Numerous technical concerns have been identified that have slowed resolution of this safety issue. After reviewing the safety analysis, the Chemical Reactions Sub-Panel of the Tanks Advisory Panel noted several issues that were inadequately addressed. These include:

- whether or not there is a criticality issue (tank C-106 contains an estimated 96 kilograms of plutonium)
- whether sluicing will be able to remove the necessary amount of heat to resolve the safety issue in tank C-106
- whether transfer of waste from C-106 to AY-102 will create conditions under which flammable gases could build up
- whether there is a potential for violent releases of energy during sluicing should superheated regions exist in tank C-106
- whether detailed contingency plans for various failure modes were adequately considered.[399]

The serious nature of these concerns has delayed resolution of the high heat safety issue. The project was supposed to have been accelerated to initiate retrieval in October 1996 as part of a "Safety Initiative" of the Secretary of Energy, but significant safety questions remain and start-up of the project is now anticipated in October 1998.

5. Criticality Safety Issues

A criticality is a self-sustaining nuclear chain reaction. There is a risk of accidental criticalities in Hanford tanks because 1) there are large amounts of plutonium

[398] DOE Richland, 1995b, page 2-1.
[399] Hudson, 1995 and Hudson, 1997.

in some tanks, 2) there are large uncertainties in the amount of plutonium in the tanks, and 3) plutonium is not uniformly distributed in the tanks. Given a certain concentration and total quantity of plutonium occurring in a certain geometry, a criticality can occur. The occurrence of an accidental criticality in a tank would be unlikely to cause a nuclear explosion because the initial burst of energy would cause the critical mass to fly apart. However, sufficient energy and neutrons may be released in the tank to cause damage to the tank's integrity and/or to initiate secondary chemical fires or explosions. These secondary events could lead to severe environmental and health consequences.

An estimated 54.5 metric tons of weapons grade plutonium and 12.9 metric tons of fuel grade plutonium was produced in the reactors at Hanford.[400] Since 100% efficient recovery of plutonium is impossible, some of the plutonium ended up in the tanks as well as in solid waste.

A small amount of the plutonium in the tanks remains in solution, bound to organic materials. Much of it precipitated out when the waste was made alkaline by the addition of sodium hydroxide.[401] Different estimates are shown in Table 28, ranging from 455 kilograms to 981 kilograms. It is interesting to note that the later reports do not include a discussion on how their estimates can be reconciled with earlier higher ones. The 1996 reports also do not discuss how the prediction of plutonium in wastes would affect materials accounting and security concerns.

We are not confident that the official analyses have provided a sound upper limit on the amount of plutonium in the tanks. Systematic sampling during the pumping of liquids from single shell tanks to the double shell tanks could help validate DOE's methods for plutonium estimation.

Table 28: Various Estimates of Plutonium in Hanford Tanks

Source	Plutonium Estimate (kg)	Publication Date
Hanford Tank Cleanup: A Guide to the Technical Issues	545	July 1996 (page 32)
Plutonium: The First 50 Years	455	February 1996 (Appendix B)
Data Needs and Attendant Data Quality Objectives for Tank Waste Pretreatment and Disposal	up to 981	June 1995 (page 144)

[400] DOE, 1996d, page 26.
[401] Slankas, 1995, page 144.

Studies at the Hanford site have concluded that "under the existing relatively static conditions, a criticality event has been found to be incredible."[402] That is DOE's way of saying extremely unlikely. "Based upon the highest analyzed plutonium concentration, low absorber content, optimal moderation, and strong neutron reflection, extremely conservative studies have shown that criticality in the UGSTs [underground storage tanks] is not possible."[403]

Thus, DOE "closed" the "Unreviewed Safety Question" for criticality in March 1994: "Criticality was addressed on a tank farm basis and did not result in identifying any individual tanks to be added as watch list tanks."[404] Activities such as operation of the SY-101 mixer pump, the cross-site transfer line (a 7.5 mile pipeline link between the 200 East and 200 West areas), and retrieval of non-complexed organic wastes from single shell tanks were all determined to fall within safety limits.

However, a close examination of the data indicates that DOE has not been conservative in declaring that a criticality is "incredible" under static conditions even in the sludge, where almost all the plutonium resides.

The maximum sampled concentration of plutonium in the sludge discovered so far is 0.35 grams of plutonium per liter. The safety trigger point has been set by DOE at a concentration of 1 gram per liter; criticality safety is not assured above 2.6 grams per liter and depends on geometry and other factors.[405] Given that the sampling of the tanks is far from sufficient to determine the inhomogeneities of radionuclide distribution, particularly in the non-uniform sludge layers, the DOE has been hasty in declaring that a criticality is "incredible." Rather, given its seriousness for tank integrity and worker safety, this is an issue that deserves more careful field work and analysis. We believe that DOE has prematurely closed this issue and should address it more carefully.

DOE has stated that criticality will be an issue during retrieval and pretreatment of the waste.[406] If the sludges that have a higher concentration of plutonium are disturbed, recombination and concentration of plutonium could create a safety concern. This issue has already affected tank management - for example, under an Environmental Impact Statement review, retrieval of sludge from tank SY-102 was deferred due to uncertainty about criticality.[407] Additionally, criticality concerns have contributed to delays in the high heat safety issue (see above). Hanford is in the process of defining the safe operating limits to be followed during future activities such as retrieval, transfer, and treatment.[408]

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[402] Ibid, page 144.
[403] Ibid, page 144.
[404] DOE Richland, 1996b, page 3-9.
[405] Slankas, 1995, pages 146-148.
[406] Ibid, page 144.
[407] DOE Richland, 1996b, page E-12.
[408] For example, Slankas, 1995, section 7.2

B. Emptying Liquids from Single Shell Tanks

Sixty-two of the 177 tanks at Hanford are classified as "known" leakers, and five are "assumed" to be leakers. All of the leaking tanks are single shell tanks. Five of the single shell tanks that are believed to have leaked contain 800,000 gallons of pumpable liquids.[409,410] In total, the 149 single shell tanks (all beyond their design lives) contain roughly 5,700,000 gallons of pumpable liquid; as such, an important part of tank management involves pumping liquids from the single shell tanks.[411]

Liquids are present in the tanks as *supernatant* and *interstitial liquid*. Supernatant occurs on top of the saltcake and sludge in the tanks. Supernatant can be relatively straightforwardly pumped from the tanks.

Interstitial liquid occurs in the pore spaces of the saltcake and sludge. Interstitial liquids can be removed by a process known as "saltwell" pumping, in which a ten-inch diameter screened stainless steel pipe is placed vertically into the solid and sludge layers, extending to near the bottom of the tank. The screened pipe is attached to a solid pipe which connects to the top of the tank. The liquid is thus pumped out of the tank. Saltwell pumping has been declared outside of the safety "authorization basis" (which defines site safety guidelines) for flammable gas tanks because of concerns that this activity could create sparks or heat that could ignite flammable gases. As a result, such pumping can only proceed after a specific safety analysis is completed.[412]

When liquids from a tank have been pumped so that less than 5,000 gallons of supernatant and less than 50,000 gallons of interstitial liquid remain, a tank is declared "Interim Stabilized."[413] Thus, even when tanks are "Interim Stabilized," liquids can still leak out and provide a continuing driving force for the migration of radionuclides and other contaminants toward the groundwater. Cesium-137 measurements in the soil around Tank SX-109 indicate high-level waste is still leaking out slowly, despite the fact that that tank has been declared as interim stabilized.[414] This is a clear indication that the term "interim stabilized" is a misleading one. DOE should review this definition and make more urgent attempts to develop methods to empty the liquids from leaking tanks in a manner compatible with safety. Moreover, there are no chemical or radiological criteria

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[409] The total amount of liquid in the tanks is greater than the amount of "pumpable" liquid because liquids can collect in the bottom part of tanks with "dish" bottoms. For definitions, see Hanlon, 6/97, pages C-7 and C-8.

[410] BY-103 (9,000 gallons pumpable liquid remaining), BY-105 (216,000 gallons), BY-106 (163,000 gallons), and SX-104 (195,000 gallons) (Hanlon, 6/97, appendix E). Additionally, SX-102 (216,000 gallons), is not officially classified as a leaker, but a report completed in September 1996 suggests that this tank has leaked (DOE Grand Junction, 1996, pages 70-71).

[411] This 5,700,000 figure is calculated using average values or actual tank data for the *porosity* of sludges and saltcake. General numbers used include 21% pore volume for sludge waste, 50% pore volume for saltcake waste. Lack of sufficient data makes the estimate somewhat uncertain (Hanlon, 9/96, page E-19).

[412] See the discussion on the flammable gas safety issue above.

[413] Hanlon, 4/97, page C-3.

[414] DOE Grand Junction, 1996, page 91.

for declaring the tanks to be "interim stabilized." We believe that, in view of the presence of explosive materials, such criteria should be included.

There is general agreement that removing the liquids from single shell tanks is desirable because they are prone to leaks. However, transferring the waste could create high heat concerns in the tank being emptied. The remaining sludges and saltcake will no longer be cooled by liquids, possibly resulting in buildup of tank temperatures. DOE claims that this has not been a problem, although 9 of the 10 tanks with the highest temperatures are tanks that have had liquids pumped from them.[415] While these tanks all have temperatures less than 190 F (less than the boiling point of water), a temperature as high as 234 degrees was measured under one tank. There is also the problem that temperatures are non-uniform in tanks, so that a complete temperature profile is not available for tanks. Thus prudence dictates that DOE very carefully sample and monitor the tanks from which liquids have been pumped.

There is also a concern that the process of pumping out of liquids may initiate new corrosion in the single shell tanks. The potential for such corrosion at the liquid-air interface has been recognized. This possibility arises from ill-understood electrochemical phenomena at the interface that could cause rapid corrosion. As liquids are pumped, new parts of inner wall of the tank are at the liquid-air interface and hence become vulnerable to corrosion. The potential for more leaks will to some extent remain even after the pumping is stopped because the pumping cannot remove all liquids (such as liquid in the pore spaces sludges or saltcake). Despite the importance of the problem, DOE abandoned work on corrosion issues without resolving them. It has yet to resume addressing it though the concerns are recognized.

Additional concerns arise from the transfer of single shell tank liquids. The liquids are pumped into double shell tanks, either directly or via an evaporator, which first concentrates the liquids by evaporating some of the water. The double shell tanks have not leaked.

Mixing wastes from single shell tanks with those in double shell tanks raises concerns about the possibility of creating new safety issues in the double shell tanks. For instance, there may be new chemical reactions due to waste incompatibilities, which may complicate the ultimate treatment of the waste, and also increase the complexity of managing the wastes in the interim. Hanford has a "Waste Compatibility" program that is charged with assessing issues associated with transferring of wastes. As elsewhere, one of the challenges facing this program is a lack of information:

> The retrieval and transfer of wastes stored in the single-shell tanks (SSTs) will require non-routine compatibility decisions to be made. Very little historical data are currently available from which an estimate of the variability of these wastes can be derived.[416]

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[415] Hanlon, 4/97, pages A-6 and I-6.
[416] Fowler, 1995, page .

The Waste Compatibility program sets the framework for evaluating transfers between tanks by identifying the sampling needs and working on the basis of "a number of critical assumptions."[417] Safety and operational considerations include:

Safety
- criticality
- flammable gas generation and accumulation
- energetics
- corrosion and leakage, and
- unwanted chemical reactions

Operational
- plugged pipelines or equipment caused by precipitation
- plugged pipelines or equipment caused by complexed wastes
- segregation of high transuranic-content wastes from low transuranic-content liquids (to reduce the ultimate volume of vitrified high-level waste)
- heat load limits in receiving tanks

Due to practical constraints, each transfer relies on a limited amount of sampling to verify that the transferred waste will not create new problems in the double shell tank. Since waste is transferred in small batches, there is relatively greater confidence in the characteristics of the waste being transferred than in the characteristics of the receiving tank. However, resolution of the concerns arising from inter-tank transfers also requires knowledge of the double shell tank contents. Acquiring this information is more problematic. Samples taken from a million gallon double shell tank to support a determination of waste compatibility are far too limited. This limited sampling necessitates many more assumptions and heavier reliance on engineering judgment and rules of thumb regarding double shell tank contents.

An example of the differing levels of confidence in the characteristics of the waste being transferred versus the waste in the receiving tank can be seen in the protocol used to protect against criticality conditions. Most of the liquids being transferred are low in plutonium content, and sampling from a 5,000 gallon batch can be done with a relatively high degree of confidence. However, for the double shell tanks, whose contents cannot be fully characterized before waste transfer, DOE has to make some assumptions regarding the implications of the transfer for safety. DOE assumes that the concentration of plutonium is evenly distributed in the layer of settled solids at the bottom of the tank and that the amount of plutonium in the double shell tanks is known with confidence.[418] Neither of these assumptions is justified or conservative. DOE should review and revise its assumptions and make them more compatible with its state of knowledge about double shell tank contents.

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[417] Ibid, page 1.
[418] Ibid, section 6.1.1.

These uncertainties could perhaps have been avoided had the DOE carefully evaluated the feasibility of calcining or vitrifying the liquids being pumped from the tanks instead of transferring them to the double shell tanks. However, the program to reduce the risks of leaks appears too far along to accommodate such a plan. This transfer program should be completed in a manner compatible with the safety of both single shell and double shell tanks. As noted above, several aspects of the program can be strengthened to improve its safety.

C. Contamination of Soil and Groundwater

Production activities at Hanford have resulted in large volumes of soil and groundwater contamination. As noted above, both concentrated high-level liquid wastes and dilute supernate liquid wastes were directly released to trenches. In addition, many of the single shell tanks have leaked; sixty-seven tanks are reported as known or assumed leakers. Some tanks have been put on and taken off the list several times due to uncertainty about the condition of certain tanks.[419] Table 29 summarizes results of a 1996 study that examined leaks from the SX tank farm by analyzing contamination of the "vadose zone" beneath the tanks. The vadose zone is the region of soil and rock between the ground surface and the top of the water table.

Leaks in tanks have been most commonly determined by analyzing changes in the volume of waste in the tanks. Waste volume is calculated by measuring the height of the waste in the tank and converting that number to a volume based on the geometry of the tank. Determining the volume of waste in the tanks can be difficult, since the surface of tanks with large amounts of solids is irregular and the height of the waste in the tanks is often measured at only one point. A difference of one inch in the measured height of waste in a tank with a 75-foot diameter translates into a volume of almost 3,000 gallons.[420]

Moreover, the height of waste in the tanks can change for several reasons, and sometimes the reason cannot be determined. Changing weather conditions (temperature, pressure, etc.) can cause the level of waste in the tank to rise and fall. Rainwater infiltrates some tanks. Liquid levels can go down as heat from the radionuclides evaporates water from the waste. Adding to the uncertainty are malfunctioning, imprecise, and outdated instruments used to measure the liquid levels in the tanks. Finally, water has been added to some tanks to keep the temperatures down. As a result of these problems, the exact amount of waste that has leaked can not always be accurately determined from the available data on waste surface measurements.

DOE estimates that from 600,000 to 900,000 gallons have leaked from the tanks based on such measurements.[421] These volumes have been described as a "major

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[419] Hanlon, 9/96, 2/97, and 3/97.
[420] 3.1415*(75/2)^2*(1/12)*7.48= 2,754 gallons for 75 foot diameter tanks.
[421] Hanlon, 4/97, page H-2.

underestimate."[422] Results from the SX tank farm report (described in Table 29) have provided more indications that leak volume estimates are often incorrect, and in several cases dramatically low. For example, Hanford officially reported in September 1997 that the amount leaked from tank SX-109 is less than 10,000 gallons[423] but the SX tank farm report published in September 1996 estimated that much or most of the 250,000 gallons lost from the tank leaked into the vadose zone.[424] True to form, the 1997 report makes no reference to the earlier number.

The SX tank farm report also estimates that two of the tanks listed by DOE as leaker have probably not leaked (Tank SX-104 and SX-110). However, the evidence presented in the report also suggests that one not listed as a leaker was found to have leaked (SX-102). It could not be determined whether or not another tank had leaked (SX-103).

Dangers from these leaks and other discharges of radioactive liquids to the soil were thought to be reduced by the ion-exchange capacity of the soil. It was felt that the soil would selectively adsorb certain radionuclides such as cesium, plutonium, etc. A semi-arid climate (6.5 inches of rainfall per year[425]) and a relatively deep groundwater table (230 feet in the West Tank Farms, 320 feet in the East Tank Farms[426]) added to general over-confidence that disposal of liquid wastes would not impact the groundwater. Concerns with such practices, however, have been voiced since at least the 1950's in general and since at least 1960 for Hanford.[427]

These long-standing concerns about vadose zone contamination were not reflected in the Environmental Impact Statement for the Tank Waste Remediation System released in August 1996. In it, DOE states simply that "there is insufficient information concerning the amount of contamination to be remediated"[428] and that an appropriate review will be conducted "in the future."[429]

DOE is just beginning to address the importance of soil and groundwater contamination. One effort is the Hanford Tanks Initiative, where the soil around two tanks will be analyzed for contamination before certain activities in those tanks begin (see the discussion on Retrieval). Another effort is characterization of the vadose zone underneath some of the the tank farms.

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[422] Alvarez, 1993.
[423] Hanlon, 4/97, page H-2.
[424] DOE Grand Junction, 1996, page 76.
[425] DOE Richland, 1996b, page 4-26.
[426] Ibid, page 4-15.
[427] See National Research Council, 1966, pages 2 and 5.
[428] DOE Richland, 1996b, page L-36.
[429] Ibid, page L-36.

Table 29: Summary of Results from September 1996 Characterization of the Vadose Zone Beneath the SX Tank Farm

Tank	Previous Official Leak Estimate, gallons	SX Tank Farm Report's Assessment of Previous Estimate	Comments from SX Tank Farm Report
SX-102	Sound; no leaks	Tank has leaked	"was listed as a leaking tank for a short time in 1993... [then] reclassified as sound...[The data show] fairly extensive plumes under north and northwest portions of the tank... Tank still contains 183,000 gallons of drainable liquid."
SX-104	6,000	Tank probably has not leaked	"classified as leaking in 1987 when a liquid loss occurred that could not be attributed to evaporation...The vadose zone contamination does not show any contamination that can be attributed to a source from this tank."
SX-107	<5,000	Volume estimate probably inaccurate	"tank was listed as a leaker in 1964, but no information regarding the cause of the designation could be found...The basis of the estimate is not known but may have originated from an estimate of an 'average' leak volume and is probably inaccurate...The total vertical extent of the high-concentration zone is about 70 ft...However, the maximum vertical extent of the lower concentration radionuclides is not known because the boreholes have not fully penetrated the lower concentration zones"
SX-108	2,400 to 35,000	Upper limit probably more correct	"estimate of 2,400 gallons...was based on the contamination distribution [in nearby boreholes]...The leak-estimation method was not based on extensive knowledge or experience with contamination migration...[An estimate] based on liquid loss from the tank places the leak volume as high as 35,000 gallons with a lower volume estimate of 2,400 gallons. The large range is an indication of the imprecision of the leak volume estimation method...This tank has leaked a large amount of radioactive liquid."

Tank	Previous Official Leak Estimate, gallons	SX Tank Farm Report's Assessment of Previous Estimate	Comments from SX Tank Farm Report
SX-109	<10,000	Up to 250,000 gallons may have leaked	"In January 1965...was declared an assumed leaker. However, liquid in the tank was not removed because of a shortage of tank storage space...In late 1965, an additional 26,000 gallons of dilute liquid waste was added to the tank...From 1965 to 1969, 250,000 gallons of liquid was lost from the tank. The amount of liquid leaked to the vadose zone and loss from evaporation is not known. Judging from the extent of contamination of the vadose zone, it is probable that much of the liquid went to the vadose zone. If such a large amount of contamination leaked from this tank, it would be the largest leak from a SST at Hanford...Increases in gross gamma activity [measured from 1986 to 1989]...probably resulted from a continuation of a leak of the liquid remaining in the tank."
SX-110	5,500	Tank may not have leaked	"designated a leaker after a 3-in. liquid level decrease occurred that could not be attributed to any other cause...No information... indicates leakage from this tank."
SX-111	500 to 2,000	No credible estimate of leak volume	"identified as a leaker when elevated activity was detected in 1974...There is no credible estimate of the leak volume for this tank."
SX-112	30,000	Relatively accurate	"In 1974, an in-tank photograph revealed a 3 inch wide crack in the side of the tank at the 17 foot level...The bottom liner of the tank also had a large bulge...This estimate was based on the liquid level decrease and is relatively accurate."
SX-113	15,000	Probably relatively accurate	"When this tank was first used in 1958, the bottom steel liner of the tank bulged upward about 4 feet. The tank was leak tested, then reused while the tank was checked for a leak. The tank bottom bulged again, a liquid level decrease subsequently indicated a leak...The Cs-137 plume beneath the west side of the tank is deeper than 75 feet, the greatest depth of the monitoring boreholes...The total vertical extent of this plume has not been determined..."
SX-114	8,000	Not accurate	"No data are available for depths of more than about 75 feet, the greatest depth of the boreholes...A deeper plume is expected."
SX-115	50,000	Could be accurate, could be high	"The ^{137}Cs distribution around this tank indicates that although a large volume of contamination leaked from the tank, it did not migrate extensively in the horizontal or vertical directions."

Source: DOE Grand Junction, 1996.

The SX tank farm investigation characterized the vadose zone by measuring gamma activity in boreholes surrounding the tanks. Cesium-137 was the major radionuclide measured by this technique. The results have highlighted the uncertainty surrounding the extent to which waste has leaked from some of these tanks, and has challenged many of the assumptions that have historically been made and continue to be made regarding the movement of contaminants from the tanks and through the soil.

The seriousness of soil and groundwater contamination in the tank farm area is apparent from the SX tank farm report. Official assumptions and justifications used to downplay the importance of contamination continue to be overturned by real-world evidence. One example relates to the mobility of radionuclides in the environment. The SX tank farm report states

> Plutonium has migrated a surprisingly far distance, contrary to what was previously understood to be representative of its behavior in the vadose zone. Previously the belief was that plutonium would drop out of solution as soon as it came into contact with the vadose zone sediment...Because plutonium was measured as deep as 100 ft at a significant level relative to its health-and-safety risk (4.6 pCi/g), the previous theories about plutonium migration through the vadose zone may need to be revised.[430]

The SX tank farm investigation has also shown that contamination appears to be moving in a broad front, and is not simply confined to the areas around the boreholes. In view of these findings in the SX tank farm report and the evidence from our review of buried TRU waste hazards, we strongly recommend that DOE revise its assumptions about lack of plutonium mobility on a complex-wide basis.[431]

In addition to the extensive contamination of the vadose zone underneath the SX tank farm, the SX tank farm report also discusses the contamination of groundwater underneath the Hanford tank farms. The monitoring boreholes in the SX tank farm do not penetrate to the depth of groundwater. As a result, the vadose zone investigation of the SX tank farm could not directly address the impact of the tank farm leaks on groundwater. However, the study notes that detection of chromium in the groundwater provides "conclusive evidence that the tanks have impacted the groundwater."[432]

The conclusion that the SX tank farm has impacted the groundwater means that a thorough revision of the 1995 Hanford "Groundwater Management Plan" is now necessary. The Plan does not address the problem because it "assumed that no

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[430] DOE Grand Junction, 1996, page 87. It is interesting to note that 4.6 picocuries per gram was considered a significant level for health and safety for Hanford and yet DOE, as part of the Rocky Flats remediation program, has proposed a level about 140 times higher on land that can be used by farmers after active controls are removed.

[431] For example, the premise of discharging plutonium-containing wastes from the Plutonium Finishing Plant between 1950 and 1973 to trenches (100 kilograms of plutonium are reported to have been dumped in one trench alone - see the discussion above) was that the soil would retain plutonium within a few vertical feet of discharge.

[432] DOE Grand Junction, 1996, page 92.

groundwater contamination originated from vadose zone contamination from the SSTs."[433] The 1996 Tank Waste Remediation EIS and the 1996 Draft Hanford Remedial Action EIS and Comprehensive Land Use Plan also need revision on this count because they used the same faulty assumption as the Groundwater Management Plan.

DOE also needs to revisit its assumptions about migration of contaminants from the vadose zone beneath the tanks to the Columbia River since the extent of contamination as well as the speed of migration are likely to be greater than DOE has so far assumed.

[433] Ibid, page 94.

DOE Plans for Tank Farm Management

A. Retrieval, Separation, and Vitrification

The ultimate goal of the tank waste management program is to put the wastes in a condition suitable for disposal in a geologic repository. The current plan at Hanford is to:

1. meet a goal set in the Tri-Party Agreement of 99% removal of waste, by volume, from the tanks
2. separate the retrieved waste into a high-level and low-level waste stream
3. vitrify (turn into glass) both the high-level and low-level waste
4. dispose of the high-level waste in a geologic repository
5. dispose of the low-level waste on site.

The separation and vitrification of the wastes is to be done by "privatized" contractors who do not get paid unless an acceptable waste form (i.e., vitrified glass) is produced. This type of contracting is in contrast to the traditional DOE contracting that reimburses contractors for their costs plus a fee, regardless of whether or not the project is successful.

We have several concerns about the proposed plan:

- Efforts to remediate the waste in the tanks are proceeding without proper integration of efforts to deal with residual waste DOE plans to leave in the tanks, contaminated soil around the tanks, and the tanks themselves.
- The 99% by volume retrieval criterion of the Tri-Party Agreement is not based on a corresponding reduction in risk since removing 99% of the waste volume may not remove 99% of the radionuclides or other hazardous constituents. The remaining 1% of waste could, in the case of many tanks, present a serious enough long-term environmental hazard that would substantially reduce many of the important benefits of the expensive Hanford tank remediation effort.
- DOE does not seem to be planning for the decommissioning of the tanks themselves
- Alternative treatment technologies to vitrification, such as calcining and ceramics, are not being pursued.
- 351,000 cubic meters of "low-level" waste with millions of curies of long-lived radionuclides will be disposed of on-site in shallow land burial.
- "Privatization" is an unproved and risky approach to this unique problem that is likely to complicate solutions rather than ease them. DOE has reduced efforts to develop a backup to the privatization plan.

In the sections below, we describe the main components of DOE's tank remediation plan:

- retrieval

- sludge washing
- vitrification
- disposal of high-level and low-level waste.

1. Retrieval

a. Past retrieval efforts

Under the Tri-Party Agreement, the Department of Energy is obligated to remove 99% of the waste from the tanks.[434] Removal of supernatant is relatively straightforward. DOE also has experience in pumping interstitial liquids from the tanks. The rest of the waste, about 125,000 cubic meters (33 million gallons), consists of sludges and solids that will be much more difficult to retrieve. Table 30 summarizes some of the operational constraints on retrieval of waste from high-level tanks.

Hanford has had limited experience with removing sludges during two different campaigns.[435] Between 1952 and 1957, about 9,700 cubic meters (2.5 million gallons) of sludge from 43 single shell tanks were removed in order to recover uranium in the waste. Another retrieval campaign involved removing 4,675 cubic meters (1.2 million gallons) of sludge in order to recover strontium from 10 single shell tanks.[436] These sludges were retrieved by *sluicing*, where jets of water were aimed at the waste in order to dislodge, dissolve, or otherwise break down the waste so it could be pumped from the tank as a slurry.

The sluicing technique used in earlier retrieval actions at Hanford is of limited use to the current retrieval needs. The techniques used in the past caused stress to the walls of the tanks - in fact, sluicing had to be stopped in two tanks because of leaks.[437] Sluicing could further damage the tanks (which are all past their design lives) or could open up cracks in the tank that have been over time plugged by hardened waste. In addition, previous sluicing used water to mobilize the waste. This practice creates large volumes of new radioactive waste. The volume must then be reduced by evaporation or else additional tank space will be needed.

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[434] Tri-Party Agreement, M-45 series of milestones

[435] Boomer, 1993, page 6-1.

[436] Incidentally, a mistake made during this campaign created the high heat safety issue in Tank C-106 when strontium rich sludge was inadvertently pumped to this tank instead of to the strontium recovery facility.

[437] Boomer, 1993, page 6-2.

Table 30: Retrieval Challenges for Single Shell Tanks

Operating attribute	Applicability	Comments
Retrieve waste with loose items discarded in tank	133 tanks	Discarded items include embedded metal tapes, wire, small steel weights, fist-sized rocks, etc.
Retrieve hard waste	Most tanks	Hard salt cake or agglomerated sludge
Retrieve soft waste	3/4 of the tanks	Soft salt cake or sludge
Work remotely in radiation environment (in-tank)	133 tanks	Radiation fields vary from low to 500 R/h
Work in a caustic environment	133 tanks	pH-12+
Access tank through 30-cm (12-in.) riser	133 tanks	At or near center of tank
"Dry" retrieval process	Possibly any tank (currently 67 assumed/ known leakers)	Does not increase tank leak potential, i.e., any water used is immediately scavenged. Backup to sluicing in the event of a leaking tank where sluicing cannot be used.
"Wet" retrieval process	Possibly any tank	Use of water volumes and recovery rates similar to sluicing to mobilize and convey the waste. Backup to sluicing where sluicing can be used but has not retrieved enough waste or where sluicing can be made more efficient
Operate in a congested tank	24 tanks	A dozen vertical structures plus guy wires from tops of four structures to the floor
Negotiate soft surfaces	~50 tanks	Sludge/mud
Clean tank walls	~133 tanks	Tanks have varying amounts of material caked on the walls
Negotiate precipitous waste surfaces	~12 tanks, est.	Stabilized salt tanks with a center depression 1.2 to 1.8 m (4 to 6 ft) deep resulting from dewatering
Negotiate stable surfaces	~80 tanks	Ranges from bare metal to damp salt to hard pan
Operate in Watch List tanks	~40 tanks	Restrictions for flammability, minimum moisture level in organic tanks, etc.
Restricted head space	24 tanks	12 tanks full, with only ~4 m (~13 ft) and 12 tanks nearly full, with only ~4.5 m (~15 ft) headspace
Operate in highly congested tank	4 tanks	2 to 3 dozen vertical components, 1.5 to 3 m (5 to 10 ft) apart

Source: Westinghouse Hanford, 1995, Table 4-1.

b. Tank Waste Retrieval Program

The tank waste Retrieval Program will have to operate under more stringent environmental and safety constraints than the previous retrieval efforts described above. In addition, the 99% stipulation of the Tri-Party Agreement means that retrieval cannot simply stop when the easiest wastes to mobilize are out of the tank. Under this criterion, most of the sludges, saltcake, and an estimated 21,000 cubic meters (5.5 million gallons) of waste classified as "hard heel" are required to be removed from the tanks. Different types of waste may need to be retrieved by different means. Technologies for the removal of tank wastes include sluicing, "robot arm" systems, and "vehicle" systems that move across the surface of the waste.

The Retrieval Program consists of several parts, as shown in Figure 12.

Figure 12: Major Components of Tank Waste Retrieval Program

1. ***Sluicing retrieval of tank C-106 high heat sludge***
   Begin retrieval: possibly October 1998 (initially slated for October 1996)
   This project wil retrieve the high heat, soft sludge layer in tank C-106 by sluicing in order to resolve the high heat safety issue.

2. ***Retrieval demonstration for remaining wastes in tank C-106***
   Begin retrieval: June 2002
   This project will demonstrate a retrieval technology on waste remaining in tank C-106 (comprised of a hard sludge layer and any remaining soft sludge) after high heat sludge is removed. If successful, the demonstration would be the first removal of hardened waste from Hanford tanks.

3. ***Initial Single Shell Tank Retrieval System***
   Complete design: June 2000
   Begin retrieval: December 2003
   This project will retrieve waste from 4 single shell tanks.

4. ***Retrieve waste from 144 remaining tanks***
   Begin retrieval: September 2005
   Complete retrieval: September 2018
   This project will complete the retrieval program. The first phase (from 2005 until 2011), will involve 31 tanks and will be performed by DOE's site contractor. The second phase (from 2012 until 2018), involves the remaining 113 tanks and will be completed by a 'privatization' contractor.[438]

Sources: TWRS, 1997 and Tri-Party Agreement, M-45 milestones.

Focusing on the retrieval requirements as written puts a premium on emptying 99% of tank contents as rapidly as possible without addressing two major issues:

- whether existing or near-term technology can be safely used to achieve the 99% goal
- whether the remaining 1% will pose severe problems for long-term management.

[438] See the discussion on privatization later in this chapter.

DOE's Retrieval Program is described below.

- *Sluicing retrieval of tank C-106*

The first project under the Retrieval Program is removal of the soft sludge from tank C-106. This project is being implemented to resolve the high heat safety issue.[439]

An Environmental Assessment published in February 1995 selected a sluicing technology in order to retrieve the high heat sludge. The retrieval effort is referred to as "past-practice sluicing" -- consisting of a high-volume, low-pressure stream of liquid to mobilize the waste.[440] The proposed design involves a recirculation of supernatant as the liquid used to mobilize the sludge in order to avoid using clean water as the sluicing liquid. Clean water would have become contaminated and increased the total volume of waste. It was estimated that if clean water were to be used, 2,000 cubic meters (525,000 gallons) of additional waste would have been created in the effort to remove 490 cubic meters (130,000 gallons) of high heat sludge.[441]

However, the prospect of using clean water was not entirely ruled out in the Environmental Assessment. It is not clear under what conditions the "recirculation" sluicing option might be discarded, but if it were, the Assessment simply states that the additional 2,000 cubic meters of waste that would then be created by contaminating clean water "is within current tank farm capabilities and in accordance with current waste management strategies (i.e., it could be sent to the evaporator for volumetric reduction)."[442] Use of clean water for sluicing of even just a few more tanks could, however, significantly increase the volume of tank waste needing to be managed.

One of the important factors in choosing sluicing as the retrieval technology was that other technologies were not considered developed enough to meet the planned start date of October 1996.[443] Also, tank C-106 is believed to be structurally sound. Sluicing in single shell tanks, however, poses a major environmental threat due to opening of plugged leaks in the bottom or sides of the tanks, or the creation of new leaks due to added stress on tanks that are all beyond their design lives. DOE's conservative estimate in its accident analysis for the sluicing of tank C-106 is a release of 40,000 gallons.[444]

DOE's reliance on sluicing for the resolution of the high heat safety issue is an extrapolation of its past reliance on sluicing for recovery of materials in the tanks. Due to the high priority of the high heat safety issue, the decision to proceed with sluicing and

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[439] See the discussion of the high heat safety issue earlier in this chapter..
[440] DOE Richland, 1995b, page ES-1.
[441] There are an estimated 655 cubic meters of high heat sludge, 75% of which is to be removed in order to reduce the heat load in the tank to safe levels. DOE Richland, 1995b, page 2-1. Also, see the section on the high heat saftety issue for further description of the tank contents.
[442] DOE Richland, 1995b, page 5-16.
[443] Ibid, page 3-2.
[444] Ibid, page 5-11.

not to wait for development of new retrieval technologies may be a risk worth taking. Of course, the sense of urgency now is due to years of inaction. Tank C-106 was on the original watch list created in 1991.[445] Moreover, the anticipated start date has been pushed back to October 1998.

The use of sluicing for tank C-106 might set a dangerous precedent, however. The danger can be seen in DOE's classification of the removal of the high heat sludge from tank C-106 as a "demonstration technology" (at the same time it is referred to as a "past practice"). DOE argues that it is a "demonstration" because "it has to be proven effective under the current regulatory framework which is much more stringent than past requirements."[446] This indicates that DOE is also laying the groundwork for widespread reliance on sluicing of single shell tanks. However, the fact that sluicing was chosen because there is an urgency associated with the high heat safety issue should not be used to provide a rationale for sluicing of all single shell tanks.

DOE has not undertaken a thorough enough analysis of the cumulative impacts that widespread sluicing may have on increased waste volumes as well as leaks that could further contaminate the soil and groundwater. The amount of water needed to mobilize the wastes is estimated to result in 170 million to 550 million gallons of waste in the tank system, based on dilution ratios of 3:1 to 10:1.[447] This enormous increase in waste volume would add great stress to the tank farm infrastructure, including the pipeline system needed to transport the waste and the evaporator needed to boil-off the additional water.

Moreover, the impacts of further contamination of the soil and groundwater has not been given sufficient analysis and has been implicitly written off as small. For example, the Tank Waste Remediation System EIS assumes that an average of 4,000 gallons will leak from the tanks during sluicing, calling this a conservative estimate. This figure is derived by dividing the "maximum" release volume postulated for sluicing retrieval of tank C-106 by a factor of ten.[448] No sound technical rationale was presented for using this factor and it is not clear that dividing the tank C-106 maximum leak by ten still yields a conservative estimate for the whole tank farm.

The environmental threats from further contamination of the soil and groundwater need to be re-evaluated in light of the ongoing work to characterize the vadose zone in the tank farm areas.[449] There has been long-standing and widespread inattention to soil and groundwater contamination, exemplified by the way the Environmental Assessment for sluicing of tank C-106 deals with the risk of leaks caused by earthquakes. DOE concludes that

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[445] Hanlon, 6/97, page A-3.
[446] DOE Richland, 1995b, page 1-1.
[447] Gephart and Lundgren, 1996, p.41.
[448] DOE Richland, 1996b, page 3-33.
[449] See the discussion on contamination of the vadose zone earlier in this case study.

> ...the chance of contamination reaching the groundwater is remote since the most conservative release from Tank C-106 is estimated to be less than 662,000 liters (175,000 gallons), and the majority of radionuclides would be trapped in the top portion of the soil column. Cleanup of a leak of more than 375,000 liters (100,000 gallons) would likely be performed with the eventual cleanup of the tank farms and would be completed well before the waste reaches the groundwater.[450]

DOE, in effect, dismissed the consequences of a major leak by relying on the disproven assumption of soil retention of radionuclides and on a remediation plan that does not exist. This is a misleading and technically unsound way to address major environmental risks.

- ***Retrieval technology demonstration***

The lack of readily-implementable alternative retrieval technologies is one of the main reasons why sluicing was chosen to resolve the high heat safety issue. The combined prospect of sluicing-induced leaks and the potential for creation of large volumes of new waste increases the importance of developing alternatives to sluicing. This deficiency is now being addressed as part of the Hanford Tanks Initiative, which is soliciting the involvement of vendors interested in demonstrating technologies that can be adapted for the retrieval of radioactive tank waste.[451] In 1997, four technologies were awarded contracts for "cold" demonstrations - two "robot-arm" systems and two "vehicle" systems.[452]

A demonstration of one of these technologies is currently planned for tank C-106, after the high-heat sludge is removed.[453] As mentioned in the section on safety issues earlier in this case study, the project to remove the high-heat sludge is one year behind schedule. Further delays could impact the planned retrieval technology demonstration, or could require the demonstration to be carried out in another tank.

This part of the Hanford Tanks Initiative would be the first retrieval of hardened waste from one of the Hanford high-level waste tanks. It can provide valuable information on the tradeoffs that must be made in meeting the 99% retrieval criteria, including technological and cost considerations. It should also lay the foundation for implementing alternatives to sluicing. In light of the importance of developing environmentally-sound retrieval technologies in order to remove waste and decommission the tanks, vigorous development of retrieval technology should be pursued.

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[450] DOE Richland, 1995b, page 5-10.
[451] Westinghouse Hanford Company, 1996; Hanford Tanks Initiative, 1997.
[452] Hanford Tanks Initiative, February 1997.
[453] See section on Safety Issues.

- *Initial Single Shell Tank Retrieval System*

DOE's plans for technology demonstration and waste retrieval are not coordinated. As noted in Figure 12, design for four retrieval systems is supposed to be completed by June 2000. This is about the same time the C-106 retrieval technology demonstration of the Hanford Tanks Initiative will be completed.[454] Thus, according to the current plan, the retrieval systems built for the first four tanks will not benefit from the Hanford Tanks Initiative. The likely result would be sluicing retrieval in these tanks, with the associated risks of leaks or increased waste volume. Despite the requirements in the milestones, sluicing should not be undertaken prior to demonstration of alternative retrieval technologies if there is not a safety-related reason for beginning the retrieval of wastes from these tanks.

2. Separation of Tank Wastes – Sludge Washing

DOE plans to separate the retrieved tank waste into two different streams. The goal is to concentrate most of the longer-lived radionuclides in a "high-level" waste stream that will be vitrified and disposed of in a geologic repository. The rest of the radionuclides will be vitrified in a large volume of "low-level" waste glass that would be disposed of at Hanford. DOE estimates that this "low-level" waste will contain some 17 million curies and have a vitrified volume of 351,000 cubic meters.[455] This waste is referred to as "Low Activity Waste" in DOE's Tank Waste Remediation System EIS. DOE states that this waste, in its final solidified form, would meet Nuclear Regulatory Commission Class C radioisotope limits.[456]

DOE has prepared several analyses examining different options for minimizing the volume of high-level waste. The volume of high-level waste that DOE plans to dispose of in a geologic repository would be a function of how much pretreatment, or separation, of the tank waste is carried out. Table 31 is one set of estimates of the amounts of high-level waste glass that might be created under different pretreatment options. As the volume of high-level waste decreases, a greater volume of low-level waste is left for disposal on-site.

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[454] Westinghouse Hanford Company, 1996, Appendix B.

[455] It may be possible to separate and re-use some constituents of the tank waste. Since residual radioactivity will remain, uses of any such materials may be limited. One of the contractors participating in the first phase of the privatization contract is proposing to recycle a large quantity of materials, particularly metals and sodium hydroxide (NaOH). It is unclear where the sodium hydroxide might be used, however.

[456] DOE Richland, 1996b, page 13 of glossary. See Appendix B for a discussion of the U.S. waste classification system.

Table 31: DOE Estimates of the Effect of Different Pretreatment Technologies on the Volume of Vitrified High-level Waste

Pretreatment method	Estimated volume of high-level waste, cubic meters
None	135,000
Sludge washing	23,650
Solvent extraction and actinide concentration	6,820
Extensive separations	1,240

Source: Boomer, 1993, page 7-46.

The tank waste Technical Strategy outlined in the Tri-Party Agreement relies, "as much as possible, on existing technology." In accordance with this philosophy, "pretreatment of tank wastes using simple processes that can be performed in existing DSTs [double shell tanks] or in relatively simple new capital facilities and that require only limited development are preferred over processes requiring complex facilities and extensive development of technology."[457]

In addition to significantly increased technical complexities and potentially enormous costs, greater efforts spent on separations in order to reduce the volume of high-level waste would involve poor non-proliferation practice, would potentially involve use of old facilities that should instead be shutdown, and would produce large quantities of secondary waste streams.

DOE's preferred alternative for separations in the Tank Waste Remediation System EIS is based on *sludge washing*. Sludge washing involves three activities:

- Separate the water-soluble waste (e.g., liquids) from the water-insoluble waste (e.g., sludge)
- Pretreat the water-soluble fraction to remove radionuclides to the extent that the remaining waste will meet Nuclear Regulatory Commission Class C regulations. (This waste will be immobilized and disposed of on-site.)
- Pretreat the water-insoluble fraction by leaching of selected constituents -- for example, aluminum, chromium, phosphate - with sodium hydroxide solution, followed by simple washing with water. (This waste will be vitrified and disposed of in a geologic repository.)

DOE's plan seems mainly to be driven by a goal of reducing the wastes that will go to a geologic repository, which DOE assumes will be the Yucca Mountain site in Nevada, even if it means a large volume of "low-level" waste is disposed of on-site. Class C waste as defined by the Nuclear Regulatory Commission, is, in our view, unsuited for shallow land burial, and would be unsuited under rules prevalent in other countries. For example, in France, waste containing greater than 27 curies per cubic

[457] Slankas, 1995, p.18

meter of beta and gamma activity is to be placed in a geologic repository.[458] In Britain, waste containing greater than roughly 0.3 curies per cubic meter is classified as "intermediate-level waste" and is to be sent to a repository.[459] At Hanford, DOE proposes to dispose of waste containing much higher concentrations of radioactivity (85 curies per cubic meter) in shallow-land burial.[460] Thus, DOE is not creating a solution to the problem of long-term high-level waste management, but is really creating an enormously expensive way to dump these wastes inappropriately into shallow land burial. In addition, as discussed below in the section on closure, several hundred thousand cubic meters of cemented waste may be left behind in the tanks -- in effect, creating 177 low-level waste sites at Hanford, possibly containing millions of curies of radioactivity.

DOE's plan for high-level and "low-level" waste disposal is driven by expediency, technically poor agreements, and a reliance on the Yucca Mountain repository. If Yucca Mountain does not have enough room for all the high-level wastes that have been generated, surely the solution cannot be simply to disguise these wastes as "low-level" wastes and dump them near the Columbia River. As we point out below, Hanford tank wastes can be disposed of much more densely in a repository than DOE assumes, thus requiring less repository space. DOE should therefore evalute disposing of the entire volume of Hanford tank waste in a geologic repository as high-level waste. DOE should develop treatment technologies that would minimize the volume of solidified waste. In parallel, DOE should initiate a new approach to management of long-lived radioactive waste. DOE should also plan for the decommissioning of the tanks themselves.

We now discuss some of the technical issues associated with the sludge washing separation for the Hanford tank wastes.

a. Separation of water-soluble waste from water -insoluble waste

The first step in sludge washing is to separate the liquids and soluble portions of the waste from insoluble portions. This may involve the addition of water to dissolve some of the saltcake and sludge, which can be recycled to prevent the creation of additional waste.[461] Table 32 gives an idea of what the composition of the two wastes would be, both the water-soluble and the water-insoluble waste stream would be considered high-level waste. The next part of DOE's plan, discussed below, is to pretreat the water-soluble stream in order to remove enough radionuclides so that it would meet "low-level" waste criteria. The radionuclides that are removed would be treated along

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[458] The actual requirement is waste greater than 370 gigabecquerels per ton (10 curies per ton). Davis, 1997, page 64. Assuming a glass density of 2.7 curies per cubic centimeter: (10 curies / 1,000 kilograms) * (2.7 grams / 1 cubic centimeter) * (1 kilogram / 1,000 grams) * (1,000,000 cubic centimeters / cubic meter) = 27 curies per cubic meter.

[459] IPPNW and IEER, 1992, page 54.

[460] 17,000,000 curies / 200,000 cubic meters (the current volume of all high-level tank waste) = 85 curies per cubic meter.

[461] DOE SRS, 1994, page 2-38.

with the water-insoluble waste stream, which would remain classified as high-level waste.

Table 32: Separation of Water Soluble and Water Insoluble Wastes

Water Soluble Waste Stream	Water Insoluble Waste Stream
Contents: supernatant; liquids recovered from sludges and solids; soluble portions of sludges, saltcake, and solids	Contents: insoluble portions of sludges, saltcake, and solids
Radioactive Components: 90% of cesium 20 to 40% of strontium 50% of technetium about 5% of actinides (e.g., uranium, plutonium, americium)	Radioactive Components: 10% of cesium 60 to 80% of strontium 50% of technetium about 95% of actinides
Classification: would be considered high-level waste if no further pretreatment is done	Classification: would be considered high-level waste if no further pretreatment is done

Source: National Research Council, 1996a; Boomer, 1993.

Table 33 lists some of the radionuclides in the Hanford tanks with long half-lives. Depending on the efficiency of the planned pretreatment, significant amounts of long-lived radionuclides could end up in DOE's "low-level" waste.

Table 33: Long-lived Radionuclides in Hanford Tank Wastes

Radionuclide	Half-life (years)	Estimated Total Tank Inventory (Ci)[1]
Carbon-14	5,730	5,300
Strontium-90	29	62,000,000
Technetium-99	213,000	40,000
Cesium-137	30	47,000,000
Uranium		
U-235	704,000,000	20
U-238	4,460,000,000	460
Neptunium-237	2,140,000	141
Plutonium		
Pu-238	88	860
Pu-239	24,110	31,000
Pu-240	6,537	8,000
Pu-241	14	50,000
Americium		
Am-241	432	150,000
Am-243	7,370	19
Curium-244	18	1,600

[1] Corrected for decay to January 1996. Source: National Research Council, 1996a, except radioactivity of neptunium-237, which is from Lang, 1997.

b. Pretreatment of water-soluble waste

As mentioned above, the goal of pretreating the water-soluble waste is to generate a waste stream that meets the Nuclear Regulatory Commission's definition of Class C "low-level" waste.[462] Cesium-137, strontium-90, technetium-99, and transuranics, in particular, would need to be removed from the water-soluble waste.

The pretreatment system would deal with the water-soluble waste resulting from the water-soluble/insoluble separation step (described above) as well as liquids resulting from the pretreatment of the water-insoluble waste (see below). The pretreatment system would be designed to remove radionuclides from the liquids and dispose of them along with the high-level waste stream. The remaining liquids containing a percentage of the radioactivity would then be considered the low-level waste stream.

[462] See Table 43 for the definition of Nuclear Regulatory Commision waste limits.

The radionuclides of interest will occur as particles in the liquid wastes. Some of them can be removed by centrifuges or filters. Some of them, especially cesium and technetium, may need to be removed by ion exchange. Other radionuclides, especially strontium and transuranics are combined with organic materials, known as complexants, which can keep the otherwise insoluble radionuclides in solution. A 1993 study by DOE of relevant technologies identified several "leading candidates" as well as several "other candidates" that could destroy complexants at high temperature or pressure, which would allow these radionuclides to be separated out and sent to the high-level waste stream.[463]

DOE identified five main procedures that can be incorporated into the liquid pretreatment for sludge washing[464]:

- Centrifuge and filtration to remove entrained solids
- Cation exchange to remove cesium
- Anion exchange to remove technetium
- Destruction of complexants to precipitate strontium and transuranics
- Absorption beds (e.g., resins) to remove strontium and transuranics.

The extent to which these techniques can be successfully implemented will determine the amount of radioactivity left in the low-level waste. Some of the technologies have not been demonstrated on the Hanford tank waste, so estimates for the removal efficiency of different radionuclides are somewhat uncertain. Take, for example, the case of technetium, which is of concern because of its long half-life and mobility in the environment.[465]

Ion exchange tests done on supernate waste from tank AW-101 were not able to remove technetium that did not occur as pertechnetate (TcO_4^-).[466] This work also estimates that 15 to 22 percent of the total technetium may occur in forms other than pertechnetate, which was an unexpectedly large amount. Because of lower removal efficiencies of technetium occurring in forms other than the pertechnetate ion, the 1% value assumed by DOE in its Tank Waste Technical Options report for the amount of technetium remaining in the low-level waste may be too low.[467]

Technology development for technetium removal includes developing better estimates of the distribution of technetium between different ionic forms, examining how oxidizers could be added to the feed stream that would produce the more easily removed pertechnetate ion, developing alternative ion exchange materials, and studying how other

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[463] Boomer, 1993, page 7-8.

[464] Ibid, Section 7, especially pages 7-1, 7-25, and 7-26

[465] Technetium is a silvery-gray metal. It decays by beta emission to a stable isotope of ruthenium. Its name comes from the greek word *technêtos*, meaning artificial. It was the first synthetic element, produced in 1937. It has a half-life of 213,000 years.

[466] Tanks Focus Area, September 1996. The "-" after TcO_4 indicates that the ion has a charge of negative one.

[467] Boomer, 1993, page 7-11.

treatment steps (e.g., cesium ion exchange) might affect the form of technetium.[468] Another effort is looking at developing means to cause technetium to precipitate into a solid, although there appear to be some safety issues associated with this.[469] This is a clear demonstration of the need for technology development. Similarly, significant efforts are needed to minimize the concentrations of radionuclides in any waste that DOE does not plan to dispose of in a repository.

Thus, DOE's plan for disposal of "low-level" wastes on-site entails significant technical and environmental risk, especially since the technologies for treating high-level wastes so as to concentrate essentially all the long-lived radionuclides in the high-level waste stream are not yet adequately developed. Class C waste disposal requirements only require intruder barriers to be effective for 500 years, yet the wastes will continue to pose threats to human health long after that. For instance, technetium-99 has a half-life of 210,000 years and so will have hardly decayed at all after 500 years. DOE should focus on minimizing both the volume and radioactivity of waste deriving from the tanks that will be left on-site, and focus on concentrating essentially all the radionuclides in a waste form suitable for a high-level waste repository. It is certainly unacceptable to spend tens of billions of dollars to create a larger volume of long-lived radioactive waste that will be dumped on-site.

c. Pretreatment of water-insoluble waste

The insoluble residue remaining in the tank, mostly consisting of sludge, will become the high-level waste stream. This insoluble material that remains after separation will be dissolved and "washed" with a warm, alkaline (pH greater than 10) solution.[470] Since most of the waste is already alkaline, minimum additives should be needed to create the high pH conditions. The washing process removes liquids that are retained in solids or sludges, and dissolves soluble parts of the sludges. The solids are then allowed to settle, and the liquid is drawn off. Sludge washing is currently done in large double-shell tanks at the Savannah River Site.[471] It is possible that some of the material in the tanks may not be soluble in water or alkali. DOE does not yet have the technology to address this and is attempting to develop the technology through the Hanford Tanks Initiative and other retrieval technology programs.

One of the important objectives of pretreating the insoluble waste stream is to remove certain constituents that have limited solubility in glass or to blend wastes with high concentrations of certain constituents with wastes containing lower concentrations of those constituents. By blending waste to produce a feed that has concentrations of key constituents that are below the solubility limits, the volume of high-level vitrified waste

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[468] DOE, 1996a, page 66.
[469] Slankas, 1995, page 118.
[470] Although the entire pretreatment system is referred to as "sludge washing" it is really this step that involves "washing" of the sludges. For the remainder of this section, we will use the term "sludge washing" to refer to just this step and not the whole pretreatment system.
[471] DOE SRS, 1994, page 2-11.

can be minimized. Potentially important constituents include zirconium, chromium, and phosphate.[472] Additionally, presence of aluminum can result in larger quantities of glass because above certain concentrations, it must be balanced with additives to the glass such as silica.[473]

The example of chromium is illustrative. Chromium is soluble in glass only to a limited extent -- about 1% in borosilicate glass.[474] As a result, if too much chromium is left in the high-level waste stream after pretreatment, diluents would have to be added to the waste stream, thereby increasing the final volume of high-level vitrified waste. In order to minimize the total amount of high-level waste glass, DOE is examining how waste from the tanks can be blended to produce an average feed that is below the solubility limit for chromium. Another option, using a special melter for these wastes, may need to be considered as well.

The uncertainties associated with chromium are illustrated in Table 34, where two models used to estimate the distribution of chromium in the tank farms are compared.

Table 34: Estimates of Chromium by Tank Farm

Tank Farm	TRAC model (kg of chromium)	Tank Layer Model (kg of chromium)
241 A	50	2,090
241 AX	813	1,370
241 B	525	3,370
241 BX	142	2,080
241 BY	97	109
241 C	182	1,470
241 S	22,300	84,600
241 SX	67,500	264,000
241 T	823	3,220
241 TX	330	138,000
241 TY	165	2,610
241 U	3,080	3,400

Source: Slankas, 1995, page F-21.

All of the Tank Layer Model values are higher than the TRAC model values but the trends are otherwise inconsistent. For example, looking at the TRAC model, one might conclude that the TX tank farm had one of the lower amounts of chromium. But the Tank Layer Model indicates that it has the second highest amount of chromium. In other words, the estimates do not even allow us to conclude which tank farms have the highest chromium contents. This highlights how great the challenges are in identifying the material that will crucially affect glass-making. The failure of the vitrification

[472] Slankas, 1995, section F3.
[473] DOE, 1996a, page 49.
[474] Slankas, 1995, page F-21.

program for the Fernald silos (see the case study on Fernald vitrification efforts in Chapter Four) should be carefully evaluated in designing the research needed for the Hanford immobilization program. The work done so far is insufficient to embark on a large-scale vitrification effort. Differences are also present in estimates of amounts of other constituents with limited solubility in glass, such as zirconium and phosphate.[475]

DOE estimates that there are 25 different types of sludge in the Hanford tanks.[476] There is only a limited understanding of the makeup of these sludges and how they will react during pretreatment. Several types of sludge washing techniques may need to be developed.

Tests are being done on small samples of the sludges; 18 different samples had been tested as of August, 1996.[477] These samples are thought to represent about 23% of the Hanford sludges. Testing of these small samples -- about 5 grams -- can verify some of the key unknowns regarding the behavior of the sludge during pretreatment and vitrification.

However, the small test sample size "does not adequately address the heat and mass transfer, mixing, and settling characteristics of actual in-tank processing of several hundred thousand gallons of sludge."[478] Sludge washing would be performed "batchwise" in million gallon tanks - a scale several orders of magnitude greater than the 5 gram samples that have been worked on. Large scale sludge washing introduces complications that could prohibit processing, including excessive settling times and the possibility of gel formation.[479] Given such large differences in scale, proper emphasis needs to be given to developing a program that includes gradual scale-up of experimental results.

However, despite the importance of further laboratory and larger scale tests, DOE funding of pretreatment technologies has been cut.[480] DOE efforts have been reduced, apparently because of the privatization plan (see below), where contractors will be responsible for pretreatment of the waste. In order to implement the privatization contract, the contractors will have to start up full-scale operation without adequate groundwork laid by DOE. DOE will only be responsible for providing the contractors with soluble and insoluble waste streams.

DOE is unloading technical responsibilities to the contractors, but is jeopardizing its own ability to implement a strategy should the privatization plan fail. Further, DOE is promising contractors that it will deliver waste streams as part of the privatization program (described below). Indeed, the lack of any data beyond information gleaned

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[475] Ibid, section F3.
[476] DOE, 1996a, page 49.
[477] Ibid, page 51.
[478] DNFSB, 1995a.
[479] DOE, 1996a, page 49.
[480] DNFSB, 1996c.

from small tests on a few of the sludges is exactly the type of situation that could jeopardize the privatization program. As the Pit 9 project (described in the TRU case study) has shown, fixed-price or privatization contracts are especially inappropriate when there are significant uncertainties. Any unforeseen technical issues will be exploited by the contractor as beyond the scope of the original contract, and endless rounds of finger-pointing and legal battles will ensue, further increasing cost and delaying action to solve the problem at hand. Continued DOE development of pretreatment technologies would help to reduce the risk of privatization failure at Hanford, and would provide useful information to treatment of other radioactive waste across the DOE complex. Indeed, failure to do so seems directly contrary to the success of the privatization effort, to which we now turn.

3. Vitrification

a. Privatization contract

In February 1996, DOE issued a final Request for Proposals that announced their strategy for treating and solidifying the Hanford tank waste. The plan involves two phases, as shown in the box below.

Hanford Privatization Contract for High-Level Tank Waste

Phase 1

Part A

A 20-month period to establish the technical, operational, regulatory, business, and financial elements required by tank treatment facilities. Multiple teams could be awarded fixed-price contracts for Part A.

Part B

A commercial demonstration phase designed to treat six to thirteen percent of the tank wastes at Hanford on a fixed-unit price basis. Based on Part A performance, DOE will decide whether to authorize up to two contractors to proceed to Part B work. Part B of the contracts is expected to take 10 to 14 years.

Phase 2

Full scale efforts to complete the treatment and solidification of the tank waste by 2028.

In September 1996, DOE announced that two teams, headed by British Nuclear Fuels, Limited, and Lockheed Martin Advanced Environmental Systems, would each be awarded $27 million dollar contracts to complete Part A of Phase 1.

The remainder of the Hanford waste treatment (Part B, Phase 1 and Phase 2) will be performed through privatization.

At Hanford, the new approach is being used to "sharpen mission focus, improve performance, and save taxpayer dollars without sacrificing the standards of nuclear and industrial safety and environmental protection."[481] DOE claims "at least a 30% savings

[481] TWRS, 1996.

over the traditional way of doing business."[482] Even if these claimed economic advantages were true, the "traditional" way of doing business is almost synonymous with high overheads and cost escalation. As discussed below, however, the real economic impact seems to be higher total cost.

As described by DOE, privatization for the Hanford tanks, as well as for other DOE projects, is somewhat different from other examples of privatization:

"Classic" Definition of Privatization:
The government, which runs a major service operation that services large client populations, sells the operation to a private sector organization so they can provide this service. The government allows the market forces to define the price, nature, and quality of the service.

Privatization as applied to the Hanford tanks:
Companies, under contract to the DOE, use private funding to design, permit, construct, operate, and deactivate their own equipment and facilities to treat tank waste, and receive payments on a fixed price per unit of treated waste meeting DOE's performance specifications.[483]

Under the Hanford privatization contract, the contractors who participate in Phase 1, Part B and Phase 2 will not get paid unless they produce a satisfactory product (i.e., immobilized waste). Thus, the DOE decision to proceed with privatization appears to shift the risk of technological success to the contractor. However, the reality is more complex.

In Phase 1, DOE would be committed to actually retrieve waste from the tanks and pretreat it sufficiently to create four separate waste streams for delivery to the contractors. Some of the most difficult technological and safety issues are associated with the stages for which DOE (or presumably its site contractor) would be responsible. If DOE cannot meet its commitments, it may not only be liable for the wastes, but would also incur financial obligations to the "privatization" contractors. This arrangement also sets the stage for technical and legal disputes that would make the wrangling over Pit 9 appear to be a polite conversation.

Several concerns could jeopardize some of the claimed advantages of privatization or even prevent privatization contracts from being awarded.[484]

- DOE insisted it needed at least three contractors to bid on the Part A contracts to achieve success, and got only two.
- There is still only one client (DOE) and the companies involved are largely the same ones involved in the old system of contracting.
- Contractors will have to raise large amounts of money from financial markets in order to pay for the up-front costs. Given DOE's history of abandoned projects, the

[482] DOE Richland, 1996d.
[483] TWRS, 1996.
[484] See Weida (1997) for a discussion of other problems with DOE's privatization approach, including thwarting of citizen oversight and negative impacts to union workers.

Hanford privatization contract may be seen as too risky and therefore not attract investment.

- This is a unique problem for which technologies are not well-developed, creating a high risk of bankruptcy if the contractor fails.
- Private companies incorporated specifically for the project may walk away from problems by declaring bankruptcy, leaving the government with the liability and little recourse to recover costs.
- Privatization creates incentives for haste to minimize interest costs and increase cash flow, setting the stage for repetition and possible worsening of the type of failures that DOE is already experiencing through insufficient preparatory work, research, and pilot plant testing.
- Under the proposed plan, a contractor would assume ownership and liability of one of the double shell tanks during the project. Whether or not a contractor would be willing to accept this risk is unclear.
- Since several years will elapse before the first immobilized wastes are produced, the cost of capital (i.e., the interest on the project) will add significant costs to the project, most likely overwhelming the claimed 30% reduction in cost. Because this is a highly speculative venture, the market will demand a premium on borrowed money.

Moreover, poorly-defined projects with large uncertainties and liabilities seem to be exactly the type of projects that are most unsuited to privatization -- the Hanford tanks constitute possibly the most poorly-defined project with the greatest uncertainties and liabilities in the DOE complex. DOE cannot provide the contractors with enough information at this time for a contract to be written that will not be challenged by the contractor when an unexpected development occurs. The Pit 9 project (discussed at length in the case study on TRU waste) shows how a contractor can make this claim as soon as something goes wrong.

b. Vitrification of tank waste

With the decision to proceed with the privatization plan, the DOE has reduced funding for fallback options in case the privatization plan does not work. Yet, the Tank Waste program still claims it is pursuing a "phased decision making approach" by proceeding with the two-phase privatization plan. The National Research Council cautioned that "phased approach" not essentially be a plan for "implementing decisions made at a single point in time by scaling up a single, preselected technological approach."[485].

DOE's tank plan is what seems to be the characteristic approach to projects by DOE that we have labelled "monumentalism." Here we see DOE starting down the same path that led to a breakdown in the Pit 9 project at the Idaho Lab based on insufficient information and inadequately-developed technology. The Fernald vitrification project faced similar problems in implementation (though it wasn't a "privatization" or a "fixed-

[485] National Research Council, 1996c, page 5.

price" contract). Given the wide variety of wastes in the Hanford tanks, it is inappropriate to limit options at this early stage, as the TWRS program is doing. Moreover, the "privatization" approach to is inappropriate and should be abandoned.

B. Waste Disposal and Tank Closure

1. Nature and Quantity of the Final Waste Form

As discussed above, DOE plans for pretreatment of the tank waste to create high-level and "low-level" waste streams. Several considerations need to be addressed for both the high-level and "low-level" waste that DOE plans to treat, including:

- final volume of treated waste
- impacts from waste transport
- disposal location of waste
- integrity of treated waste over time.

As we discuss below, DOE's analysis of the tradeoffs between disposing of "low-level" waste on-site versus disposing of a greater volume of waste in a repository lacks sufficient analysis. Different cost estimates made by DOE for each option range over ten billion dollars and are based on assumptions that change dramatically from report to report. Additionally, DOE does not consider alternatives to using Yucca Mountain as a repository.

a. Final waste form assumptions in tank waste EIS

DOE's Record of Decision for the Tank Waste EIS establishes the "preferred option" for Hanford's high-level tank waste: separate the tank waste into high-level and "low-level" waste streams and vitrify all waste in a "phased" approach (described above). The amount of separation is based on sludge washing and is referred to as "Intermediate Separations." Table 35 shows some of the assumptions used for this option. DOE estimates the treatment costs for this option to be $25 to $33 billion.[486] In addition, the disposal costs for the low-level vitrified waste (on-site) and the high-level waste (in a repository) are estimated to be $5.3 billion.[487]

One of the other options considered was vitrification of wastes and disposal of all of the resultant high-level waste glass in a geologic repository. Table 35 shows some of the assumptions used by DOE for this option. DOE estimates treatment costs for this option to be $23 to $28 billion, roughly the same as for the preferred option.[488] However,

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[486] DOE Richland, 1996b, page 3-122.
[487] Ibid, page 3-118. The $5.2 billion estimated for repository disposal includes the cost of packaging and transportation (page 3-117).
[488] Ibid, page 3-122.

DOE estimates that the cost of disposal is $39 billion.[489] As discussed below, our analysis indicates that this cost estimate is excessive.

Table 35: DOE Estimates of Waste Volumes for Alternatives in Tank Waste EIS

Before treatment (current estimates)		
Tank waste		
volume, m^3	206,000	
radioactivity, curies	177,000,000	
After treatment		
	Sludge Washing Alternative[a]	No Separations Alternative[a]
Vitrified high-level waste		
volume, m^3	14,200	291,000
radioactivity, curies	160,000,000[b]	177,000,000
Vitrified low-level waste		
volume, m^3	351,000	0
radioactivity, curies	17,000,000	0

Sources: Hanlon, 7/97, page E-2; DOE Richland, 1996b, page 3-122.
[a] Radioactivity estimates do not include radioactivity in the 1% of waste assumed to remain in the tanks.
[b] Calculation based on 177,000,000 curies minus 17,000,000 curies. However, some of the 160,000,000 curies will remain in the 1 percent of waste that DOE estimates will remain in the tanks.

b. Comparison of final waste form assumptions in Tank Waste EIS to other data and estimates

DOE's analysis in the Tank Waste EIS concludes that a lower cost would result by disposing of large quantities of waste on-site. However, many of the assumptions used to calculate the cost of the two alternatives in the Tank Waste EIS are significantly different from those used in past analyses, as discussed below.

1. *Tank Waste EIS assumes higher total waste volume for No Separations Alternative*

The current volume of high-level waste in the tanks is about 206,000 cubic meters. The Tank Waste EIS assumes 291,000 cubic meters of waste would have to be disposed of in a repository under the No Separations Alternative. However, the 1993 Tank Waste Technical Options report uses a volume of 135,000.[490] A volume of 180,000 cubic meters was used in Gephart and Lundgren.[491]

[489] Ibid, page 3-118. The $39 billion estimated for repository disposal includes the cost of packaging and transportation (page 3-117).
[490] Boomer, 1993, page 7-46.
[491] Gephart and Lundgren, 1996, page 45. This figure is based on a sludge washing alternative, which results in approximately 16,000 cubic meters of high-level waste and 163,000 cubic meters of low-level waste, for a total of roughly 180,000 cubic meters of vitrified waste.

2. *Tank Waste EIS uses a smaller volume of high-level waste for Sludge Washing Alternative*

The Tank Waste EIS assumes that only 14,200 cubic meters of waste will need to be disposed of in a repository under the Sludge Washing Alternative. Gephart and Lundgren use a volume of 16,000 cubic meters, while the 1993 Tank Waste Technical Options report uses a volume of 23,400 cubic meters. Another report estimates the volume of high-level waste to range from 21,000 to 61,000 cubic meters for the sludge washing alternative, depending on the success of pretreatment and the ability to blend wastes from different tanks to produce homogeneous feed to the melters.[492]

3. *Tank Waste EIS uses a higher cost per cubic meter of waste disposed for the No Separations Alternative*

Hanford's 1993 Tank Waste Technical Options report uses $1,032,000 for disposal in a repository of an 11 cubic meter package of high-level waste ($94,000 per cubic meter).[493] The Tank Waste EIS implicitly uses $134,000 per cubic meter for containers capable of holding 10 cubic meters of radioactive glass (1995 dollars).[494] Both of these estimates imply a density of loading waste roughly one order of magnitude below that of TRU waste, and similar to Savannah River waste, though Hanford waste will have far lower heat output than Savannah River waste. DOE's assumptions about repository space requirements do not appear to take into account differences in heat generation.

All three of the assumptions used in the Tank Waste EIS increase the cost of the No Separations Alternative relative to the Sludge Washing Alternative. The cost of the No Separations Alternative seems to have been calculated using assumptions that would result in the highest cost, while the cost of the Sludge Washing Alternative seems to have been based on assumptions that would result in the lowest cost.

In fact, it is not clear that any of these numbers can be used with a large degree of confidence. The discussion earlier in this case study notes several uncertainties that could dramatically affect the final waste volumes. For example, a Los Alamos study estimates that there may be 20,000 fewer tons of sodium than previously thought; if correct, the volume of vitrified waste would be lower. Also, the presence of constituents such as iron, zirconium, chromium, and phosphorous could result in an increase the volume of high-level waste under alternatives involving separation. Finally, the development of pretreatment technologies such as calcining for portions of the waste and use of ceramic and glass waste forms more tailored to the specific wastes could considerably reduce final waste volumes.

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[492] Slankas, 1995, page F-7.
[493] Boomer, 1993, page 9-1. Likely, this figure is 1993 dollars.
[494] DOE Richland, 1996b, page B-198.

DOE's plan to dispose of wastes on site seems mainly to be driven by a goal of reducing the wastes that will go to a deep geologic repository, which DOE assumes would be at the Yucca Mountain site in Nevada. DOE has constrained options by assuming that only 1,800 "multi-purpose canisters" of high-level waste from Hanford will be allowed in the Yucca Mountain repository. This volume is lower than DOE's optimistic number of canisters under the Sludge Washing Alternative (3,000 canisters), yet DOE has not reconsidered its assumptions about its repository program.[495]

An alternative approach would be to consider that the lower heat generation of Hanford wastes would make it possible to increase the density of waste disposal in a repository to about the same level as for TRU wastes at DOE's proposed Waste Isolation Pilot Plant, 1,600 cubic meters per acre. DOE has estimated 135,000 to 291,000 cubic meters of vitrified waste if all tank contents are vitrified as high-level wastes. The heat generation in such a large volume of waste will be quite low -- only a few watts per canister, as compared to a maximum decay heat for Savannah River Site vitrified waste of 730 watts. Presuming that Hanford vitrified waste could be loaded into a repository at a density similar to TRU waste slated for the Waste Isolation Pilot Plant (about 1,600 cubic meters per acre), between 84 and 182 acres of repository space would be required.[496] We estimate that repository space would be on the order of $24 million per acre in 1996 dollars (based on $20 billion estimated for an 840 acre Yucca Mountain repository), resulting in total Hanford high-level waste disposal costs of $2 billion to $4.4 billion. The costs for packaging and transporting the vitrified waste could amount to several billion dollars, making for an overall cost on the order of five to ten billion dollars.[497]

Preferably, DOE would implement a phased program that addresses urgent safety issues without compromising high-level waste treatment options aimed at developing ways to substantially reduce high-level waste requiring long-term management. Currently, there is no geologic repository available to take any high-level waste, nor have EPA regulations for a repository been set. Given uncertainties even within the context of a Yucca Mountain repository, there is no reason for DOE to circumscribe the technologies it is willing to consider because of a presumed space constraint. The

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[495] Ibid, pages B-197 and B-198 (Table B.10.2.1).

[496] Various figures have been put forward for the area of a repository. The current assumption is that the repository area required for 70,000 metric tons of spent fuel (heavy metal content) would be about 840 acres, if a high-temperature repository is approved. A repository with relatively low heat loading would require a considerably larger area.

[497] A recent DOE estimate of total repository cost, including the cost of high-level waste disposal is 18.8 billion dollars (1994 dollars) which we have rounded to $20 billion in 1996 dollars (DOE, 1995, page 3). Area estimate based on 84,000 metric tons in the repository and 100 tons loading per acre, yielding a repository of 840 acres (DOE, 1995, pages 2 and 7). Our transportation cost estimate is based on an examination of the various scenarios that DOE has published regarding TRU waste transport. In most of the scenarios, DOE estimates the costs of secure transportation of 100,000 cubic meters of waste to be several billion dollars. If the Hanford high-level wastes were all vitrified, the external radiation levels would be somewhat higher than those for TRU waste, but far lower than those for Savannah River vitrified waste or spent fuel from commercial power plants.

problems with Yucca Mountain and the fact that its suitability as a repository may not be determined for a number of years make it even more inappropriate for DOE to rely on this location as a reference repository for its Environmental Management program, including for the Hanford tank wastes.

DOE's plan to dispose of large quantities of "low-level" waste on site is environmentally unsound and is based on dubious technical and economic analyses. Treating all tank waste as high-level waste would significantly increase the volume and the number of packages to be disposed of in a repository. At the same time, it will eliminate the need for huge, shallow disposal vaults at the Hanford Reservation. It will prevent clean land from becoming contaminated and protect the Columbia River from the threat of contamination from long-lived radionuclides planned for shallow land burial.

2. Tank Closure

The Hanford Tanks Initiative is carrying out a "closure assessment" of tank AX-104. This will be the first attempt to define what risk will remain after a tank has met the 99% criterion of the Tri Party Agreement using real data from a specific tank. "Closure" is a regulatory term referring to the final disposition of the tanks and falls under the jurisdiction of the State of Washington.[498]

Tank AX-104 was classified as a leaker in November, 1977, although no estimates of the volume of waste leaked are listed in the Waste Tank Summary Reports.[499] After being listed as a leaker, the tank was sluiced in 1977 and 1978 to remove its contents and retire it from service. It is estimated that this tank has 7,000 gallons of sludge (200 cubic meters), and spots of bare metal on the bottom are visible in photographs of the tank.[500] In addition to characterizing this "residual" waste, the closure assessment will also characterize the soil around the tank. Putting these two components together will give a more complete idea of long-term risk, addressing questions such as:

- what will be left in the tanks if the 99% retrieval criteria is achieved?
- how would the contamination around the tanks compare to the contamination left in the tanks?
- what concerns would the remaining wastes and contaminated soil present to groundwater and the Columbia River?
- how do they compare to other concerns at the Hanford site?

This Hanford Tanks Initiative effort will provide some much needed information to the overall tank management program. Characterization of the soil around tank AX-104 will be the first coordinated effort by the tank waste management and vadose zone

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[498] DOE 1996b, page 3-20. The State of Washington is responsible for "closure" of the tank farm area, which also includes contaminated soil and groundwater in addition to the tanks and associated equipment.
[499] Hanlon, 9/96, page H-2.
[500] Westinghouse Hanford Company, 1996, p.1-4

programs.[501] The Hanford Tanks Initiative could provide a starting point for discussion if it is carried out in a scientifically sound manner and with due attention to the need to eventually get all the wastes out of the tanks and decommission them.

However, the current predisposition in the DOE seems to be to pour cement into the tanks over the residual waste volume as a method of closure. This is being done on the one tank that has been emptied of sludge at the Savannah River Site, pursuant to an Environmental Assessment.[502] This closure method could leave tens of thousands to millions of curies of long-lived radionuclides in each tank at the time of closure. It would put these wastes in forms that would be very difficult to retrieve, because they would be hardened cement. This method of closure is converting one of the few programs actually reducing risks at a weapons site (i.e., vitrification of high-level waste in the Defense Waste Processing Facility) into a potential long-term liability, in a manner analogous to examples that we have discussed where short-term waste management "solutions" are converted into long-term environmental problems.

Pouring cement into the tanks should be ruled out as a method of closure, especially as there is insufficient understanding of the long-term risks to soil and groundwater from residual waste and there has been insufficient retrieval technology development. If hardened wastes cannot now be retrieved, then the focus for such waste should be on technology development, because they do not pose risks that would be mitigated by cementation in the near-term. Cementing would also make remediation of the vadose zone far more difficult than it already is. Cementing the tanks appears to be DOE's way of washing its hands of the environmental problem of tank decommissioning.

DOE's own analysis shows that the risks from the residual waste in the tanks would generally be 100 or more times greater than the risks posed by the vitrified "low-level" waste that it plans to dispose of at the Hanford site.[503] We believe that much more effort is necessary to address the issue of closure. This issue should be addressed now, so that when work begins on the tanks, appropriate consideration is given to removing as much waste as possible. However, aside from the small effort by the Hanford Tanks Initiative, DOE's TWRS Environmental Impact Statement has inappropriately separated decisions regarding retrieval of tank waste from decisions about closure of the tanks. Both of these are in turn separated from remediation of the vadose zone that has been contaminated by leaks from the tanks and is subject to the possibility of further leaks, possibly caused by sluicing or by continued deterioration of the tanks. The existing contamination of the vadose zone threatens to further contaminate the groundwater, and, eventually, the Columbia River.

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[501] Ibid; Hanford Tanks Initiative, 1997.
[502] DOE SRS, 1996a.
[503] DOE Richland, 1996b, page 5-167.

Chapter Four: Radium- and Thorium-Contaminated Waste at Fernald from Uranium Refining

Fernald: Site Overview

The Fernald site, originally called the Feed Materials Production Center, is located approximately 20 miles northwest of Cincinnati in Crosby Township. From 1952 until 1989, it processed a wide variety of uranium-containing materials, such as ore concentrates and recycle materials. Fernald converted materials into (1) finished uranium metal, for use in the fuel and target elements of plutonium production reactors and (2) depleted uranium metal, for fabrication into nuclear weapons components at the Oak Ridge Y-12 Plant and Rocky Flats Plants.[504] In all, Fernald produced about half a million metric tons of uranium metal for the nuclear weapons complex.[505]

Production at Fernald was suspended in July 1989 due to declining demand and a recognition of the need for environmental restoration. This suspension came two months after the Department of Energy (DOE) settled a class action tort lawsuit that was brought against National Lead of Ohio, its contractor for the site until 1985. In October 1990, DOE transferred responsibility of the site from its Office of Defense Programs to the Office of Environmental Restoration and Waste Management (now known as the Office of Environmental Management). In February 1991, DOE formally announced that production at Fernald had permanently ended.[506]

Fernald generated large quantities of waste, including "low-level" radioactive waste, non-radioactive toxic waste, "mixed" waste (toxic and radioactive waste), water treatment sludges, fly-ash, and general waste and refuse.[507] Waste was sent to pits, stored in drums, silos, and scrap piles, discharged to surface and groundwater, and released into the air. In November 1992, DOE entered into an initial 5-year, $1.9 billion contract with Fluor Daniel Fernald (until September 1996, the company was known as Fernald Environmental Restoration Management Company) for Environmental Management activities at the site. Cost estimates for total Environmental Management activities at the site have ranged from $3 billion to $5.4 billion, and activities could stretch to the year 2030.[508]

Several key legal milestones have established the regulatory structure for remediation at the Fernald site. In 1986, DOE and the U.S. Environmental Protection Agency (EPA) entered into a Federal Facilities Compliance Agreement which covered environmental impacts associated with site operations.[509] In 1989, the Fernald site was

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[504] Cochran, 1987, page 8.
[505] DOE, 1996c, page Ohio 16.
[506] Westinghouse, 1991, page 1.
[507] Makhijani, Hu, Yih, eds., 1995, page 212.
[508] DOE, 1996c, page Ohio-34.
[509] DOE Fernald, 1994, page 2-1.

added to EPA's National Priorities List. Sites on this list are popularly called "Superfund" sites. In 1990, DOE and EPA signed a consent agreement (amended in 1991) that grouped areas of the site into five "Operable Units" for the purposes of managing remediation. Each Operable Unit was the subject of a "Remedial Investigation" and "Feasibility Study." The final result for each Operable Unit is a legally-binding "Record of Decision." A brief description of the Operable Units is given below.[510]

Table 36: Overview of Operable Units for Fernald Site

Operable Unit	Description	Status
1: Waste Pit Area	Low-level radioactive waste in six pits, includes 340,000 m^3 of sludge, 60,000 m^3 of soil, 24,000 m^3 of rubble/debris, and 290,000 m^3 of contaminated wastewater. Soil around and underneath the pit will also need to be remediated. According to DOE, there are 35 "consitutents of concern," including radioactive, organic, and inorganic materials.	Record of Decision signed March 1995. Low-level waste will be dried and transported off-site to a commercial disposal facility.
2: Other Waste Areas	Low-level radioactive waste volumes include 13,000 m^3 of sludge, 51,000 m^3 of soil, 96,000 m^3 of rubble/debris, and 83,000 m^3 of contaminated ash. Five main areas include: Solid Waste Landfill, Lime Sludge Ponds, Inactive Flyash Pile, South Field, Active Flyash Pile. According to DOE, there are 28 "constituents of concern," most notably uranium and lead.	Record of Decision signed in 1995. Most waste will be excavated and disposed of in an on site disposal cell. Some waste above the disposal cell acceptance criteria will be disposed of off site.
3: Former Production Area	Covers 128 buildings and 72 miscellaneous facilities and almost 8,000 metric tons of uranium bearing materials. According to DOE, there are 60 "constituents of concern," most notably uranium and technetium-99.	Record of Decision signed in September 1996. Some depleted and "natural" uranium currently being sold to various manufacturers; remaining uranium materials to be sent to other DOE facilities. Most waste will be disposed of on site.

[510] This summary based on DOE, 1996c, Fernald section.

Operable Unit	Description	Status
4: Silos Area	Four large silos and the contents of Silos 1, 2, and 3 (Silo 4 is empty), an earthen berm, and associated facilities. 10,650 cubic meters of waste classified as "byproduct" waste - materials generated as a result of processing ores for uranium or thorium (defined in section 11(e)2 of the Atomic Energy Act).	Record of Decision signed in December 1994. Early actions have experienced major difficulties and the site is currently renegotiating milestones set in the ROD. The ROD may need to be re-opened as a result. This Operable Unit is the focus of this case study.
5: Other contaminated soil and groundwater throughout the site	DOE estimates 1.2 million cubic meters of contaminated soil and 237 million cubic meters of contaminated water. According to DOE, there are 26 "major constituents of concern."	Record of Decision signed in January 1996. Actions will include excavation of soil and disposal on site. A wastewater treatment plant will treat contaminated process water, stormwater runoff, and groundwater. A key concern is limiting concentration of uranium in drinking water derived from surface and groundwater.

Operable Unit 4: The Silos

This case study focuses on Operable Unit 4, which includes three silos containing uranium processing waste. There are several reasons why we chose to focus on this one part of the Fernald remediation:

- The most dangerous air emissions have historically been in the form of radon-222 emissions from Silos 1 and 2.[511] This is expected to continue until waste in the silos is treated. Thus remediation of these silos is crucial to protection of the health of the communities around Fernald and to limiting worker exposure.
- Official studies have noted that there is a threat of roof collapse, since the structural integrity of the silos is in question.
- Vitrification of the waste, the technology selected for remediation in the Record of Decision, held the promise of reduction of waste volume, toxicity, and mobility. Successful use of this technology could potentially be of benefit to some other sites.

[511] Radiological Assessments Corporation, 1996, page 82. The radiation dose is actually primarily from the decay products of radon-222, also known as radon "daughters."

- The difficulties faced by the remediation program, including huge cost increases, appear to exemplify many of the problems that DOE and its contractors face in many different projects. This case study therefore holds some important lessons for the overall Environmental Management program.

The silos contain numerous radioactive and hazardous constituents. Of greatest concern from a health perspective are high concentrations of radium-226, which, as it decays, acts as a continuous source of radon-222, a radioactive gas.[512] The high radium-content waste in Silos 1 and 2 have been known to be a significant source of radon, as recorded in site documents dating back to 1955.[513] A radiological dose reconstruction study for residents near the site concluded that "inhalation is the most important pathway of exposure and radon is the source of most of the dose."[514]

The risks posed by the waste are increased by concerns over the structural integrity of the silos in which they are stored. Cracks and seepage of waste have been noted from the 1950s.[515] Risk of roof collapse has been cited as a concern due to the fact that the silos are well beyond their design life.[516] Actions taken so far to reduce radon concentrations and/or reduce the further deterioration of the silos are listed in Table 37.

Table 37: Actions Taken to Stabilize Silos and Reduce Radon Emissions

Date	Repairs or Improvements
May 1964	Cracks in walls patched, waterproofing sealant applied, and earthen berm constructed to counterbalance material inside silos
June 1979	Openings in silo domes, including the gooseneck pipe and other penetrations were sealed, with gaskets installed, to prevent radon emissions
June 1983	The earthen berms were enlarged to correct erosion problems
Early 1986	Dome covers added to protect the center sections of the silo domes; neoprene membrane layer applied to part of Silo 2
November 1987	Radon Treatment System installed to treat displaced radon during work on silos (not continuously operated)
December 1987	Rigid, polyurethane foam layer and urethane coating applied to exterior of silo dome surfaces to weatherproof the silos
November 1991	Addition of layer of bentonite clay on top of K-65 material in silos to reduce radon emissions

Reproduced from Radiological Assessments Corporation, 1995a, page J-7.

[512] Unless otherwise stated we will use the term "radium" to mean radium-226 in this report. The Fernald site also has radium-224, but not in silos 1 and 2, the silos with the greatest radium concentrations.
[513] Strattman, W.J. K-65 dumping operation - K-65 area. Internal memorandum to C. R. Chapman, Cincinnati, Ohio: National Lead Company of Ohio; 6 April 1955, cited in Radiological Assessments Corporation, 1995a, page J-2.
[514] Radiological Assessments Corporation, 1996, pages xiv-xv.
[515] Radiological Assessments Corporation, 1995a, page J-5.
[516] DOE Fernald, 1994, page 5-3.

In 1990, even after the actions shown in Table 37 were taken, chronic radon emissions from Silos 1 and 2 were estimated to result in an incremental lifetime risk of fatal lung cancer of 9 in 1,000 to a member of the general public. In addition, a structural failure of both silos, as might occur in a tornado, was estimated to have the potential to release 66 curies of radon, resulting in an incremental lifetime risk of fatal cancer of 14 in 10,000. Finally, the potential existed for a "spontaneous" collapse of one or both silos due to deterioration. The chronic emissions were stated to be the most significant risk, and eliminating a tornado-induced dome failure was listed as a secondary objective.[517]

Several options for reducing these risks were examined in a July 1990 "Engineering Evaluation / Cost Analysis," including addition of bentonite clay to the silos to form a "seal" over waste, construction of an airtight tornado-resistant enclosure over the silos, and construction of an airtight "light" enclosure (not capable of resisting a tornado). Both of the enclosure options included a radon treatment system.[518] The criteria for evaluating the options included protection of public health for a period of five years, the amount of time until the final remedial action was expected to begin.[519] Typically, DOE did not make any provisions for possible delays in remediation, though it was implementing a pilot program.

In the Engineering Evaluation, the addition of bentonite clay was estimated to cost $2.9 million and implementation was not expected to exceed 10 months. The tornado-resistant enclosure was estimated to cost $5 million and require 10 months to implement. The light enclosure option was estimated to cost $600,000 and require 10 months.[520] All three options were judged to meet requirements for reducing risks from chronic releases as well as for a spontaneous collapse of the dome. However, only the tornado-resistant enclosure and the addition of bentonite were judged able to meet requirements to reduce releases from collapse caused by a tornado.[521] Another important difference was that the bentonite clay option involved increasing the material that would require treatment. Short-term remedial actions are required to be "consistent with the anticipated long-term remedial action and contribute to the efficient performance of the long-term remedy to the extent practicable." Interim actions are also supposed to be consistent with long-term goals such as reduction of volume.[522] Other than noting that the bentonite option would increase the volume of waste, there was no analysis of how the additional material might impact the eventual retrieval and treatment of the waste in the silos.

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[517] Bechtel, 1990, pages 10-11 and 35. We have not independently evaluated these claims regarding radon risks from the silos.
[518] Ibid, pages 46-63.
[519] Ibid, page 12.
[520] Ibid, pages 76, 83, and 89.
[521] Ibid, page 70. In the case of bentonite, it was assumed that even after falling rubble from the dome fell on the bentonite and some bentonite was dispersed by high winds, enough of the bentonite would remain intact so as to prevent significant releases of radon (page 86)..
[522] Bechtel, 1990, pages 10 and 85.

DOE announced that it would proceed with the bentonite clay option, stating that it had rejected the tornado-resistant enclosure "because of the relatively high cost, $5 million, and the time required to implement the action."[523] This is a somewhat confusing statement since both options had similar time frames. The $2.1 million difference in cost between the bentonite clay option and the tornado-resistant enclosure, then, seems to have been the major discriminating factor. However, it does not appear that the cost estimates for the bentonite considered the increased future costs due to treating a larger volume of waste. In fact, none of the cost estimates appear to have included the cost impact of the short-term action on the final action.[524] This omission means that the choice between a tornado proof roof and a bentonite clay layer was made without taking into account the full costs of the options. Biases in favor of bentonite criterion were introduced by using a criterion that the solution would have to be effective for only five years.

The addition of 670 cubic meters of bentonite clay to Silos 1 and 2 in 1991 dramatically reduced the emanation of radon from the silos. Before the bentonite clay layer was added in 1991, concentrations of radon in the headspace of Silos 1 and 2 were 25 to 30 million picocuries per liter. After addition of the bentonite layer, levels of radon in the headspace were reduced to 200,000 to 300,000 picocuries per liter.[525]

However, the addition of bentonite clay was a short-term solution. Despite the claims in the Engineering Evaluation that the bentonite clay would form an effective cap over the waste and be resistant to cracking if kept moist, radon levels have been steadily building up since the bentonite clay was added.[526] In September 1996, the radon concentrations in the headspaces of the silos were approximately 7 to 9 million picocuries per liter. According to the silos project manager, the concentrations are reaching "action levels" presumably meaning that the EPA goal for radon-222 concentration at the nearest neighbor to the plant of 0.015 picocuries per liter above background is close to being, or actually is being exceeded.[527] The headspace levels reported for September 1996 are about 25 percent of the concentrations present when chronic fatal cancer risks were estimated to be 9 in 1000.

Thus, the bentonite remediation has not been very effective as an interim measure and it has complicated considerably the problem of retrieval of the waste from Silos 1 and 2. Remediation will now not only be more expensive, it may be further delayed to address the problem of bentonite removal. These delays will cause doses to increase over those anticipated when the remediation program was put into place. Moreover, the delays due to bentonite removal will also increase the risk of roof collapse and attendant safety, health, and environmental consequences.

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[523] DOE, 1991, page 6.
[524] Bechtel, 1990, Table 6-3.
[525] Paine, 1996, pages 44-45
[526] Bechtel, 1990, page 84.
[527] Paine, 1996, pages 42-45.

A 1986 evaluation of the structural integrity of the silos indicated a significant reduction of the load-carrying capacity at the center of the domes on Silos 1 and 2. However, a 1994 study indicated that the silos are more sound than previously reported and are not in danger of immediate collapse.[528] We have not evaluated the validity of the structural integrity assessments or the estimates of health risks due to roof collapse. In view of the delays that have already occurred, the large slippage in schedule for completion of silo remediation, the major uncertainties facing the project, and the rising levels of radon, DOE should implement the tornado-resistant enclosure option. Its cost is small compared to cost escalations that have already occurred. Had it been done earlier, it would have been the one demonstrable achievement of the remediation program for the silos.

In addition to addressing one of the major health and safety concerns at the site, the treatment plan for waste in the silos aimed to demonstrate vitrification as a viable technology for treatment of radioactive and hazardous waste. Vitrification involves melting waste with a mixture of glass-forming additives at high temperatures; when cooled, the waste is incorporated into a glass matrix that can be analogous to naturally occurring materials such as obsidian, a hard volcanic glass.

A. Generation of Waste

Four reinforced concrete silos at Fernald were constructed in 1951 and 1952. Silo 1 was built specifically to store waste from uranium ore processing at other sites in the U.S. Silo 2 was built to store waste from off site as well as on site processing. Silos 3 and 4 were built to handle waste generated only at Fernald. The silos are cylindrical, above-grade, and measure 24.4 meters in diameter and 11 meters high in the center of the dome. Each silo has a volume of about 4,500 cubic meters (about 1.2 million gallons).

Different kinds of waste are stored in the Silos 1, 2, and 3, as described below. Silo 4 has always been empty and remains so.

1. "K-65" residues from Mallinckrodt Chemical Works in Silos 1 and 2

Silos 1 and 2 contain waste generated from the processing of uranium ore at the Mallinckrodt Chemical Works in downtown St. Louis, Missouri. Mallinckrodt Chemical Works processed high uranium-content pitchblende ores (the ore contained 40-50% uranium oxide, U_3O_8) from the Shinkolobwe Mine in the Belgian Congo (subsequently called Zaire and now renamed the Democratic Republic of Congo). The term "K-65" was used to refer to a particular waste stream (that contains high concentrations of radium)

[528] DOE Fernald, 1994, page 5-3.

resulting from the processing of high uranium-content ores such as those from the Shinkolobwe mine.[529]

The Shinkolobwe mine, operated by the Belgian-owned African Metals Corporation, was originally opened in 1921 for the purpose of obtaining radium, which was used at the time for applications such as making the dials of watches and instruments luminescent. When the US began to import the ore in 1943 for the purposes of extracting uranium, the African Metals Corporation retained the rights to radium in the residues, in order to extract the radium. Beginning in 1949, the residues from uranium processing were no longer shipped back to the African Metals Corporation, and they began to accumulate at Mallinckrodt.[530,531]

Due to a lack of storage facilities, the residues were shipped in drums to Lake Ontario Ordnance Works, near Niagara Falls, New York, where some were stored in the 55-gallon drums they were shipped in. Some of these drums were emptied into a concrete water tower converted for storage. After completion of Silos 1 and 2 at Fernald in 1952, about 6,000 55-gallon drums at the Lake Ontario site were shipped to Fernald. In addition, a total of approximately 25,000 55-gallon drums of residues were shipped directly from Mallinckrodt to Fernald.[532]

Silo 1 was filled from July 1952 through November 1953 with the contents of approximately 24,000 drums received from Mallinckrodt and the Lake Ontario site. The drums were temporarily stored near the silos, the contents then were slurried and pumped into Silo 1. The remaining 7,000 drums were similarly put into Silo 2 from 1953 through January 1956.[533]

2. K-65 Residues from Fernald refinery in Silo 2

Silo 2 also contains K-65 residues from the processing of uranium ore at Fernald. This waste was also referred to as "hot raffinates." The "hot" descriptor refers to the high radioactivity of the waste.

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[529] Radiological Assessments Corporation, 1995a, page J-4. The "code" for the ore was "Q-11." There seems to be some confusion on the terminology, since Fluor Daniel Fernald (1996b, page 1-8) states that the term K-65 was used to describe the processing of ores, as well as the residues, or "raffinates," remaining after extraction of uranium. In any case, the term as used today commonly refers to the waste in Silos 1 and 2.

[530] Fluor Daniel Fernald, 1996b, Volume 2, page 1-4.

[531] The radium-containing residues generated after 1949 were never sent back to the African Metals Corporation. It is unclear exactly why shipments stopped in 1949. Radium was still considered commercial in the 1950s. In time, it came to be recognized as too dangerous either for medical treatment or for making dials luminous and radium lost any potential commercial value. Ownership of and liability for these materials were transferred to DOE in 1983 in exchange for Belgium allowing U.S. Pershing 2 missiles on Belgian soil. (Makhijani, Hu, Yih, eds., 1995, page 214)

[532] Fluor Daniel Fernald, 1996b, Volume 2, page 1-4.

[533] Ibid, Volume 2, pages 1-5 and 1-7.

The processing of uranium ore at Fernald was done in Plants 2 and 3 ("the refinery") of the former Production Area. These ores came mostly from the Shinkolobwe Mine, with a smaller amount of ore from two Australian mines -- the Radium Hill Mine and the Rum Jungle Mine. The refining process for the three ores was somewhat different at Fernald than at Mallinckrodt, although the high-radium content residues from both processes were referred to as K-65.[534]

The "hot raffinate" was produced as follows.[535] Milled uranium ore from Plant 1 was sent to the refinery, where it was mixed with nitric acid and water in "digester" tanks. After about 3 hours, a slurry from the digester tanks was then sent to the uranium extraction system. The uranium extraction system produced a solution high in uranium content (uranyl nitrate) and a byproduct known as K-65 raffinates, which contained metals and other impurities from the original ore.[536] The K-65 raffinates were then filtered. The filter collected most of the gamma-emitting contents of the K-65 raffinates, including radium, and thus this portion of the waste stream was termed "hot raffinate" waste. Once a day, the materials collected in the filter were reslurried, neutralized with lime, and pumped into Silo 2. The radium was collected on filters because, as noted above, the African Metals Corporation at the time held the rights to the radium.

The last K-65 residues were sent to Silo 2 in January 1959. The last processing materials to be placed in Silo 2 were approximately 150 drums of radium-contaminated material in June 1960.

3. "Cold Metal Oxides" from Fernald refinery in Silo 3

From 1954 through 1957, "cold metal oxide" waste was put into Silo 3. The "cold" descriptor refers to the amount of radioactivity -- the waste contained lower concentrations of radioactivity (specifically, radium-226) than those sent to Silos 1 and 2; this is because of the filtering described above. The metal oxides in Silo 3 come from processing of high uranium content ores (which were not milled before these materials were processed at Fernald) as well as processing of uranium ore concentrates (which were milled before these materials were processed at Fernald).[537] The processing was different for uranium ores and uranium ore concentrate.

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[534] Ibid, Volume 2, page 1-4.

[535] This description adapted from Fluor Daniel Fernald, 1996b, Volume 2, section 1.3.

[536] Much of the thorium, including Th-230, remained soluble in a nitrate form and traveled in solution with uranyl nitrate to the extraction process area. It is therefore not in equilibrium with radium in the K-65 residues (Fluor Daniel Fernald, 1996b, p. 1-5). See Table 38 for the thorium and radium concentrations in the different silos.

[537] High uranium content ores processed at Fernald came from the three mines mentioned above. Uranium ore concentrates were received from several foreign and domestic mills.

Processing of high uranium content ore generated cold metal oxide waste as follows.[538] The liquids that passed through the filters described above (the filters that collected the "hot raffinates") contained some metal oxides in solution. These liquids were evaporated and then sent to a calciner, which produced finely-powdered, dried metal oxides. The calcined material was then sent to Silo 3.

During processing of uranium ore concentrates, there was no filtering of the waste ("raffinate") after uranium extraction; therefore, all of the raffinate was sent to the evaporator and calciner and then sent to Silo 3. It was felt there was no need for the filtration step in the processing of uranium ore concentrates because a large percentage of the impurities, such as radium and other metals, were removed at the off-site mills. However, although a large percentage of the impurities were removed in the off-site mill, significant concentrations of impurities remained in the concentrate, notably thorium-230.[539]

B. Waste Constituents

The K-65 residues in Silos 1 and 2, as well as the metal oxides in Silo 3, are classified as "by-product" materials, according to Section 11(e)2 of the Atomic Energy Act.

Silos 1 and 2 contain an estimated total of 6,130 cubic meters of K-65 residues. These materials were placed in the silos as a slurry. As a result, the residues are wet, silty solids. In addition, as noted above, 670 cubic meters of bentonite clay were added to Silos 1 and 2 to reduce the emissions of radon.

The K-65 residues are one of the greatest safety and environmental concerns at the site. "These radionuclides contribute to an elevated direct penetrating radiation field in the vicinity of the silos and to the chronic emission of significant quantities of the radioactive gas, radon, to the atmosphere."[540] The high direct penetrating radiation field is mostly due to gamma radiation produced by radium, bismuth-214 and lead-214. The estimated contact dose rate for a 55-gallon drum of Silos 1 and 2 material is 550 to 600 millirem per hour.[541]

In addition to the high radiation field, the residues in Silos 1 and 2 have a high radon emanation rate resulting from the decay of radium. The waste itself emits 50,000 picocuries of radon per square meter per second.[542]

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[538] Fluor Daniel Fernald, 1996b, Volume 2, page 1-11.
[539] Ibid, Volume 2, page 1-11.
[540] DOE Fernald, 1994, page 1-4.
[541] Fluor Daniel Fernald, 1996b, Volume 2 of 2, page 1-23.
[542] Merrill and Whittington, 1994, page 2.

Silos 1 and 2 also have high concentrations of non-radioactive hazardous materials, including barium and lead.[543] These constituents leach from the waste at high enough concentrations to fall under Resource Conservation and Recovery Act (RCRA) regulations. Additionally, Silos 1 and 2 contain elevated concentrations of polychlorinated biphenyls (PCBs).[544]

Silo 3 contains 3,890 cubic meters of metal oxides. As a result of being calcined before being placed in the silo, the waste has a dry, powdery consistency. They are therefore easily dispersible and present a potential respiratory hazard during retrieval and treatment. Silo 3 waste contains high concentrations of thorium-230, at an average concentration of 51,200 picocuries per gram. An estimated 450 curies of thorium-230 are in Silo 3. However, the waste in Silo 3 does not have the high levels of radium that the waste in Silos 1 and 2 have. As a result, the emission of radon gas from the waste is about 70 picocuries per square meter per second, which is much lower than from waste in Silos 1 and 2 but still above the EPA regulations covering mill tailings (20 picocuries per square meter per second). Silo 3 waste also has a lower gamma radiation field due to lower quantities of radium, lead-214, and bismuth-214. The estimated contact dose from Silo 3 is about 10 millirem per hour.[545]

Several non-radioactive metals also are present at elevated concentrations in Silo 3, including arsenic, cadmium, chromium, and selenium. These constituents leach from the waste and exceed regulations set in RCRA.[546]

Table 38 summarizes the main radioactive constituents in the three silos.

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[543] Paine, 1996, page 5.
[544] DOE Fernald, 1994, page 5-2.
[545] Fluor Daniel Fernald, 1996b, Volume 2 of 2, page ES-2.
[546] Ibid, Volume 2 of 2, pages ES-2 to ES-3.

Table 38: Estimated Radionuclide Content of Silos 1, 2, and 3

Radionuclide	Mean Concentration, picocuries per gram		
	Silo 1 (3,240 cubic meters)	Silo 2 (2,845 cubic meters)	Silo 3 (3,890 cubic meters)
Actinium-227	5,960	5,100	618
Protactinium-231		2,350	487
Lead-210	165,000	145,000	2,620
Polonium-210	242,000	139,000	
Radium-224			290
Radium-226	391,000	195,000	2,970
Radium-228			297
Thorium-228	422	645	590
Thorium-230	60,000	48,400	51,200
Thorium-232	424	402	656
Uranium-234	800	961	1,480
Uranium-235/236	38	73	94
Uranium 238	642	912	1,500

Source: Paine, 1996, pages 8 and 11.
Note: Volumes for Silos 1 and 2 do not include 357 and 314 cubic meters, respectively, of bentonite clay. Bentonite clay was not added to Silo 3. There appears to be a slight discrepancy in the volumes cited in Paine for Silos 1 and 2 (3,240 + 2,845 = 6,085 cubic meters) with the volume listed in the Record of Decision, 6,120 cubic meters (DOE Fernald, 1994, page 1-4).

In addition to physical and radiological differences, the silos have different chemical constituents. Characterization of the chemical makeup of the waste in the silos is important to determine which constituents in the waste are above RCRA regulatory limits and to measure the concentration of constituents that may affect the treatment of the waste.

Several constituents are of interest for the vitrification technology selected for treatment of the waste in the silos. A significant concern has been a group of materials present as sulfates.[547] Both the total amount of sulfate and the types of sulfate present affect the vitrification of waste materials. Another constituent is lead, which is present in Silos 1 and 2 waste as lead oxide in relatively high concentrations.[548] The vitrification process must be controlled so that the lead in the glass melter does not become reduced to its elemental state (that is, where it is not bound to oxygen). Elemental metals in the glass melt could produce a short circuit in the melter.[549] These issues are discussed in detail later in this chapter.

[547] The chemical formula for the sulfate anion is SO_4. However, in the glass-making industry, sulfates are measured in terms of their sulfite (SO_3) equivalents because sulfates break down into an oxide and an SO_3 component.
[548] Merrill and Whittington, 1994, page 13.
[549] Fluor Daniel Fernald, 1996c, page 2-20.

Record of Decision for the Silos Area

A. Public Process for Silos Remedial Actions

The legal process for remediation at the Fernald site began in March of 1985 when the US Environmental Protection Agency (EPA) issued a "Notice of Noncompliance" to DOE regarding concerns over environmental impacts of past and then-current activities. In 1986, DOE and EPA entered into a Federal Facilities Compliance Agreement to ensure compliance with environmental statutes and regulations.[550] As a result, a Remedial Investigation / Feasibility Study (RI/FS) was initiated at Fernald in 1986.

The RI/FS characterizes the nature and extent of contamination and examines potential remedialactions. It is part of a formal legal process. Moreover, the RI/FS serves as a basis for public comment and public participation in decision-making. Public involvement included review of draft versions of the RI/FS, public meetings, official comment periods, and other activities.[551] The result of this formal process is the issuance of a Record of Decision that legally establishes the remedial actions to be taken at the site.

Subsequent events led to changes and delays in the RI/FS process. In November 1989, Fernald was placed on the National Priorities List. This listing, in addition to early findings of the RI/FS that identified some immediate actions needed, required changes to the original Compliance Agreement.[552]

The changes to the Compliance Agreement were formalized in a Consent Agreement, signed between EPA and DOE in April 1990. In October 1990, DOE submitted the first version of the Remedial Investigation, which was judged by the EPA to be inadequate.[553] DOE was issued "Notices of Violation" for the first version of the Remedial Investigation, as well as for other ongoing work in the RI/FS. DOE was required to pay a penalty for these violations.

In September 1991, EPA and DOE signed an amended Consent Agreement that established the revised schedules for completing the RI/FS for the five operable units at Fernald.

Another important component of the legal process was the completion of an Environmental Impact Statement for remedial actions. The EIS was requested by local

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[550] DOE Fernald, 1994, page 2-1.
[551] Ibid, Chapter 3.
[552] Ibid, pages 2-1 and 2-2.
[553] Ibid, page 2-2.

stakeholders and was integrated by DOE with the RI/FS.[554] The EIS process is defined in the National Environmental Policy Act (NEPA); it requires analysis of the impacts of a proposed action as well as a consideration of alternatives. The EIS process requires that a draft EIS be circulated for public comment. The final EIS identifies a proposed plan, which must respond to public comments received.

The draft Remedial Investigation for the silos was issued in April 1993. The draft Feasibility Study (which also served as the draft EIS under DOE's integrated approach) was issued in September 1993. After a public process, which included hearings and public comment, a Record of Decision for Operable Unit 4 was issued in December 1994. This included public comments from Nevada, the proposed destination for the final waste.

B. Evaluation of Alternatives

In considering alternatives for Operable Unit 4, the silos area was broken down into three "subunits"

- waste in silos 1 and 2 and the contents of a decant sump
- waste in silo 3
- remaining parts of the silos area such as the berms, soil under the silos, etc.

Alternatives for each of the subunits were evaluated independently of each other. The selected alternative for the silos area involves vitrification of the contents of silos 1, 2, and 3 and disposal at the Nevada Test Site. Although vitrification was selected as the preferred alternative for waste in all three silos, the Record of Decision did not prescribe whether or not the materials would be mixed and treated together or treated separately. Investigations as to whether or not they should be mixed were not conclusive on this issue at the time the Record of Decision was signed (see later in this case study for the development of vitrification techniques).

Other materials, such as the berm soil, contaminated soil and groundwater underneath and around the silos, and the silos themselves, are to be disposed of in an on-site disposal cell (along with low-level waste from other parts of the site) provided they meet the waste acceptance criteria for such disposal.[555]

The cost and schedule estimates for the selected alternative, as initially estimated in the 1994 Record of Decision for Operable Unit 4, are shown in Table 39. The total cost was estimated to be $91.7 million, and vitrification was estimated to be completed within 6 years - in December 2000.

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[554] Ibid, page D-i.

[555] As of July 1997, waste acceptance criteria had not been published by the site.

Table 39: Original Estimated Treatment Option, Cost, and Time for Silos Project

Subunit	Selected Alternative	Cost[a]	Time to Implement[b]
Waste in Silos 1 and 2 and decant sump	vitrification, disposal at Nevada Test Site	$43.7 million	6 years
Waste in silo 3	vitrification, disposal at Nevada Test Site	$28 million	4 years
Remaining waste and contamination in silos area (silos themselves, soil, etc.)	disposal on site	$34.3 million	2 years

[a] The total cost of the activities described in the table is estimated to be $91.7 million, which is less than what the individual projects add up to ($106 million). This is because activities for Silos 1 and 2 and activities for Silo 3 share common costs for site preparation, construction of removal and processing facilities, and packaging and transportation (DOE Fernald, 1994, page 9-7). Cost figures listed are present worth, in 1994 dollars. Undiscounted cost figures presented in the Record of Decision are 12 to 14 percent higher.
[b] Activities for the first two "subunits" would occur simultaneously. The remaining activities would begin after treatment was completed.
Source: DOE Fernald, 1994, section 7.

Alternatives under Superfund are evaluated based on nine formal criteria defined by the Environmental Protection Agency.[556]

There are two criteria that, at a minimum, must be met in order for an alternative to be considered (referred to as "threshold criteria"):

- overall protection of human health and the environment
- compliance with all reasonable and appropriate regulations

There are five criteria that, taken together, establish the tradeoffs between alternatives (referred to as "primary balancing criteria"):

- long-term effectiveness and permanence
- reduction of toxicity, mobility, or volume through treatment
- short-term effectiveness
- implementability
- cost

[556] DOE Fernald, 1994, pages 8-1 and 8-2.

The last two criteria are used in the final analysis of alternatives (referred to as "modifying criteria"):

- state acceptance
- community acceptance

Two of the most important issues in deciding between alternatives were the type of treatment and the location of the disposal site.

1. Treatment Alternatives

Waste in the silos can be treated in several ways. Stabilization of the waste can be accomplished by mixing with asphalt, cement, polymers, or a mixture of lime and flyash. All of these methods would accomplish the solidification of the waste, eliminating concerns arising from their current form, such as emission of radon from Silos 1 and 2, fine particles in Silo 3 (which pose inhalation hazards), and mobility of contaminants in groundwater. Waste can also be stabilized by vitrification, which involves mixing the residues with glass forming agents and processing the mixture in a high temperature furnace. As it is cooled, the mixture is converted into a stable glass matrix.

Another option is to chemically treat the waste, which would involve extraction of the radium and thorium -- the radiological constituents of greatest concern. The waste could be processed for storage as high-level waste in a repository. Extraction of the radium and thorium may result in much lower volumes of waste needing off-site disposal than the current plan of waste shipments to Nevada Test Site (see next section). The remaining waste could be further processed for storage in the on site disposal cell. This option was not evaluated in the Record of Decision because it was considered too expensive. This alternative does not seem to have been reviewed in light of the new, much higher cost estimates for the project (see below).

Cementation and vitrification were the treatment alternatives that were evaluated in the public process. Each "subunit" was evaluated separately: that is, the evaluation process identified the best option for waste in Silos 1 and 2 and separately identified the best option for waste in Silo 3. For both of these "subunits," vitrification was found to be preferable to cementation. Important differences between the two treatment options were volume of treated waste, ability to contain radon, maturity of technology, and cost.

a. Silos 1 and 2

For the waste in Silos 1 and 2, vitrification was judged to result in a significantly better final waste form than cementation. Laboratory tests indicated that cement stabilization of the K-65 residues "does not effectively reduce the radon emission rate from the waste and the tendency of the waste to leach contaminants into the groundwater."[557]

In addition, cementation would result in a larger volume of waste. Transporting larger volumes of waste would increase costs of shipment to the off-site disposal facility as well as increase the risks of traffic accidents. Mostly because of the additional costs due to greater volumes, cementation was estimated to be 67% more costly than vitrification (a total cost of $73 million vs. $43.7 million).[558]

Both treatment alternatives were judged to be technologically difficult to implement.[559] Cement was stated to be a more reliable technology, while vitrification was identified as a less mature technology.

b. Silo 3

The analysis of vitrification versus cementation for the waste in Silo 3 also resulted in the selection of vitrification as the preferred option. The overall advantages and disadvantages of vitrification versus cementation of Silo 3 waste are similar to those of Silos 1 and 2. One difference was that the Silo 3 materials do not have as significant a problem with radon emission, which was an important factor in choosing vitrification for the waste in Silos 1 and 2. Overall, however, vitrification was judged to result in a much smaller final waste volume, and be less expensive -- a total cost of $28 million for vitrification versus $36 million for cementation.

Cementation was judged to be a reliable technology. Vitrification was described as an "innovative technology." Both alternatives were judged to be difficult to implement.[560]

Table 40 shows a summary of the cementation versus vitrification results that were presented in the Record of Decision.

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[557] Ibid, page 8-8.
[558] Ibid, page 8-3.
[559] Ibid, page 8-3
[560] Ibid, page 8-4.

Table 40: Summary of Cementation vs. Vitrification Treatment Alternatives for Silos 1, 2, and 3

	Waste Volume (cubic meters)			Waste Toxicity	
	Before Treatment	After Cementation	After Vitrification	After Cementation	After Vitrification
Silos 1 and 2	6,800	18,000	2,800	unchanged	reduced because organics destroyed by high temperature
Silo 3	3,900	6,000	1,500	unchanged	unchanged

Source: DOE Fernald, 1994, Section 7.

2. Disposal Alternatives

The disposal location of the silo waste was also a major issue during the public process. A large amount of waste is to be disposed of at the Fernald site under the current Records of Decision for the other operable units (see the site overview in the beginning of this chapter).

The waste in Silos 1 and 2 is not allowed to be disposed of on site according to guidelines set by the Environmental Protection Agency.[561] This waste, if buried on-site, would pose unacceptable risks.

However, in the Record of Decision, DOE concluded that disposal of treated Silo 3 residues on-site in an engineered, above-grade disposal vault could be protective of human health and the environment.[562] This would require a leachate collection system, a clay layer to reduce radon emissions, a barrier to prevent intrusion by burrowing animals, security fencing, permanent markers, and a review every five years after closure to ensure continued protection of human health and the environment.[563] This appears to be an unrealistic system for long-term management (thorium-230 has a half-life of 75,400 years) and carries the potential for having to once-again remediate Silo 3 materials. As such, the suitability of on-site disposal created strong local controversy. The final decision was to send treated waste from all three silos to the Nevada Test Site for disposal.

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[561] Ibid, section 11.
[562] Ibid, pages 7-10 to 7-11.
[563] Ibid, pages 7-10 to 7-11.

DOE argues in the Record of Decision that the Nevada Test Site is considered a superior site for the disposal of the silo waste because of demographics (sparsely populated area), climate (arid, desert region), and hydrogeology (235 meter minimum depth to groundwater).[564] Disposal of the waste in Nevada would obviously greatly reduce future radiation doses at Fernald. However, many groups in Nevada expressed opposition to the Nevada Test Site as a disposal site for the waste. The Western Shoshone also object to the use of the Nevada Test Site for further disposal of waste, as it is located on their historic lands.

Remedial Action - Vitrification Pilot Plant

The plan for the Operable Unit 4 remediation was developed after the extensive public process centering on the Remedial Investigation / Feasibility Study and Environmental Impact Statement. This formal process (which led to the 1994 Record of Decision) establishes central environmental and waste management goals that cannot be legally abandoned without revisiting the process.

The original plan is now in shambles. Engineering design flaws, unanticipated technical difficulties, and problems with project management during the first two years of the project led to the accidental destruction of the melter and a halt to remediation of the waste in the silos.

The plan involved construction of a vitrification pilot plant during which a two-phase "treatability" study would be completed.[565] This two-phase study would build on the results of the Remedial Investigation / Feasibility Study. The pilot plant study was critically important to resolving key questions and demonstrating new technologies. Phase I of the pilot plant study would allow the plant to be run as an integrated system in a non-radioactive environment, allowing operators to gain experience as well as identify the safe limits of operating the plant. Additionally, testing of the new melter design was needed - the one metric ton per day, three-chamber, high-temperature melter was a first-of-a-kind design (see description below, as well as Figure 13). Also, verification of earlier laboratory results with small quantities of actual waste and surrogates needed to be scaled up to much larger throughputs. Phase II would demonstrate operation with radioactive materials from the silos, as well as technologies for retrieving waste from the silos. Information generated during the pilot plant studies was also to be used in the design of a production-scale vitrification plant, planned to be a 25 metric ton-per-day facility.

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[564] Ibid, page 8-6

[565] Fluor Daniel Fernald, 1996a, sections 1.3 and 1.4.

The purpose of Phase I of the pilot plant study was to demonstrate:

- Feed preparation (mixture of surrogates and glass-forming materials)
- Vitrification of surrogate Silos 1, 2, and 3 material
- Off-gas control and treatment

Phase I technologies carried over to Phase II of the pilot plant study, which would demonstrate:

- Hydraulic[566] removal of the material from Silo 2
- Pneumatic removal of the material from Silo 3
- Vitrification of actual radioactive waste from Silos 2 and 3
- Off-gas control and treatment.

Despite the fact that vitrification was judged to be the less mature technology, neither DOE nor the contractor made any contingency plans in case part or all of the vitrification technology was found to be unworkable. However, as mentioned, laboratory work was carried out at Pacific Northwest Laboratory (now known as Pacific Northwest National Laboratory), using small samples of simulated and actual waste, prior to the selection of vitrification in the Record of Decision. In addition, prior to start-up of the pilot plant, vitrification studies were carried out at the Vitreous State Laboratory, part of the Catholic University of America.

A, Design and Construction of Pilot Plant

There was lack of sound judgment from the beginning of the project. An investigation of the vitrification pilot plant by the General Accounting Office noted several weaknesses on the part of DOE and its contractor, Fluor Daniel Fernald. The GAO concluded that DOE "could have avoided major problems if it had exercised more oversight of the contractor's early decisions."[567] Further, the General Accounting Office noted that DOE and the contractor decided early on to accelerate the project, "without having fully tested the feasibility of the technology." This pattern is evident in many of the DOE projects that we have examined in this and other research.

A major problem resulted because Fluor Daniel Fernald proceeded with design and construction of plant systems to interface with the melter (the key piece of equipment for vitrification) according to preliminary information provided by the subcontractor that was designing and constructing the melter. This manner of proceeding is against elementary engineering principles especially since there were many new aspects to the specific project at hand. The subcontractor delivered components substantially different

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[566] Silos 1 and 2 wastes are wet and a hydraulic slurry system is to be designed for their retrieval. Silo 3 wastes are a dry, fine material (since they were calcined before sent to the silo) and will be removed "pneumatically," using air pumps.

[567] GAO, 1997a, page 5.

from the preliminary design, resulting in Fluor Daniel Fernald having to issue 225 design change notices between May 1995 and May 1996.[568] These design changes caused Fluor Daniel Fernald to miss the milestone for completion of construction on the plant. Moreover, in November 1995 -- less than a year after the Record of Decision was signed -- the contractor announced a seventeen month delay in completion of the pilot plant studies.

In a document prepared for the General Accounting Office investigation, DOE stated its initial cost estimate of $15.8 million for the vitrification pilot plant estimate "did not include operational costs, maintenance costs, escalation costs, or construction and project management costs." It is astounding that a professional cost estimate could exclude all these items. When these were added, the cost estimate increased to $20.6 million. In the next year-and-a-half (by the time the pilot plant was ready to begin testing), the revised cost estimate for the project had more than tripled to $66 million due to problems in melter and other procurements, the engineering plan's failure to allow for adequate testing time, declines in anticipated efficiency and consequent increases in operating and maintenance costs, and schedule extensions.[569]

The increases in costs are somewhat mysterious, given the initial capital cost estimate of $15.8 million and the operating and maintenance cost of about $5 million that can be inferred from the first two estimates. Neither the DOE nor Fluor Daniel Fernald has given a public explanation of how $5 million in operating and maintenance costs could come to be a major component of a more than $45 million cost increase, even given a three-fold decline in operating efficiency used in different estimates.

These failures show an appalling lack of engineering judgment and a lack of elementary procedures to ensure that the basic parts to make the system work would match. DOE has yet to explain how a contractor that failed to exercise elementary judgment was awarded a contract or why that contractor has been allowed to continue despite further repeated poor judgment, huge cost escalations, and project failures. DOE appears not to have done a thorough investigation before allowing such enormous cost escalations in short periods of time. We have also noted this pattern in the Pit 9 project in the chapter on TRU waste.

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[568] Ibid, page 31.
[569] DOE Fernald, 1997.

B. Getting the Pilot Plant to Run

Amidst these distractions, the construction of the pilot plant was completed and start-up of the pilot plant began in June 1996.

The vitrification pilot plant was envisioned to consist of several subsystems. The waste retrieval system was to mobilize the waste from the silos and transfer the waste to staging tanks. The slurry feed system would transfer the waste from the staging tanks, mix it with glass-forming agents, and deliver the mixture to the melter. The waste and glass forming materials would be heated into a vitreous state in the melter. The off-gas system would collect and treat the gases that were generated in the melter. The gem making system would cut the continuous stream of molten glass that was discharged from the melter into discrete "gobs," which would then cool into the final vitrified waste form (called "gems" or "marbles" because of their size and shape). The waste retrieval system was not part of Phase I of the testing.

During startup of the pilot plant, significant problems were found with many of the systems. The resulting amount of "uptime" experienced (the percentage of time that materials were actually being fed to the melter) during the first "campaign"[570] was only 19%. "Uptime" increased to 27% in the second campaign.[571] These values are not necessarily that low when one considers that a significant number of problems should be expected with the startup of an experimental facility.

However, cost estimates in December 1994, based on the detailed design of the pilot plant, assumed an illogical 100% efficiency for the melter during operations at the pilot plant.[572] Such estimates are indicative of poor engineering judgment and they not only call into serious question the judgment of the contractor bidding for the job, but also of DOE, who approved such an unrealistic operating efficiency. A 100% efficiency, which means that the melter will run at rated capacity for the entire scheduled time of operation, is sometimes achieved in well-established technologies with long operating experience. It is entirely unrealistic to expect it in pilot plants for new technologies, especially ones involving hazardous and radioactive materials such as those present in the silos.

The primary causes of the low "uptime" of the pilot plant were problems with the slurry feed and off-gas systems.[573] The problems with the slurry feed were caused by

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[570] Four campaigns were initially planned as part of Phase I of the pilot plant treatability study. Campaign 3 (vitrification of silo 3 surrogates) was canceled by DOE, and Campaign 4 ended prematurely due to failure of the melter (9 of the 18 planned runs for Campaign 4 were completed). Campaign 1: June 24-July 31, 1996. Campaign 2: August 26-September 24, 1996. Campaign 4: November 30-December 26. (Fluor Daniel Fernald, 1996c and Independent Review Team, 1997a).

[571] Fluor Daniel Fernald, 1996c, page 1-13

[572] DOE Fernald, 1997 and GAO, 1997a, page 5.

[573] Fluor Daniel Fernald, 1996c, page 1-12

- sharp bends in the piping that restricted flow and allowed solids to collect
- small diameter piping in long sections that restricted flow
- slurry pumps, seals, and construction materials that were inconsistent with abrasive constituents in the waste slurry
- insufficient agitation and/or clay-like cohesive material that resulted in settling of solids in the bottom and sides of the slurry tanks.[574]

As a result, a significant amount of time was spent on removing blockages from piping and repairing and replacing pumps. In a system handling radioactive waste, such repair and maintenance activities would result in high worker exposure.

Problems in the feed system made their impact on other systems. For example, because the feed system could only handle a low weight percent of solids, the feed had to be made more dilute than anticipated. This in turn meant larger volumes of water in the melter feed. As a result, more power was consumed in boiling off the water. This resulted in a lower glass production rate and higher volumes of water to the off-gas system (see below for the problems with the off-gas system). Additionally, the increased power needed for the melter, in part caused by the need to boil off extra amounts of water, is thought to have contributed to the increase in the corrosion rate of the melter observed during Campaign 2.[575]

The off-gas system also presented problems. The system was overwhelmed by the amount of moisture in the off-gas. In order to prevent activation of the emergency off-gas system, glass production rates were kept low.[576] Additionally, a tower that contained moisture-absorbing materials (desiccants) had "serious" problems that resulted in cumbersome and time-consuming refilling, low glass production rates, and would have resulted in worker exposures during radioactive processing.[577] The problems attendant upon the lengthy and indirect routing of piping in the off-gas system reduced the flow of off-gases. This, in turn, reduced the capacity of the exhaust system and hence the production rate.

Because of the high levels of maintenance stemming from such design flaws, operation of the pilot plant with radioactive materials would have resulted in a high level of worker exposure. This concern was voiced in a letter by a member of an Independent Review Team convened in November 1996 by Fluor Daniel Fernald:

> Overall - The pilot plant does not appear to have had much thought to personnel radiation exposure in the design. Change out of pumps, valves, and the melter look, to me, to ensure very high personnel exposures. For that reason, any thought to process actual material from Silos 1 & 2 needs to be evaluated very carefully.[578]

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[574] Ibid, page 1-12
[575] Ibid, page 1-8
[576] Ibid, page 1-6
[577] Ibid, page 3-48
[578] Roal, 1996.

These concerns were generally acknowledged. Fluor Daniel Fernald and DOE undertook several efforts in 1996 to evaluate the best use of the pilot plant.[579] The options discussed included 1) pilot plant, non-radioactive testing only, 2) pilot plant, upgrade for radioactive testing, 3) increase capacity, upgrade to allow processing of radioactive materials, but remain a pilot plant, and 4) increase capacity, upgrade to allow processing of radioactive materials, operate as a production plant.

The fact that the design did not incorporate the processing of radioactive materials that would take place during Phase II testing is another indication of poor judgement and planning from the very beginning of the project. Moreover, insufficient attention was given to allowing for the option of expanding the capacity of the pilot plant. In short, DOE and Fluor Daniel Fernald's management of the pilot plant project resulted in designing and building a plant that was not capable of fulfilling its own mission, never mind having the capability to possibly perform an expanded mission. At the same time, the costs escalated from $15.8 million dollars to $66 million dollars. Ultimately, the pilot plant did not even complete Phase I non-radioactive testing, because the melter failed partway through (see below).

The initial plan for Phase I testing included 4 Campaigns, with the following goals:

- Campaign 1 was to start the plant and operate with "benign" glass (no addition of simulated[580] or actual waste)
- Campaign 2 was to test glasses made from a blend of Silo 1, 2, and 3 simulants
- Campaign 3 was to test glasses made from Silo 3 simulants
- Campaign 4 was to test glasses made from a blend of Silos 1 and 2 simulants.

C. Technical Issues in Vitrification Design

Initial vitrification testing of the waste in the silos was conducted as part of the Remedial Investigation / Feasibility Study. Pacific Northwest Laboratory issued a final report on vitrification development in April 1994 that addressed some unresolved issues from earlier tests in the RI/FS. Specifically, Pacific Northwest Laboratory considered:

- separation of molten sulfate and reduced metal
- crystallinity in the silo 3 melts, which leads to "devitrification" of the glass
- increased viscosity resulting from blending K-65 material with the bentonite clay that was added in an attempt to reduce emanation of radon

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[579] For example, see Fluor Daniel Fernald, 1996d, and Numatec, 1996.

[580] Using simulants that represent the actual behavior of the waste is of crucial importance. This requires adequate knowledge of key constituents in the waste. See below for a discussion of how uncertainties about the types of sulfates led to tests that used simulants that were not necessarily representative of the waste.

- durability of the glass.[581]

The first issue, preventing sulfates and reduced metals (such as lead) from forming separate phases, or layers, in the melter, turned out to be the most difficult. On December 26, 1996, halfway through Campaign 4, the melter was destroyed as lead eroded one of the bubbler tubes on the bottom of the melter and allowed glass to eat away at the underside of the melter. Below we describe some of the efforts taken to deal with these problems and examine the technical issues surrounding the destruction of the melter.

1. Vitrification of Waste High in Sulfates

Glass making is not just a melting process but also a complex dissolution and chemical process.[582] In fact, most constituents in glass have a higher melting point than the glass itself. For example, quartz (SiO_2), the main constituent in glass, has a melting point of over 1700 degrees Celsius. This is much higher than commercial glass-melters (which operate around 1500 degrees Celsius) and radioactive waste melters (which operate at even lower temperatures). Introduction of certain substances to the melter can break down bonds in constituents with high melting points, thereby allowing them to dissolve into the glass.

Some substances are only moderately soluble in glass such as the sulfates in the Fernald silos. This makes vitrification of waste containing many different kinds of chemicals different from ordinary glass-making. Sampling done by Pacific Northwest Laboratory indicated that there was 2.7 percent sulfate by weight (measured as SO_3) for Silos 1 and 2, and 15 percent sulfate by weight (measured as SO_3) for Silo 3.[583] The solubility of sulfate (the amount of sulfate that can dissolve in the glass melt) in silicate-based glass is typically less than one percent.[584] Concentrations of sulfate above its solubility in glass could lead to an accumulation of electrically-conductive sulfate on the surface of the melt, known as a "sulfate layer," causing the heat generated by the melter electrodes to flow through the sulfate layer rather than distribute throughout the melter.[585] The dissolution of sulfate, then, was identified as early as 1994 to be potentially disruptive to the operation of the melter.

Experiments by Pacific Northwest Laboratory as part of the Remedial Investigation / Feasibility Study examined potential techniques for increasing the rate of dissolution of sulfate. Simple tests conducted by Pacific Northwest Laboratory early in the Feasibility Study concluded that the sulfate layer could be avoided by increasing the temperature of the melt and by adding carbon to help decompose and volatilize the

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581 Merrill and Whittington, 1994.
582 Fluor Daniel Fernald, 1996c, page A-4.
583 Merrill and Whittington, 1994, page 7
584 Ibid, page 9.
585 Fluor Daniel Fernald, 1996c, page 1-10.

sulfate.[586] Pacific Northwest Laboratory then tested other techniques including changing the formula for "glass-additives," which are the materials combined with the waste.[587]

Not all of these techniques were practical or effective. Operation at higher temperature (1250 degrees Celsius to 1350 degrees Celsius) results in more stress to melter components and a shorter melter life. Addition of the reductant carbon was found to cause precipitation of lead (see next section).[588] Changing the glass-additive formula sometimes created problems with other consituents.[589] However, the Pacific Northwest Laboratory tests did result in identification of several promising techniques warranting further development.

Another issue raised by Pacific Northwest Laboratory was that a sulfate layer was present during vitrification of waste from Silos 1 and 2 and not during vitrification of waste from Silo 3, even though the concentration of sulfates was much higher in Silo 3.[590] This seemingly contradictory result should have stimulated careful inquiry on the part of Fluor Daniel Fernald, given the potential problems arising from limited solubility of sulfates in glass. Yet, this crucial issue was not given sufficient attention during further laboratory testing and the initial work on the pilot plant. In fact, it was only at the end of Campaign 2 that Fluor Daniel Fernald offered a plausible explanation for the seemingly contradictory result noted by Pacific Northwest Laboratory - that different kinds of sulfate created different chemical results during the vitrification process.

Whether or not a sulfate layer forms is now believed to be attributable to the presence of different sulfate compounds in Silos 1 and 2 versus Silo 3.[591] The exact composition of the sulfate compounds present in the waste was not initially considered important; it was assumed that "a sulfate is a sulfate since most chemical compounds break down thermally in the molten glass."[592] As a result, studies by Pacific Northwest Laboratory, and later by Vitreous State Laboratory, used the proper sulfate percentages in the simulated waste, but did not necessarily use the same sulfate compounds as are in the waste itself. Fluor Daniel noted that "most (if not all) of the sulfate surrogates used by PNL and VSL were calcium sulfate ($CaSO_4$)."[593] However, sulfate compounds in the silos may include barium sulfate, magnesium sulfate, and sodium sulfate, as well as calcium sulfate. Each of these sulfates behaves differently during vitrification.[594]

The issues surrounding sulfate, initially raised during the Pacific Northwest Laboratory studies before the signing of the Record of Decision, remained unresolved

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[586] Merrill and Whittington, 1994, page 10.
[587] Ibid, pages 10 and 11.
[588] Ibid, page 10.
[589] Ibid, page 11.
[590] Ibid, page 10.
[591] Fluor Daniel Fernald, 1996b, Volume 2, page 1-21.
[592] Ibid, Volume 2 of 2, page 1-21.
[593] Ibid, Volume 2 of 2, page 1-21.
[594] Ibid, Volume 2 of 2, pages 1-21 to 1-22.

through the testing at the pilot plant. In fact, even basic information seems to be lacking. During the meetings of the Independent Review Team, one of the members commented on deficiencies in sampling methodology and the lack of data, particularly with respect to sulfate:

> ...the Silo 3 analyses will indicate horizontal but not depth variations, and the Silo 1 and 2 analyses may indicate some depth variations but no horizontal [variations].
>
> For several reasons discussed at the IRT meetings, more samples need to be taken from the silos....
>
> Knowledge of waste composition is ... of paramount importance if vitrification is to be pursued. The first rule of successful glass making is to control the [composition of the] batch. To do so requires up-front knowledge of any raw material variation so that suitable adjustments are made prior to furnace charging--afterwards is too late to prevent disaster...
>
> Another concern is that though the presence of anions [e.g., sulfates] was recognized, no attempt was made to assign what anion to what cation [i.e., what positive part attaches to the sulfate compound - barium, magnesium, etc.]. Knowing this is highly desirable when trying to plan treatability strategy. The importance of this for sulfates has been stated to the FDF glass melt personnel.[595]

In sum, adequate laboratory work was not completed prior to the pilot plant design. We have documented other instances of this in this report.

2. Vitrification of Waste High in Lead

Lead in Silos 1 and 2, present as lead oxide, was reported by Pacific Northwest Laboratory as 9.8 percent by weight.[596] The concentration of lead in Silo 3, estimated to be 0.2 percent by weight, is not present in high enough concentrations to be of concern for vitrification. Lead oxide is soluble in glass (and is, in fact, used to make crystal glass). Lead oxide can be *reduced* to an elemental state or to lead sulfide - which are both insoluble in glass - if the melter does not operate under oxidizing conditions. Elemental lead can precipitate and produce an electrical short circuit across the electrodes.[597] Also, formation of a separate phase at the bottom of the melter can damage and erode the melter due to the increased amount of power conducted through the lead. Finally, lead can react with materials used in construction of the melter, such as electrodes made of molybdenum. It was the presence of molybdenum in the melter "bubbler tubes" that, in fact, resulted in the destruction of the melter, as we will discuss.

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[595] Independent Review Team, 1997d.
[596] Merrill and Whittington, 1994, page 7.
[597] Fluor Daniel Fernald, 1996c, page 2-20.

3. Vitrification of High Sulfate, High Lead Waste: Mixture of Silos 1, 2, and 3 Waste

The Remedial Investigation / Feasibility Study tests done by Pacific Northwest Laboratory examined several options for vitrification of the waste in the silos, including vitrification waste from Silos 1 and 2 (separately waste from Silo 3), vitrification of a mixture of waste from all three silos, and vitrification with and without bentonite clay.

Efforts subsequent to the Pacific Northwest Laboratory testing, performed by the Vitreous State Laboratory, concentrated on identifying suitable techniques and melter designs that would allow vitrification of a combination of waste from all three silos. Although the other options were also developed and their testing was planned for the pilot plant, the emphasis was on vitrification of waste for all three silos together. The melter design was chosen on this basis (see below).

The decision to vitrify a mixture of waste with different characteristics presented a very difficult challenge:

> The dilemma here is that the highly oxidizing conditions required for lead glass induces SO_3 [sulfate] to enter the structure to the extent that the glass becomes "super-saturated" and various conditions will cause sudden release of SO_2 gas. This sometimes causes violent and catastrophic foaming. Thus it has been known by all lead glass makers that sulfates should be avoided, and most who have been around for awhile have stories to tell about how dangerous it is.[598]

To address this problem, a novel approach was tested at Vitreous State Laboratory, involving a design consisting of a high-temperature, three-chamber melter (described below). This design showed promise and was chosen for the pilot plant. The pilot plant, then, would be involved in testing an entirely new melter design. Yet, as mentioned above, DOE and Fluor Daniel Fernald proceeded on a fast-track basis for the project without back-up plans.

4. Vitrification Pilot Plant Melter Design

Fluor Daniel Fernald contracted with GTS Duratek to design and manufacture the melter for the Pilot Plant.[599] The concept consisted of a joule-heated melter. "Joule-heated" is the term used to describe a melter heated by electricity passing through the material to be vitrified.[600] An electrical current is created between electrodes which are immersed in the glass melt. The melter would operate at high temperature in order to handle sulfates, and would consist of three chambers to isolate the electrodes from the waste (described below). This design was experimental and had not previously been

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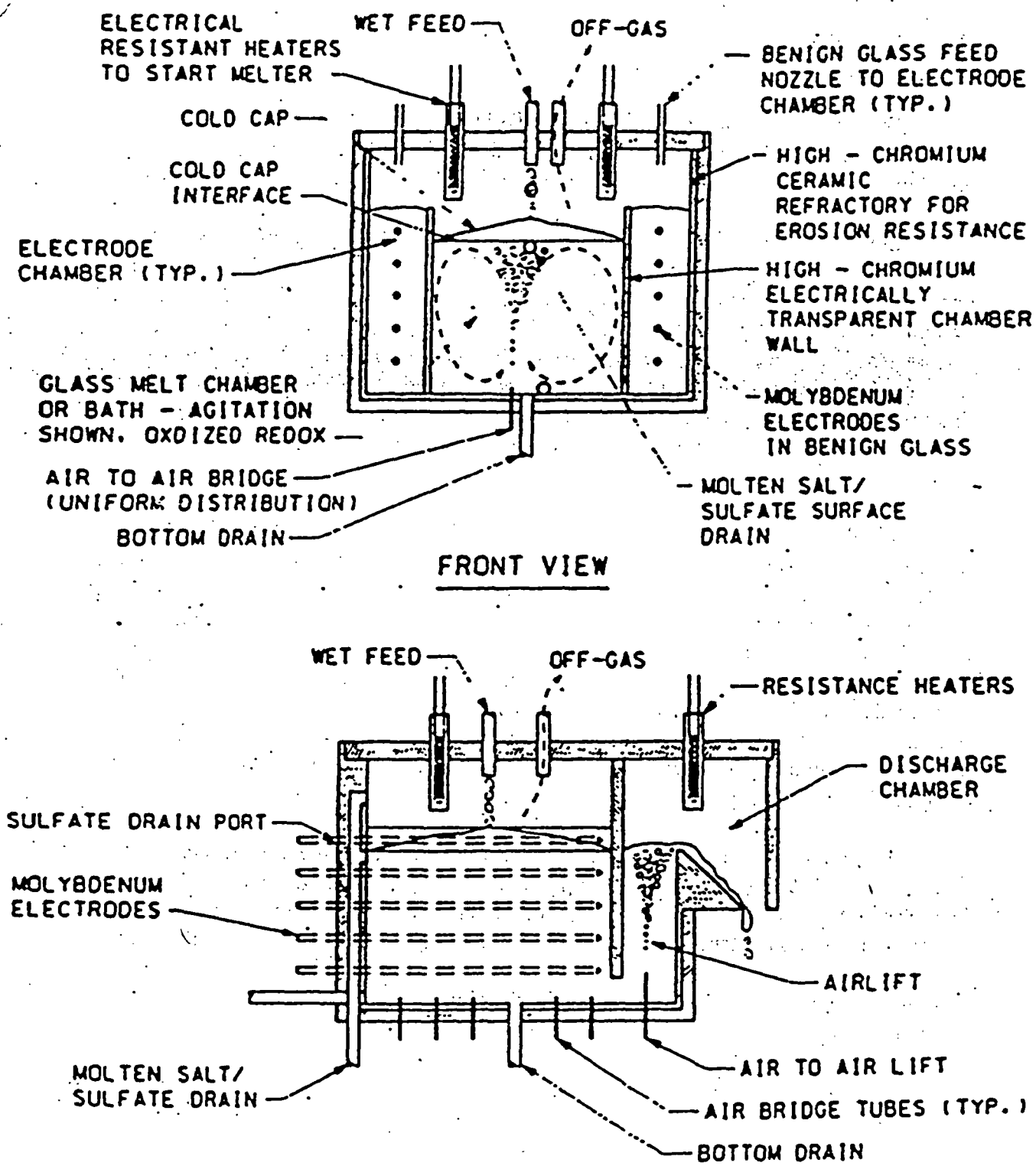
[598] Independent Review Team, 1997d.
[599] Fluor Daniel Fernald, 1996c, page A-4.
[600] Ibid, page A-3.

FIGURE 13: Diagram of Vitrification Pilot Plant Melter



OU4 Melter Concept -- Simplified

Source: Fluor Daniel Fernald, 1996c, p. A-5.

demonstrated for a melter of the size in the Pilot Plant (rated at 1 metric ton of glass per day, possibly up to 3 metric tons per day with agitation).[601] As noted above, the experimental design was partially tested at the laboratory scale to addresss some problems specific to the material in the Fernald silos.

Figure 13 shows a schematic of the GTS Duratek melter. The three chambers were separated by "isolation walls" which would permit the flow of electricity but would not allow an exchange between the "benign" glass and the glass containing the waste.

Several melter design problems were noticed during the early operation of the pilot plant. The melter discharge chamber was oversized, allowing for either potential excess flow of cool air into the melter, or flow of melter off-gas into the building HVAC system - which would potentially release radon, other gases, and particulates to the atmosphere.[602] Additionally, welds in one of the four bottom drains failed, causing leakage of coolant solution into the melter glass chamber. Another design problem was that the side feed tube became plugged and inoperable as a result of an improper angle and sizing. The melter cooling water system also did not provide adequate coolant flow.[603]

Finally, the material used to make the "bubbler tubes," molybdenum, was inappropriate for the task. The "bubbler tubes" were installed to provide agitation of the waste.[604] Agitation of the waste increases the mixing and allows for a greater production rate. The bubbler tubes also provided oxygen to the melt to prevent metals from being created in the melt and separating from the glass. The tubes were located in a row down the center of the melter and bubbled air through the bath. Inexplicably, the bubbler tubes were made of molybdenum disilicide ($MoSi_2$) even though they were in direct contact with the waste. As we have noted, at the time the melter was designed, it was already known that molybdenum would be eroded by the lead in the waste.[605] This proved to be the fatal flaw in the project.

Erosion of the bubbler tubes led directly to the failure of the melter. On December 26, 1996, while carrying out part of Campaign 4 Testing, a small hole in the bottom of the melter opened up, leaking molten glass from the bottom of the melter. The entire molten glass content of the melter, approximately one cubic yard, leaked from the melter. Molten glass spilled onto the floor, igniting a small fire. An emergency response team was on-hand and effectively dealt with the situation: no one was hurt in the incident.[606] The melter, however, was ruined.

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[601] Ibid, page A-4.
[602] Fluor Daniel Fernald, 1996d, p.3-70 to 3-71.
[603] Fluor Daniel Fernald, 1996e.
[604] Fluor Daniel Fernald, 1996c, page A-6.
[605] Ibid, page A-4.
[606] Fluor Daniel Fernald, 1996f.

The cause of the melter accident was the erosion of the molybdenum in the bubbler tubes by the lead in the waste simulant. Metal oxides are soluble in glass but pure metals and many other compounds of metals are not. The bubbler tubes made of insoluble molybdenum disilicide reacted with the lead oxide in the waste to form an oxide of molybdenum which is soluble in glass and molten lead, which is not. The equation below shows the reaction that took place:

$$MoSi_2 + 7\ PbO \rightarrow MoO_3 + 2\ SiO_2 + 7\ Pb.$$

Thus, the molybdenum in the tubes ($MoSi_2$) dissolved away and the molten lead (Pb) began to drop out at the bottom in the form of drips, or "teardrops" on the eroding bubbler tubes. Eventually, Bubbler Tube #3 was eroded down through the first layer of underlying "bricks" -- insulating materials specially-designed to withstand the conditions of the melter. This allowed the molten glass to flow into the understructure of the melter. As the glass reached the second layer of underlining "bricks" -- which were chosen for their insulating characteristics and not resistance to erosion, the glass began to eat away at this whole layer of bricks. Finally, the bubbler tubes eroded completely, allowing molten glass to flow out the bottom of the melter.[607] See Figure 14, Figure 15, and Figure 16.

It is unclear why molybdenum was chosen for the bubbler tubes. Reaction of molybdenum with lead is well-known in the glass industry, and potential problems were noted in the Pacific Northwest Laboratory studies about the electrodes.[608] In fact, a review of the "melter incident" stated:

> The first lesson learned is that project personnel identified a concern about bubbler tube erosion, and the concern was addressed in the initial Phase I Test Plan and Hazards and Operability Report. The concern was omitted from the Final Hazard Analysis Report without mitigating measures identified or implemented. [emphasis added][609]

In fact, a warning that the melter might fail for this very reason was raised by a Fluor Daniel Operations Manager in a table describing "potential off-normal melter scenarios." Scenario #19 raised the issue of excessive wear of the bubbler tubes:

> Excessive erosion will require charging [changing] the bubbler tubes frequently to keep up with the wear. If wear cannot be controlled, the ends of the tubes will erode away and then erosion will take place on the melter bottom where the tubes are or were. Extensive erosion could result in a breach of the melter bottom. Methods to measure the rate of erosion or the amount of wear (real-time) needs (*sic*) to be be developed.[610]

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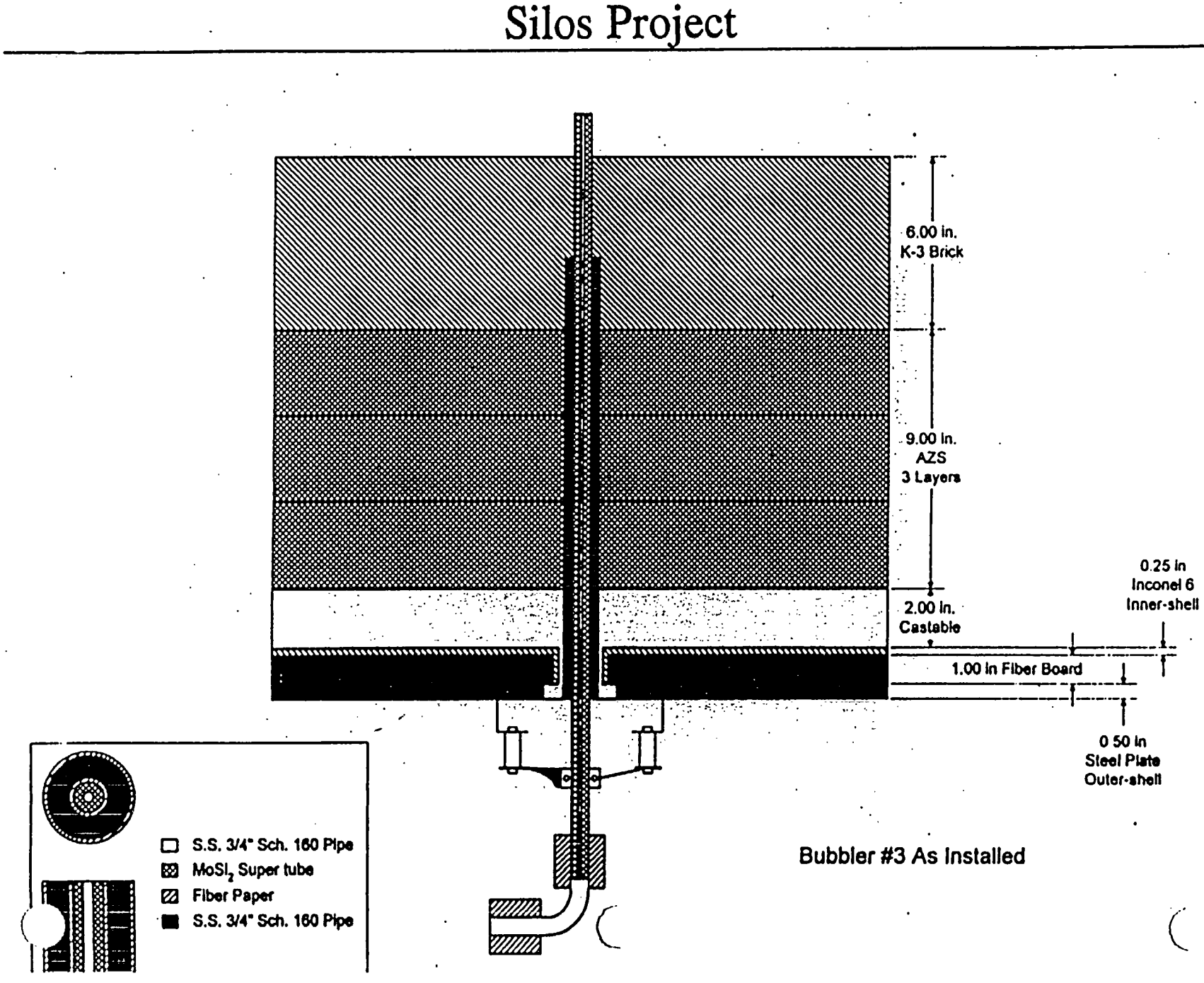
[607] Independent Review Team, 1997b.
[608] Merrill and Whittington, 1994, page 14.
[609] Fluor Daniel Fernald 1997a, p. 2-4.
[610] Table 9-5 of the Phase II Test Plan, as quoted in Fluor Daniel Fernald, 1997a, Safety Review Team Report, Attachment 2.

Figure 14: Bubbler Tubes, as Installed in Fernald Melter



Source: Independent Review Team, 1997b.

Silos Project

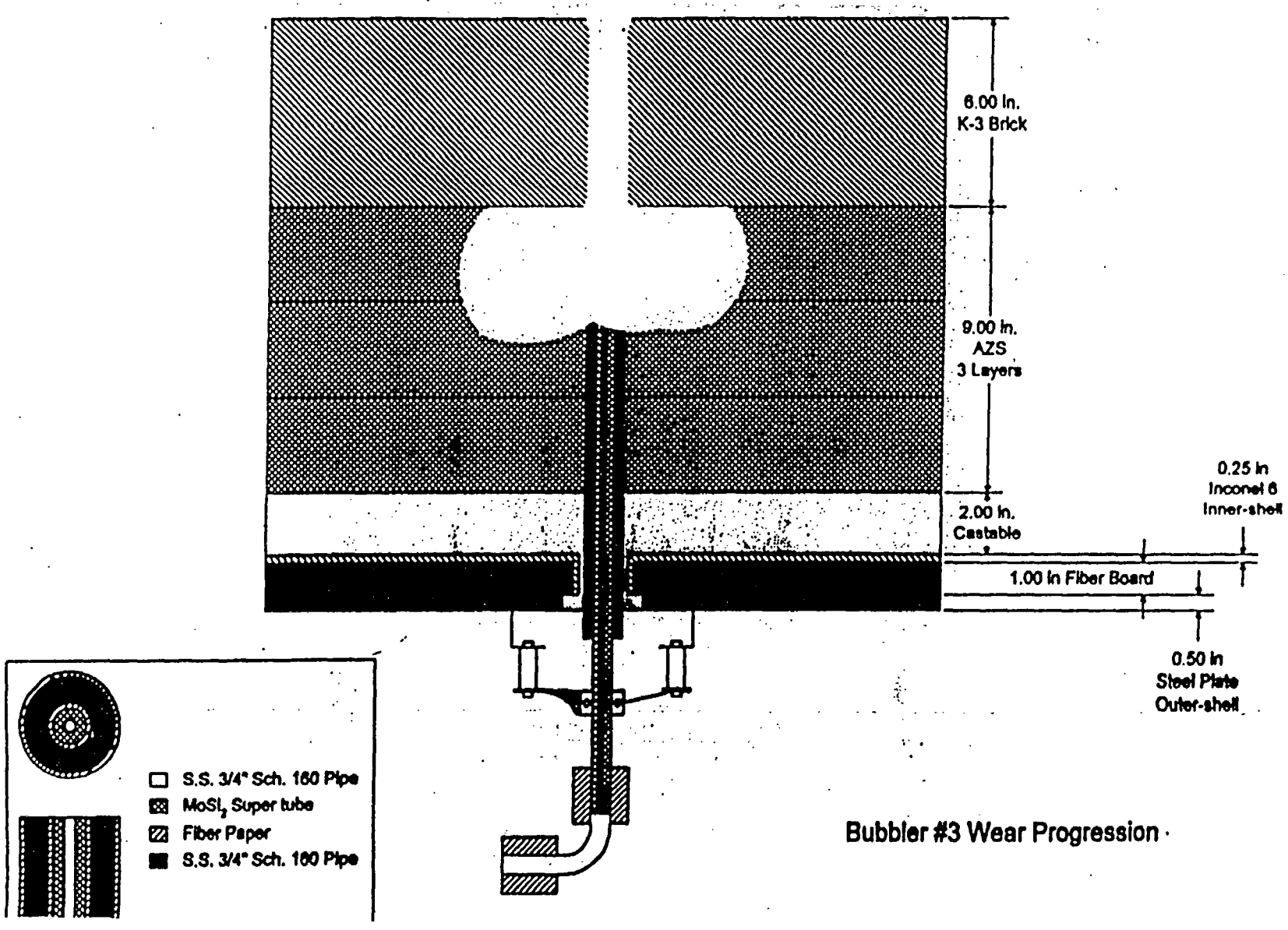
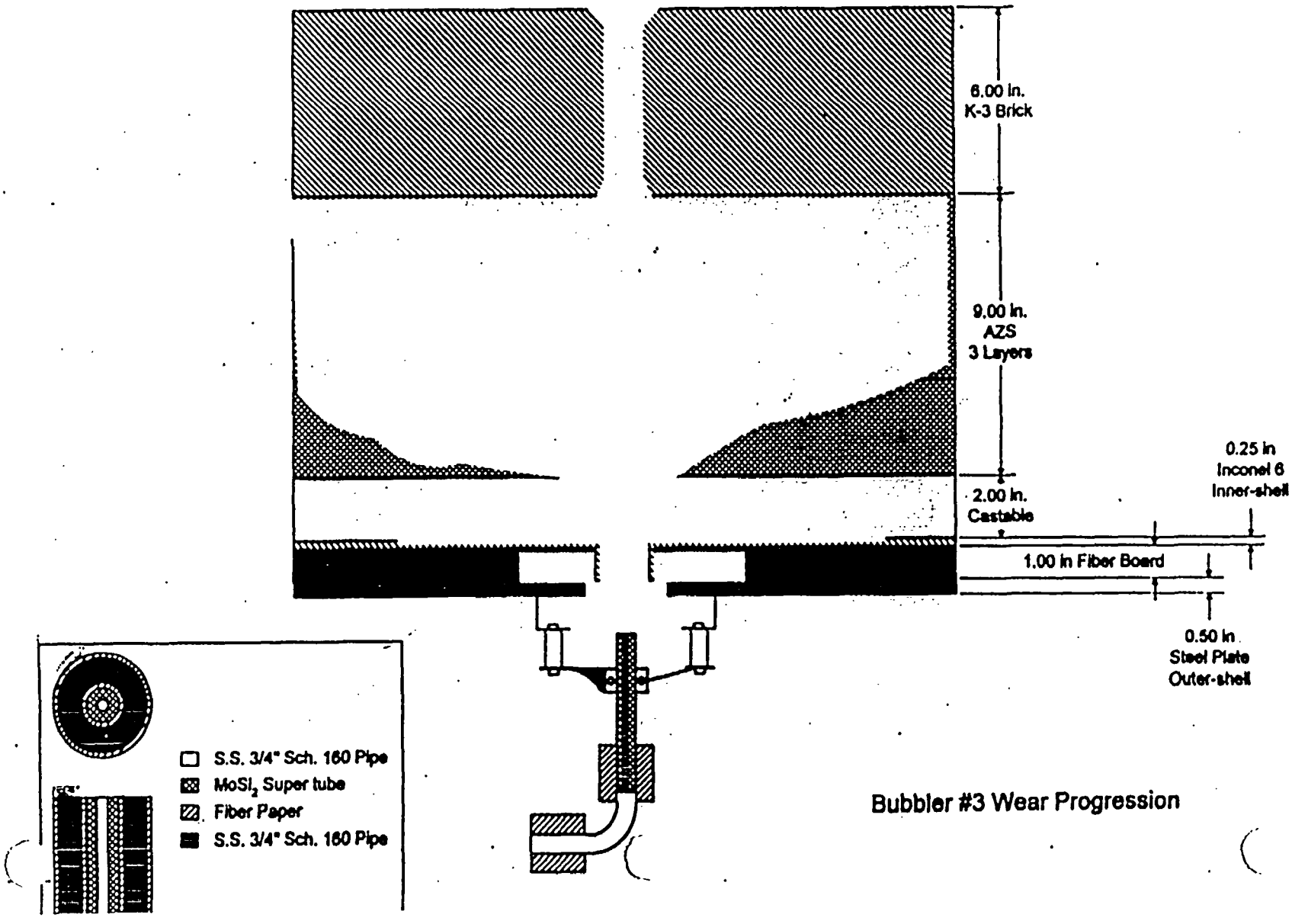


Figure 15: Erosion of Fernald Melter

Source: Independent Review Team, 1997b.

Figure 16: Destruction of Fernald Melter

Silos Project



Source: Independent Review Team, 1997b.

The list of scenarios was submitted to DURATEK (the melter manufacturer) in February 1995. As it turned out, neither DURATEK, nor Fluor Daniel, nor DOE paid attention to the problem and the melter failure occurred essentially as described in "Scenario #19." The melter failure raises questions about the design process and the ability of contractors, sub-contractors, and the DOE to listen to their own employees. DOE and its contractors must make sure that formal procedures are in place to resolve such issues before moving ahead with projects. However, our review indicates that this basic problem keeps recurring. They must also make sure that the procedures are followed -- an example of a failure to do so is discussed in this report in the Hanford high-level waste case study, in the section dealing with organic safety issues in Tank C-103.

In sum, our review of the Fernald Silos remediation pilot project has found serious, avoidable flaws in the entire project, from the design phase to the melter failure. The errors were not mere failures that one might expect to encounter in a pilot project. Rather, most of the problems occurred because of inattention to basic scientific and engineering issues.

Analysis of Silos Project and Discussion of Alternatives

A. Management and Cost

The failure of the bubbler tube on December 26, 1996, that led to the destruction of the melter marked the end of two years of experience with the Fernald Vitrification Pilot Plant. Considerable experience was gained during the construction and operation of the pilot plant. Many of the engineering design flaws were correctable for work with non-radioactive surrogates. A good deal of information was generated on the treatability of the silo waste. Experience was gained with a first-of-a-kind, high-temperature melter. Much of the information gained during the project will be useful for future work on the waste in the silos, as well as across the DOE nuclear weapons complex.

However, the information has come at a significant price. In fact, the roughly $50 million dollars spent through November 1996 on the partially-completed Phase I of the pilot plant is about what the original projections for vitrification and disposal of all of the waste in the three silos were.[611] In July 1996, DOE estimated that the final cost for completion of the Vitrification Pilot Plant would be $66 million. However DOE spent $50 million before it even began tackling the harder aspects of the pilot plant planned for Phase II, such as retrieval technology development and vitrification of real waste at 1 metric ton per day. Meanwhile the waste remains in structurally unsound silos with radon concentrations that are building back up to high levels.

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[611] The Record of Decision estimated $91.7 million total for the project, including $34.3 million for residual contamination in the silos and the soil, leaving roughly $57 million for vitrification and disposal of all of the waste in the silos.

Along with the escalation of costs in the pilot plant, projections for completions of actual remedial work according to the Record of Decision began to increase dramatically. In January 1996, roughly one year after the Record of Decision was signed, costs for the whole project topped $300 million, with completion of vitrification delayed from the year 2000 to 2004.[612] In April, Fluor Daniel Fernald provided the Independent Review Team with an estimate of $476 million for vitrification of Silos 1 and 2 only (and cementation of Silo 3 -- see below for a discussion of alternative treatment options), with vitrification not starting until 2006. The cost estimate, however, is based on limited engineering and the schedule is based on "pre-conceptual" engineering assumptions.[613] Moreover, due to the need for DOE to prepare an Explanation of Significant Differences and/or an amendment to the Record of Decision, the entire project is in a state of confusion and uncertainty.

We have been unable to find an engineering justification for such huge cost increases. We are also troubled by the fact that the Independent Review Panel did not present a review of the costs but quoted Fluor Daniel Fernald's estimates and opined that they "appear to be of the correct order of magnitude."[614] Given that the project now involves hundreds of millions of dollars and prior egregious misestimates, there should be a thorough independent review, involving both accounting and engineering aspects, before these requested cost increases are allowed.[615] We should note here that the cited cost estimates for processing about ten thousand cubic meters of radioactive dirt are now comparable to major engineering projects. For example, the new National Airport terminal near Washington, D.C. completed in 1997 cost $400 million.[616]

Many of these shortcomings resulted from "problems in project management that led to deficiencies in design control, process control, effective contracting, contractor oversight, and contractor accountability."[617] These "shortcomings of the VITPP design call into question the capabilities of the site A-E [architecture-engineering] to perform the design as well as the FEMP [DOE's site managers] to oversee the effort without additional support."[618]

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[612] Value Engineering, 1996, Estimate Worksheet file 123R31\OU4_B0, pages 1-4 .
[613] Independent Review Team, 1997e, page 16.
[614] Ibid, page 17.
[615] The cost increases for Silos 1 and 2 are so great that the EPA has asked that the ROD be amended to reflect the new costs (Saric 1997). This implies that the DOE should grant these cost increases. We do not believe that this is justified at this stage. A thorough review is needed first.
[616] Shirfin, 1996, page 60.
[617] Martin, 1997.
[618] Independent Review Team, 1996a.

B. Technical and Regulatory

Because of the cost and schedule overruns for the pilot plant, DOE and Fluor Daniel Fernald began to look at alternatives for treatment of the waste. Indeed, before the pilot plant even began operations, these efforts were in full gear.[619]

Fluor Daniel Fernald and DOE have actively pursued changing the treatment for the waste in the silos from vitrification to cementation. In convening an Independent Review Team (IRT), Fluor Daniel Fernald charged it with evaluating three options, at a minimum:

- vitrification of Silos 1, 2, and 3 waste together
- vitrification of Silos 1 and 2 waste, cementation of silo 3 waste
- cementation of Silos 1, 2, and 3 waste.

The IRT concentrated on these three options. An important option not included in Fluor Daniel Fernald's charge is vitrification of Silos 1 and 2 waste separately from vitrification of Silo 3 waste.

The majority of the IRT came to the following conclusions:

1. Silos 1, 2 and 3 waste should not be vitrified together, because it would create a high sulfate, high lead waste stream
2. Silo 3 waste should be immobilized through cementation
3. Additional characterization of the silos waste is needed
4. Immediate attention should be given to waste retrieval
5. Fluor Daniel Fernald should pursue some form of commercial involvement rather than in-house design, construction, and operation
6. Cementation of Silos 1 and 2 waste should be retained as a back-up, but should not divert funds from the vitrification effort.[620]

We agree with the IRT conclusion that Silos 1, 2, and 3 waste should not be mixed together before vitrification, because it unnecessarily complicates development of vitrification techniques. We also agree that additional characterization of the Silos is needed and that immediate attention is needed for waste retrieval development.

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[619] For example, DOE convened a "Value Engineering" team to provide recommendations in January 1996. This team recommended alternatives for treatment of the waste, such as cementation. This effort was strictly a cost savings effort, performed over the course of one week, with no mention given to meeting the legally-binding conditions of the Record of Decision. (Value Engineering, 1996)

[620] Independent Review Team, 1997e, pages 1-2.

However, we do not agree that a recommendation should be made to cement Silo 3. In fact, Pacific Northwest Laboratory tests on the vitrification of Silo 3 concluded "the glass formulation for the Silo 3 material readily promoted the decomposition of sulfate in the Silo 3 waste ... A separate phase [i.e., a sulfate layer] was not observed in the Silo 3 melts despite very high initial sulfate concentration."[621] And later development by the Vitreous State Laboratory concluded that "several processable, leach resistant glass compositions were identified for the [Silo 3] waste stream."[622] Vitrification of Silo 3 waste was not carried out at the Fernald pilot plant because Fluor Daniel Fernald canceled these tests "because of proposed stabilization [e.g., cementation]"[623] and not because it was conceptually inappropriate or financially unsound. In fact, the testing completed to date indicates that vitrification of the Silo 3 waste may have been improperly and prematurely abandoned by DOE and Fluor Daniel Fernald. This appears to be due to issues that are mostly unrelated to the Silo 3 materials themselves, but rather the numerous problems in design and management detailed in this report.

We believe it is inappropriate to proceed with another option for treatment of the Silo 3 waste without a thorough evaluation comparing vitrification with any potential treatment. Moreover, results from such an evaluation that differ from information published in the Record of Decision need to be fully investigated before any changes should be accepted. For example, the 1994 Record of Decision estimated the cost for the vitrification alternative for Silo 3 to be $28 million, less than the $36 million that was estimated for cementation. Yet Fluor Daniel Fernald now estimates the cementation option for Silo 3 waste will cost $22 to $29 million.[624]

The entire remediation program for Operable Unit 4 needs to be put on a sound footing to implement the Record of Decision. One of the principal reasons being offered for abandoning vitrification at this stage is that the danger of a roof collapse makes the problem urgent. Had the DOE and its contractors properly internalized this urgency, they would have conducted the Pilot Plant project far more prudently. Deadlines have slipped greatly and DOE must in any case make contingency plans to protect workers and the public in case of a roof collapse. The risk makes it imperative that the necessary studies for waste processing be done with some speed. However, it does not justify jumping right into another project that may result in a repeat of past failures, more delays, and higher costs.

At this stage the most appropriate approach is for DOE to initiate a vigorous one- to two-year program of laboratory investigations of various melter technologies as well as an urgent program to thoroughly characterize the chemical and physical properties of the contents of the three silos. DOE needs to exercise sufficient oversight to ensure that private industry approaches remediation work with at least the same integrity that it does

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[621] Merrill and Whittington, 1994, page 10.
[622] Fu, 1996, page 3-1.
[623] Fluor Daniel Fernald, 1997b, page 1-1.
[624] Independent Review Team, 1997e, page 16.

work funded by non-governmental entities. We do not believe that the project so far indicates that this level of technical integrity has been brought to bear on this work. The lack of proper oversight is a crucial problem. Simple "privatization" -- that is, handing over the problem to private industry to solve with even less oversight -- risks even more serious problems, as we have seen in the Pit 9 project of the TRU waste case study. Finally, DOE needs to initiate a program to address roof collapse contingencies; this needs to be done whatever approach is chosen to remediate the silo contents.

Chapter Five: IEER's Recommendations for Restructuring the Environmental Management of the Nuclear Weapons Complex

The nuclear arms race and its aftermath have created the largest and most complex problem of environmental remediation and waste management in U.S. history. The problem is so complicated and costly that there is a tendency in the nuclear establishment to simply bury the problem, literally and figuratively, creating what have been called national sacrifice zones. That would not only be unjust to the communities that have already borne an enormous burden of contamination, cover-ups, and worse at the hands of the nuclear weapons establishment during the Cold War. It would also be dangerous, regrettable, and unnecessary.

It would be dangerous because by its very nature long-lived radioactive and toxic contamination cannot be confined by a fence. It will spread and contaminate vital resources that will be important to the well-being of future generations. People around the country eat the potatoes that are grown with water from the Snake River Plain Aquifer which extends under the Idaho weapons lab, the vegetables that are grown with water from the Tuscaloosa aquifer underlying the Savannah River Site, and the fish that come from the waters of the Columbia River. Institutional memory is short and, if the past is any guide, people in the future may use contaminated resources for some time and make investments before they discover the contamination. They will then be faced with wrenching decisions of whether to abandon their investments or live with what would normally be unacceptable risks, or pursue remediation that in many cases may be far more costly than the original remediation and waste management "solutions."

It would be regrettable and unnecessary because the basic approach to a solution is at hand, even if all the technologies are not. In the next two to three decades, we can eliminate or greatly reduce the most urgent threats, while pursuing technologies and long-term waste management strategies to minimize risk to generations far into the future.

It is to be expected that there will be failures and mistakes along the way to solving this daunting problem. But these must be distinguished from the kind of short-sightedness and mismanagement that presently plague the Department of Energy's Environmental Management program. The long tradition of devotion to nuclear weapons production at the expense of health and the environment seems to have stuck to DOE.

The case studies we have presented in this report, along with other work done by IEER on radioactive waste management, have lead us conclude that, overall, the Department of Energy's Environmental Management plan is faced with problems that are so fundamental that only a thorough restructuring can cure them. Under the current approach, not only are huge sums of money being wasted, but major programs are failing without lessons being learned. Cold War technologies that create more dangerous waste, like reprocessing, are being pursued in the name of Environmental Management. Short-sighted and ill-designed remediation programs are being implemented that are on the

course to becoming even larger environmental problems in the future. Even much basic data is of appallingly poor quality, with numbers jumping around from one year to the next and one report to the next without explanation, coordination, quality control, or scientific review process.

We have come to these dismal conclusions about DOE's programs despite having observed that there are many competent professionals in the DOE system (including its contractors). Some good pieces of work have been done, as we note in Chapter 1. There is also widespread and deep support in the country for a clean environment, and the communities that are near DOE facilities are no exception. These elements can be a part of the foundation of a sound environmental management program. But they are not enough. Institutional and technical changes will also be needed, as we discuss below.

A restructured program must also begin with a thorough reassessment of environmental remediation and waste management programs taken together. We are presenting what is essentially an outline of an approach for environmental management that has resulted from our preliminary and admittedly partial assessment. We also discuss below the specifics that we have been able to derive from our case studies and previous work on the DOE complex, as our contribution to that restructuring.

The starting point for examination of the options for dealing with the radioactive legacy of nuclear weapons production is that we cannot "clean it up" in the conventional sense of the phrase. Rather, the objective is reduction of risk, which has three aspects.

1. The first aspect relates to urgent problems. These risks are immediate and failure to take action could result in environmental or health disasters, or further spread of contamination so that it is irremediable, or both. Examples are the risk of waste tank fires or explosions and the migration of plutonium, cesium-137, and other long-lived radionuclides from waste dumps into groundwater.

2. The second aspect involves long-term risk reduction. This means that we must devise ways to isolate or contain radioactive waste for periods comparable to the times for which they will remain dangerous. Many of the scientific and engineering judgments we make in the next few decades must hold up for tens or hundreds of thousands of years.

3. The third aspect involves non-radioactive toxic substances. Some of these, like organic compounds, can be rendered relatively less harmless by chemical treatment. Others, like heavy metals, must be isolated from the environment. Finally, some materials may be uncontaminated and could be reused.

In sum, the popular term "clean-up" really involves removing dangerous materials from places and resources that human beings may use ("the human environment") and devising treatment strategies for chemical waste and isolation strategies for radioactive waste to minimize risk to future generations. All of this must be done in ways that also keep exposure of workers and present-day populations to low levels.

General Programmatic Recommendations[625]

1. Create a new, rational, environmentally-protective system of radioactive waste classification according to longevity and specific activity, so that comparable hazards are managed comparably.
2. Coordinate waste management and environmental remediation and make reduction of short-term risks compatible with minimizing long-term risks.
3. Approach environmental management with independently enforced, national health-based clean-up and waste management standards, including specific provisions to protect groundwater resources and mandatory guidelines to keep doses as low as reasonably achievable (ALARA) both for workers and for off-site populations. The ALARA guideline for release of sites for unrestricted use should be to remediate to background levels, if reasonable, or else to keep doses to under 2 millirem per year (which is the British ALARA guideline).
4. Put an institutional structure into place that is both scientifically and financially accountable and that demonstrably has as its top priority the protection of health and environment, rather than weapons production or perpetuation of Cold War technologies.
5. Suspend the politically expedient Yucca Mountain and WIPP repository programs and put in place a scientifically sound program of long-term high-level waste management, including repository research, sub-seabed disposal research, and construction of materials to contain radioactivity that are analogous to natural materials that can last for millions of years. (See Appendix B for more details on IEER's waste management recommendations.)
6. Provide funds and technical support to communities that have residual contamination so that they can monitor the environment and keep themselves informed. Such funds are needed to protect communities against future known risks and also against risks due to inadequate characterization or present incomplete understanding of risks. The size of the fund should depend on the size and character of the residual radioactive and non-radioactive hazardous contamination of land, remaining structures, surface waters, river beds, and groundwater, as well as the total amount of radioactivity and non-radioactive hazardous material left in disposal areas on site.
7. Create a rigorous, open, and truly independent procedure for evaluating successes and failures. This process should include an integrated technology evaluation program that can assess successes and failures as well as judge new technologies for their relevance to the DOE complex.
8. Manage non-radioactive toxic components of waste in ways that do not seriously compromise management of radioactive components.
9. Make risk reduction for off-site residents and for workers compatible with minimizing risk for future generations.

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[625] Based on Makhijani, 1992 and in part on the Military Production Network's 1996 position on Clean-up.

10. Stabilize waste so as to greatly reduce or eliminate the most serious environmental and health threats and store it on-site while sound long-term management strategies are developed.
11. If sound remediation technologies are not available, take interim measures (such as restricting access to resources), make investments in research and development, and create rules that allow for a future progressive return of resources to general use.
12. Provide the states, Indian tribes, and the public (with special emphasis on the affected communities and workers) with timely information so that they can participate effectively in decision-making.
13. Make public all information relating to health and environment that was created at taxpayer expense, including that produced and/or held by contractors and sub-contractors.
14. Impose stringent financial accountability on the contractors and institute engineering-based methods to review project budgets and large budget increases. One method to accomplish this review on an ongoing basis would be for DOE to create a permanent panel under the Federal Advisory Committee Act, composed of people who do not have financial conflicts of interest with specific projects. Project budget documents should be public. This panel should also have the power to appoint *ad hoc* staff and committees to look into specific areas and problems.
15. Allow state, local governments, and Indian tribes to apply stricter clean-up standards.

We will discuss the first five points in more detail and then discuss our recommendations specific to the case studies.

1. Waste Classification

The restructuring of waste management and waste classification is essential to putting into place an environmental remediation program in which the urgent problems of preventing increases in contamination and reducing severe safety and security risks can be made a top priority, without resort to measures such as shallow land burial of radioactive waste that has substantial concentrations of long-lived radionuclides.

The current waste classification system is not rational in that some highly radioactive waste is treated as "low-level" waste, while others are designated for repository burial. Appendix B covers this issue in some detail and presents IEER's technical and policy guidelines for waste reclassification. In the specific instance of "low-level" waste, the classification system created by the Nuclear Regulatory Commission (NRC) was not meant to deal with tens of millions of curies of long-lived fission products or million-gallon high-level waste tanks that DOE is planning to put into shallow land disposal sites. For example, the total amount of Class B and Class C waste expected to arise from decommissioning all US commercial nuclear reactors is about 30,000 cubic meters, of which only about 3,000 cubic meters would be Class C waste. DOE plans to create more than 100 times this amount of Class C waste from the Hanford tanks waste processing alone, all to be disposed of on one site -- Hanford. Such a use of the "low-level" waste category is highly inappropriate.

Moreover, as we discuss in more detail in Appendix B, even the NRC regulations themselves are deeply flawed and should be revised. U.S. Class C waste is far more radioactive than waste that, in countries such as Sweden, France, and Britain, is intended for deep geologic disposal.[626] DOE's 350,000 cubic meters of Class C "low-level" generated from Hanford tank processing could contain up to 7,000 curies per cubic meter of strontium-90 or 4,600 curies per cubic meter of cesium-137. (Under the Nuclear Regulatory Commission's definition, the limits are proportionately lower if the waste contains more than one radionuclide.) French regulations define intermediate level waste to be disposed of in a repository as containing more than 10 curies per ton of beta or gamma emitters (such as strontium-90 or cesium-137). If the material is glass, this translates to 27 curies per cubic meter. British "intermediate-level" waste to be disposed of in a repository contains greater than 0.324 curies per cubic meter.[627]

There are also instances of inappropriate use of the "low-level waste" designation by the Nuclear Regulatory Commission, which allows under some circumstances for depleted uranium to be designated as Class A "low-level" waste, when in fact it possesses characteristics similar to transuranic waste. (See Appendix B.)

Finally, we have also illustrated the problem arising from the arbitrary and varying definition of TRU waste and the resultant tortuous efforts to separate "low-level" waste from TRU waste at considerable cost, even as contamination of groundwater increases and spreads. Not only are there inconsistencies in the internal DOE definitions of waste over time, but there are also inconsistencies between DOE and NRC designations for the TRU waste category (which under NRC rules belongs to the "Greater than Class C" waste classification). DOE regulations are far more lax than NRC regulations because they do not simultaneously restrict fission products and transuranic elements in TRU waste.

The U.S. waste classification needs to be revised so as to correspond to longevity and hazard of the waste. We suggest a specific classification scheme in Appendix B.

2. Coordinate Waste Management and Environmental Remediation

Environmental remediation efforts must keep one eye on minimizing current risks and keep the other steadily fixed on long term waste management. Unless remediation actions taken are compatible with sound long-term waste management, they may simply lay the basis for future problems. Decommissioning of highly contaminated facilities, long-term protection of groundwater from reckless dumping practices of the past, and solidification of highly radioactive waste will all result in substantial volumes of long-lived radioactive waste. (These processes do not create new radioactivity, but put existing radioactivity in new forms to be managed with the objective of risk reduction.)

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[626] See Hanford case study for more details.
[627] IPPNW and IEER, 1992, page 54.

Remediation actions that aim at short-term risk reduction are required to be compatible with keeping risks low from long-term waste management. But DOE has not systematized this simple principle. For instance, at Fernald, DOE could have built tornado-proof enclosure for the silos containing radium-contaminated waste, and taken a more careful approach to emptying the tanks and putting them into a waste form suitable for long-term management. Instead DOE took the cheaper route of putting a bentonite clay layer to reduce radon emissions. This short-term solution is already failing, and it has complicated efforts to retrieve the waste from the silos to process them into a form more suitable for long-term management.

As another example, DOE has not coordinated the treatment of its buried transuranic waste with the planned treatment of its stored transuranic waste in the Advanced Mixed Waste Treatment Facility, though these wastes have similar characteristics. One reason appears to be that retrievably stored waste is part of the Waste Management program, while buried TRU waste is part of the environmental remediation program.

The location and types of repositories, the kinds of waste forms, the technologies and steps used to stabilize waste are all connected issues. DOE's failure to integrate them has in part been responsible for high costs and inadequate results. At least some parts of the DOE appear to recognize this failing and DOE has initiated an effort toward such integration. It is too early to conclude how this effort will be reflected in real programs, and whether other efforts such as "privatization" will overwhelm them.

Careful coordination of environmental remediation and waste management and short-term and long-term risk reduction are essential to a successful management program and it should be a principal goal of the program integration effort to achieve that coordination.

3. Clean-up Standards

DOE should reverse its decision to oppose EPA efforts to set clean-up and waste management standards and instead cooperate in the setting of stringent standards to which it can be held accountable by the public and to which it can hold its contractors accountable. We suggest that a single framework for environmental remediation and waste management would consist of the following technical elements, among others (see Appendix A), when sites are released for unrestricted use:

- a set of remediation standards that apply nationally and that include protection for health of future generations as well as for resources, notably water resources
- the "as low as reasonably achievable" (ALARA) guide for release of sites for unrestricted use should be to remediate to background levels, if reasonable, or

else to keep doses to under 2 millirem per year (which is the British ALARA guideline)

- a remediation standard involving a maximum dose of 10 millirem to a future maximally exposed individual (often the subsistence farmer) for as long as the threat persists and sublimits for protection of groundwater as per the Clean Water Act regulations
- systematic consideration of non-cancer risks and synergisms between risks from radioactive and non-radioactive toxic materials.

In order to implement the protection of groundwater provisions, models need to be revised to reflect experience at the sites, particularly with respect to mobility of transuranic elements. Examples of faulty assumptions in this area are detailed in Chapter Two of this report.

The same guidelines and rules should be followed when sites are released for restricted uses. The main difference between restricted and unrestricted uses should stem from the fact that under restricted use, dose can be limited by institutional and technical means not available in the unrestricted case, in addition to remediation measures that would be implemented.

Within the context of a restructured environmental remediation program, it will also be possible to more realistically address two other needs. First, it is necessary to have a good deal of flexibility in the environmental remediation program to meet complex, unprecedented, and technologically difficult challenges. But this is not possible under the present structure because DOE tends to subvert flexibility it is given to expedient ends rather than to long-term environmental protection. This political expediency is also abetted by pressure from the weapons-makers, from the commercial nuclear power industry (in the case of the Yucca Mountain repository), and from other parts and branches of government. Given that, those whose interests coincide most with environmental remediation, such as the states, communities near the plants, or the Environmental Protection Agency, have often tended to tighten rules and reduce flexibility. The needed flexibility cannot be restored until a sounder institutional structure is achieved.

Second, the risks from some non-radioactive toxics, notably organic materials, can be reduced. But this often requires technologies that will impose some risk to the present generation. Implementing such approaches to overall risk reduction requires a great deal of trust between the implementing agency, the workers who will implement it, and the communities who are near the facilities. Specifically, there must be a shared confidence that the implementing institutions (today, the DOE and its contractors) will put public health and environment first. It requires great openness to input from all quarters and a seriousness of taking that input into account (and not just when it is convenient). The DOE and its contractors do not inspire the requisite confidence (to say the least) because of past abuse of the public trust and continuing resort to political

expediency and Cold War technologies. Therefore, an appropriate technical program of risk reduction cannot be implemented without an institutional restructuring of environmental remediation and waste management, to which we now turn.

4. Institutional Structure

We have concluded that the most important problems preventing the creation of a sound program of environmental remediation as well as short- and long-term waste management are not technical but institutional. These problems lie in the Department of Energy and its contractors. Despite some progress, especially in the area of delineating the problems that face the nuclear weapons complex (see Chapter 1), and despite the presence of many scientifically-competent people, the environmental remediation program has yet to find a direction where programs are well-conceived and properly implemented. The principal institutional problems that we have identified are:

- an attachment to Cold War technologies related to weapons research, development, testing, and production
- a tendency to "monumentalism" -- that is, rushing into big projects without proper preparatory scientific and engineering work (perhaps deriving from a desire to maximize the flow of funds into the weapons complex)
- a lack of a sound process of internal scientific and technical peer review that actually matters in decision-making in approving and implementing large projects, and a corresponding tendency to ignore inconvenient extra-departmental advice
- a tendency to approve large budget increases for contractors without thorough engineering based-reviews of the failures that led to the budget changes
- a failure to learn lessons from past failures
- an attachment to the Yucca Mountain and Waste Isolation Pilot Project repository programs out of institutional, legal, and financial inertia even though these are compromising a much larger effort to remediate the weapons complex, manage long-lived highly-radioactive waste, and develop a scientifically sound repository program
- a lack of independent regulation of the DOE's nuclear activities.

Fundamentally compounding all of the problems is a simple underlying fact: DOE, because of its mismanagement of waste and its low priority for environmental protection has lost the trust of the communities it must deal with ("stakeholders" in official jargon). DOE seems generally ready to claim in any specific instance that "no one was hurt" even before the management is in possession of the relevant facts.

Institutional reform must specifically address DOE's tendency to jump into projects at scales that are too large, only to see them fail or be seriously compromised in quality. Solid experimental work, careful problem characterization, engineering evaluations, frank analyses of successes and failures, and pilot projects all need to be

made part of the establishment of sound science and engineering practices in the DOE environmental restoration and waste management program. There is no easy way to accomplish this goal. But without it, the taxpayers will continue to spend five billion or more dollars a year to little purpose other than to maintain the capability to restart portions of the nuclear weapons complex, for example the Fast Flux Test Facility at Hanford, by guarding buildings and materials and to increase the flow of tax dollars into the bank accounts of DOE contractors.

Nor do we have the option of simply abandoning the DOE complex. Even putting aside environmental considerations, security issues, such as large quantities of plutonium in waste and in shut-down facilities, and the continuing dangers of fires and explosions, such as the one that occurred in the Hanford Plutonium Finishing Plant in May 1997, will necessitate several billion dollars every year. Therefore, the question is not whether spending taxpayer dollars can be avoided. It cannot. That is part of the cost and the legacy of the Cold War. The question is how the spending of it shall be effectively organized so as to achieve health, environmental and security goals for this and future generations.

One of the main obstacles confronting institutional reform is that the same people who are now mismanaging the environmental programs may wind up also being the managers of any new structure. In other words, we should ensure that institutional reform amounts to more than changing nameplates and letterheads. Moreover, the institutional memory of long-standing workers (including scientists, engineers, and technicians) is needed to address many issues, since documentation is often poor or non-existent. This problem should be overcome by making sure that the decision-making authority is shifted to those who do not have a personal interest in justifying or perpetuating the actions taken during the Cold War.

There are two levels of institutional reform needed. First, there are a number of measures that DOE can take to ensure that projects are properly conceived and implemented, and that lessons are learned throughout the weapons complex when projects fail. The second, far more difficult, is to create a new institutional framework that will detach remediation and waste management at closed sites (as well as long-term waste management) from the weapons culture that still permeates much of DOE.

a. Reforms within DOE

DOE should create an internal technical and financial project review structure for large projects as well as for smaller projects that may have application throughout the weapons complex. DOE could build on the model of the Technical Advisory Panel for Hanford tanks, which helped diagnose and create a remediation plan for reducing the risk of a hydrogen explosion in tank SY-101 and examined a number of other urgent issues relating to risk of fires and explosions. The features of this model should be strongly independent, empowered with adequate authority and responsibility, and composed of a relatively small number of highly-competent and publicly-accountable personnel to

ensure responsiveness and rigor. DOE should also create a standing advisory committee, under the Federal Advisory Committee Act, to review projects from early stages through implementation both as regards their technical aspects and the reasonableness of budgets from an engineering standpoint. The majority of members on this committee should be free of conflicts of interest with regard to contracting with DOE or its contractors.

DOE should also reinstate the practice of issuing annual Baseline Environmental Management Reports, and make them more complete. Specifically, DOE should include all sites, whether closed or operational, in this report. This would also be a good place to start to institute an internal peer review of the budgeting of environmental management projects and to make engineering-based estimation a standard part of the estimation of project costs.

b. Overall institutional reform of remediation and waste management

We do not have a definitive recommendation to offer on institutional reform, but alternatives for consideration, outlined below, each with its own strengths and weaknesses, as a starting point for intensive public debate. Our principal recommendation is that President Clinton appoint an independent commission on Institutional Reform of Environmental Remediation and Waste Management under the Federal Advisory Committee Act to hold hearings around the country and make definitive recommendations within a six- to twelve-month period.

We suggest the following alternatives be considered in reforming the environmental management program of DOE:

1. The EPA could be given the authority to carry out the remediation, with regulation by the Nuclear Regulatory Commission. This suffers from the disadvantage that it is the option most likely to result in a wholesale transfer of existing management structure to the new system with only a change of nameplates. Moreover, EPA now regulates the non-radioactive toxic aspects and some radioactive aspects of DOE programs. These would no longer be independently regulated if the EPA is the implementing authority. It may also create new funding uncertainties and jeopardize the program: most Environmental Management funding is part of the Congressional process for funding nuclear-related military expenditures. Overall, despite some strengths, this option appears to have too many weaknesses to be effective.

2. The affected states and Indian tribes could be given the authority and the money to remediate the weapons complex in their states, under national clean-up standards enforced by the Environmental Protection Agency, and mandatory guidelines for public participation. Contrary to the federal government, states and Indian tribes would have an interest in remediating contaminated sites and in minimizing the amount of land that is written off

because they would have use of this land. But provisions would have to be made that the money they are given is contingent on actually carrying out remediation according to national standards, enforced by federal agencies. While there are clear advantages to this approach there are also many weaknesses. The states may not have the staffing and expertise to do the job, nor the experience to oversee it. Moreover, politics at the state level may be even more vulnerable than federal-level politics to the influence of contracting corporations with deep pockets. Further, guaranteeing a flow of funds to the states, given the vicissitudes of federal politics, is also a huge problem. Finally, the issue of dispute resolution between states and Indian tribes may be become more difficult.

3. A federally-owned corporation, operating under strict public accountability and openness rules, could be created for the purpose of doing and/or subcontracting environmental remediation. In order to prevent the reform from being an exercise in a change of nameplates, a majority of the Board of Directors and top management of the corporation could be appointed by the governors of the affected states, with the rest being appointed by the President of the United States.

In all cases, we believe that a parallel restructuring of long-term waste management should be carried out, with research and development being the main priority at this stage, perhaps under the purview of the National Science Foundation, and long-term implementation being under the purview of a body similar to that mentioned in option 3. Overall, it appears that the last option may have the smallest number of weaknesses, provided a process exists to ensure openness as well as considerable control by affected states and Indian tribes. Finally, stringent, nationally-mandated, and independently-enforced remediation and waste management standards are crucial to the success of any institutional reform. Without them, public accountability and yardsticks by which to clearly measure environmental performance will be lacking.

5. Restructure Long-term Waste Management

The two repository programs that DOE is pursuing, the Waste Isolation Pilot Plant, in New Mexico and Yucca Mountain in Nevada, are obstacles to sound long-term waste management. DOE has put a high priority on WIPP because of politically expedient promises made to the states of Colorado and Idaho arising out of the fire at the Rocky Flats plant in 1969. However, WIPP cannot accommodate all the TRU waste in the weapons complex. Moreover, it is a site with many flaws (see Appendix B). Yet DOE is focusing most resources on it for political and legal reasons, while the urgent environmental problems fester. Buried TRU waste are affecting or threatening several of the country's vital groundwater resources, and in the case of Hanford, the Columbia River. The resources being poured into Yucca Mountain also arise out of unrealistic promises made to utilities that are being given a higher priority than any sense of addressing the immense, historically unprecedented problem of how we shall protect

generations tens of thousands of years into the future. Yucca Mountain is also a flawed site, and radiation doses to maximally exposed individuals are calculated to be high (see Appendix B.) Finally, the EPA standards for waste disposal at WIPP are not stringent enough since they do not limit maximum doses for the duration of the threat from the waste, but for an arbitrary period of 10,000 years, which is far shorter than the half-lives of important constituents of TRU waste such as plutonium-239 and neptunium-237. There are no EPA standards for Yucca Mountain.

Our detailed examination of the problem of buried TRU waste and TRU contaminated soil in this study and previous examination of the high-level waste that DOE now assumes will go to Yucca Mountain has led us to conclude that neither the long-term waste management problems nor the DOE environmental remediation program are likely to be put on a sound footing until the WIPP and Yucca Mountain projects are stopped. In addition, the problem of the long-term management of all highly radioactive, long-lived waste, independent of present classification status, must be separated from DOE and reorganized to put scientific investigation and environmental protection first.

Stabilization and storage of TRU waste and other long lived waste can proceed in a much more sound fashion if the DOE is not acting under a primarily political mandate to send TRU waste to WIPP and commercial spent fuel and vitrified high-level waste to Yucca Mountain. It will take some time to implement a thorough program of management of long-lived radioactive waste. Interim storage and long-term management need to be coordinated so long-term goals can be achieved without compromising safety.

Many fear that taking the time to structure a long-term program of research and development may result in DOE and commercial reactor sites becoming de facto sites for indefinite storage. That would be unacceptable both from a security and environmental point of view. A commitment to find enduring answers must accompany interim stabilization and interim on-site storage. The program for long-term management of long-lived radioactive waste should include:

1. A through integration of all waste containing substantial quantities of long-lived waste with concentrations above those which could produce radiation doses to maximally-exposed individuals above the limits for stringent remediation standards. This should include spent fuel, reprocessing waste, waste presently defined as Class C waste, Greater-than-Class-C waste, TRU waste, and depleted uranium, as well as much of what is now in the Class B waste category.
2. A scientifically sound program of research, including research into natural materials and formations that contain radioactive materials for millions of years;
3. A program of research into subseabed disposal;
4. Stabilization and interim on-site storage of waste;
5. A definition of "long-lived" radionuclides that includes all radionuclides with half-lives more than 10 years;

6. Scrapping present high-level waste repository and "low-level" waste shallow land burial programs.

Recommendations for TRU Waste Management

The vast majority of resources being spent on TRU waste management are being devoted to the development of the WIPP repository program. The waste slated to go to WIPP are the retrievably stored TRU waste. Of all TRU waste, this category poses the least risks to short- and medium-term health and the environment because waste packaging is relatively sound and the waste is stored in buildings or shelters of some sort.[628] Moreover, DOE plans treatment of this waste to further stabilize them and reduce the organic toxic component. DOE's focus on this waste does not arise out of environmental considerations but of political commitments, notably to the state of Idaho, that the waste would be moved to a repository. At the same time, buried TRU waste are the stepchild of the program, getting little attention.

Our case study of TRU waste shows that in Idaho and several other sites, such as Hanford, buried TRU waste and TRU contaminated soil pose far more urgent and severe risks to precious groundwater and surface water resources than retrievably stored TRU waste. We have found agreement about the relative gravity and urgency of these threats in private discussions with the DOE and even in one "on the record" discussion with Assistant Secretary for Environmental Management Alvin Alm, who acknowledged that political commitments were driving the program.[629] We do not believe that the risks this generation's activities will pose for children far into the future should be addressed by resort to political expediency. WIPP cannot accommodate most TRU waste, which are in the form of buried TRU waste and associated highly contaminated soil. At this stage it is far more important to take measures to protect water resources from further contamination and to remove and stabilize buried TRU waste and TRU soil. Moreover, the WIPP site as well as the regulations governing TRU disposal there are flawed. Thus a host of considerations point to stopping the WIPP program and redirecting scarce resources to where they are most needed -- preventing further damage from past practices and the creation of a sound long-term waste management program (discussed above).

Our main recommendations for TRU waste management are:

1. DOE should work with Congress and the affected states to stop the WIPP program and reorient the TRU management program to buried waste and TRU soil. Monitoring of retrievably-stored waste should be continued.

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[628] DOE has called a variety of TRU wastes "retrievably stored." It does not currently consider all of its "retrievably stored" waste to in fact, be readily retrievable. Also, some "retrievably stored" waste is currently being removed from dirt cover and being placed in covered buildings or shelters.
[629] IEER, 1997.

2. DOE should create an urgent program of estimating how much buried TRU waste there is along the lines of the Idaho Lab's effort, the only site that has attempted to review records in order to develop scientifically-defensible waste volume and radioactivity estimates. The overall effort could perhaps be modeled on the plutonium and uranium vulnerability studies.

3. DOE should abandon a strict distinction between the current TRU waste classification (100 nanocuries per gram) and waste with somewhat lower TRU concentrations (10 to 100 nanocuries per gram) and proceed to treat all waste associated with TRU burial areas as TRU waste, unless a there is a technically and economically defensible rationale to do otherwise.

4. DOE should examine the feasibility of excavating all buried TRU waste and associated soil (as defined in item 3 above) and storing it retrievably along with TRU waste that is already classified as "retrievably stored." Due to the existing soil and groundwater contamination caused by buried TRU waste, as well as the long half-lives of transuranic radionuclides, "institutional controls" and "caps" are especially inappropriate "solutions."

5. DOE should pursue a more technically-sound effort to develop safe retrieval technologies for TRU waste. Particular attention should be given to serious hazards that could affect worker safety and health, including explosives and highly-toxic materials that may be buried at some sites. DOE should continue to develop remote-excavation technology for those areas where there may be special risks, such as dangers of chemical explosions. We have not examined the remote excavation system at the Pit 9 project in sufficient detail to comment on its technical merits. (The treatment system has not been built.)

6. DOE should accelerate development of technology to reduce waste volume and treat the organic toxic component of the waste, which would mainly leave a radioactive waste and heavy metal disposal problem. It should integrate treatment of buried and retrievable TRU waste. For instance, it should integrate the treatment of excavated waste at Idaho with treatment of retrievably stored waste.

7. DOE should merge the TRU repository program and the high-level waste repository program into a single program, as discussed in the section on general recommendations.

Recommendations for Hanford High-Level Tank Management and Vadose Zone Remediation

DOE's approach to management of the Hanford high-level waste tanks and the vadose zone (the soil and rocks between the tanks and the groundwater table) exemplifies many of the problems that plague the entire environmental management program. It is based on the idea that Yucca Mountain will be the repository, though mounting evidence indicates that this is an inappropriate assumption. With that starting point, the plan is to reduce the amount of waste going to the repository, even if it greatly increases the volume of highly radioactive waste that is dumped on site. This waste, which is called "low-level" in the United States, would in other countries such as Britain or France, be designated for repository disposal. DOE is focusing on the tanks without a concomitant high priority to the highly-contaminated vadose zone (that is, the soil between the tanks and the groundwater table).

Further, DOE has not accounted for the cost of local dumping of highly-radioactive Class C waste. Were commercial low-level waste disposal costs to be attributed to Hanford low-level waste disposal, these costs would be of the same order of magnitude as those for repository disposal, especially if the waste created by filling the tanks with cement are taken into account.[630]

Moreover, DOE does not appear to be planning for the decommissioning of the tanks themselves. Rather, the plan appears to be to pour cement into the tanks after DOE meets the legal agreement to empty them of 99 percent of the waste. This Tri-Party Agreement goal is arbitrary and also scientifically and environmentally unsound. One percent of waste left behind in the tanks will possibly have millions of curies quantities of residual radioactivity. Further, the cementation of the tanks will greatly complicate any future attempts to remediate the vadose zone.

We have addressed in detail the flaws in the high-level waste repository program elsewhere and will not repeat them here.[631] We strongly urge that the current repository program be terminated. The restructuring of the Hanford tanks program, however, does not depend on the restructuring of the entire high-level waste management program. Even if the Yucca Mountain program were to proceed, there are strong, indeed, decisive arguments, in favor of treating the entire tank contents as high-level waste to be immobilized for repository disposal. Simply put, remediation of the site and protection of groundwater resources and the Columbia River over the long-term cannot be

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[630] Low-level waste disposal costs are in excess of $200 per cubic foot, up roughly a hundred fold from the costs two decades ago. DOE plans to create 350,000 cubic meters (more than 12 million cubic feet) of low-level wastes. Filling the tanks with cement would create another 500,000 cubic meters, for a total of almost 30 million cubic feet. The total imputed costs for low-level waste disposal at $200 per cubic foot would therefore be $6 billion.

[631] See Makhijani and Saleska, 1992 and IEER, 1997b. A part of IEER, 1997b is reproduced in Appendix B of this report.

accomplished unless the tank farms are decommissioned and the vadose zone substantially remediated.

As we have discussed in Chapter Three, 84 to 182 acres of repository space would be required if DOE's assumptions about total vitrified waste volume are correct. We estimate total repository disposal costs of $2 to 4.4 billion an overall disposal costs (excluding processing) of about $10 billion. This is $30 billion less than DOE's cost estimate for the same thing. We find DOE's cost estimate to be without clear technical foundation. The repository space requirements and costs could be reduced further through other high-level waste treatment options.

Vitrification (after preprocessing), however, is not the only alternative, nor necessarily the best one. Vitrification at Hanford seems to have been decided as an extension of the Savannah River Site program, where a high-level waste vitrification plant is in operation. DOE seems not to have learned the lessons of the huge cost overruns and delays of that program. The Savannah River program was deeply flawed by the absence of thorough pilot plant testing of all the processes required for successful waste vitrification. As a result, pretreatment of cesium-containing waste is still not operational. The $4 billion plant was supposed to go fully on line in 1989, but only vitrification of sludge has been initiated and even this portion did not begin until 1996. Further, only part of the sludge can be vitrified until other safety issues are resolved.

Hanford waste is far more complex in chemical composition and physical state than Savannah River Site waste. DOE has not paid enough attention to the huge technical issues facing satisfactory pretreatment or glass production. It does not appear to have assessed the failure of the Fernald silo waste vitrification pilot plant for any lessons it might hold for Hanford. Yet, it has already decided that vitrification of both the high-level and "low-level" components is the appropriate technology to pursue. If the Savannah River experience is any guide, the highly complex nature of Hanford waste is likely to pose severe technical and operation problems. DOE's approach of "privatizing" treatment for two tanks is a very inadequate basis on which to proceed with Hanford waste treatment.

Further, DOE's assumption that Hanford high-level waste glass will be of sufficiently uniform and controlled quality that will be qualified to be put into a repository is also questionable. Savannah River waste is far simpler than Hanford waste because Savannah River Site operated only one type of chemical reprocessing plant -- that based on the PUREX process. Hanford had several different reprocessing plants, and also added a variety of other materials to the waste, such as ferrocyanides. As a result the composition of Hanford glass may be quite different from that at Savannah River Site. Proceeding with vitrification of Hanford waste in the hasty fashion that DOE is will not only likely increase the technical difficulties, costs, and delays -- it may result in a failed program.

There is another approach to solidification of Hanford waste that DOE has rejected because waste solidified in this way would not be qualified for repository disposal. That approach is to heat the Hanford wastes and turn them into a powder form -- a process called calcining. While calcining Hanford waste will be far more difficult than similar processes carried out at Idaho and in France, and calcination process chemistry specific to Hanford waste will likely have to be worked out. Calcination it will result in greatly reduced and stable waste volume and one which is likely to be more compatible with either vitrification or immobilization in ceramics. Calcine can be stored without the same kind of serious short- and medium-term risks to the environment associated with the current form of tank waste. There is no need to assume that calcined waste forms would be put into a repository, as DOE has done in its Tank Waste Remediation System EIS.[632] Calcined waste can be immobilized at a later date with glass or with ceramics.

In sum, the Hanford tank program needs to be thoroughly revamped, including goals, technology development, milestones, contracting arrangements, accountability, cost estimates, and oversight. The Hanford tank program should shift from the present arbitrary goals to ones that are better suited to environmental protection, and to short- and long-term waste management and disposal.

Our recommendations for the Hanford high-level waste management program are based on the premise that it is essential to protect the groundwater resources and the Columbia River. *For this, the long-term goal must be to empty the tanks, to decommission them, and to remediate the vadose zone.* This will require many steps and a long-term commitment. Some of the technology remains to be developed. Considerable amounts of time and resources will be needed to remediate the tank farm areas. Given that a large program of technology development is needed, it is impossible to say at the present time to what extent a goal of remediation can be achieved and what restriction there may be on the area. But the principle that we have articulated in our general recommendation needs to be kept in mind. While it may not be possible to meet stringent standards for remediation today in all cases, present actions should not foreclose or make far more difficult actions that may be taken in the future.

We are reasonably convinced that DOE is on a needlessly risky course. Given the complexity of the problem and our limited resources, we can only make preliminary recommendations that DOE and the Technical Advisory Panel on Hanford tanks, as well as the EPA and the State of Washington, should evaluate thoroughly. Our suggested approach has the following elements:

1. DOE should continue the transfer of the liquids in single shell tanks to the double shell tanks with far greater attention to safety issues. Specifically,
   - Sampling of all ferrocyanide tanks should be completed and these tanks should continue to be monitored.

[632] See discussion of the calcination option in DOE Richland, 1996b, pages 3-72 to 3-78.

- DOE should re-evaluate the criticality safety issues for sludges as they presently lie in the tanks and re-institute this as a safety priority.
- Assessment of dangers from organics in the tanks should be given more urgent consideration.
- Chemical and radiological criteria for declaring the tanks to be "interim stabilized" should be established, especially in view of the presence of explosive materials and the potential for tanks without water to increase in temperature.

2. DOE should abandon the plan to dispose of Class C "low-level" waste on site and adopt a goal to process all high-level waste tank contents for management as high-level waste.

3. The Tri-Party Agreement should be amended to discard the 99 percent retrieval goal and replace it with two sets of goals.[633] The long-term goals should be to empty the tanks entirely, decommission them, and remediate the vadose zone. The interim goals should be (i) stop all leaks, (ii) stabilize the single shell tanks and ensure the safety of the hardened waste remaining in them, and (iii) ensure the safety of the double-shell tanks, especially with regard to the compatibility of any waste transferred to them.

4. In light of investigations into contamination of the vadose zone (e.g., the SX Tank Farm report), groundwater models need to be thoroughly revamped. Further, decisions regarding remediation of the environmental contamination due to the tank farms should be integrated with the tank waste program. DOE should greatly expand its program to characterize the vadose zone and the migration of contamination within it to the groundwater and thence to the Columbia River.

5. DOE should expand its program of technological research and development into safely emptying the tanks of hardened waste.

6. DOE should initiate two parallel programs for solidification of high-level waste. One program should develop methods for calcining the high-level waste coupled with research into ceramic immobilization forms for calcined waste. This program should be implemented along with a program of vitrification research and development for calcined waste forms. The second should pursue the development of pretreatment and specific glass-making approaches that would not require calcining.

7. In all three areas of solidification specific to Hanford waste -- calcining, vitrification, and ceramic immobilization -- DOE should immediately expand existing laboratory work and initiate small pilot-plant programs that would thoroughly test all technologies and waste forms using non-radioactive materials. A considerable body of work has already been done in various contexts and DOE should draw upon it in

[633] We wish to emphasize that we are not recommending that the Tri-Party Agreement be abandoned; only that the 99 percent goal be amended as discussed.

designing the Hanford program. But much more work remains to be done that is specific to Hanford tanks, including development of retrieval and pretreatment technologies as well as immobilization processes that will be compatible with a long-term waste management program.

8. DOE should accelerate its efforts aimed at characterizing inactive and improperly abandoned tanks and the soil around them.

9. Auxiliary facilities such as transfer pipelines, junction boxes, and pumps need to be investigated to determine the extent of contamination and the scope of decontamination and decommissioning.

10. DOE should not pursue "privatization" for Hanford tanks. It is fraught with risks for the government and likely to create new problems, disputes, and delays. At the very least, a thorough analysis and wide public debate of the failing "privatized" Pit 9 project in Idaho should be mandated before any other significant environmental remediation or waste management program work is "privatized" -- let alone the largest, most complicated and unprecedented work in the DOE weapons complex.

Recommendations for Fernald's Radium- and Thorium-Contaminated Silos

The management and technical flaws in the vitrification program for the radium-contaminated waste at Fernald have not only increased costs and uncertainties, they have exacerbated specific short-term threats to workers and communities nearby. The short-term measure taken to reduce radon emission, the addition of a layer of bentonite clay to Silos 1 and 2, is failing and radon levels in the headspace of the silos are rising. Addition of bentonite has also complicated and made more expensive long-term remediation efforts and it did not address roof integrity problems. At the same time, delays are exacerbating the possibility of a silo roof collapse. Such a possibility would increase radon emissions and create a far more dangerous situation for remediation.

To address this problem, DOE appears to be again resorting to an approach that has failed time and again -- rush into a "new "solution" without adequate preparation. Given the past record, this approach may not solve the long-term problem and does not address the dangers arising from the delays that have already occurred. In view of the delays that have already occurred, the large slippage in schedule for completion of silo remediation, the major uncertainties facing the project, and the rising levels of radon, DOE should implement the tornado-resistant enclosure option. Its cost is small compared to cost escalations that have already occurred. Had it been done earlier, it would have been the one demonstrable achievement of the remediation program for the silos. This will not prevent a collapse of the roof, of course, but it will address the main dangers that would arise from it.

Our main recommendations for the radium- and thorium-contaminated waste at Fernald are:

1. The entire remediation program for the silos needs to be put on a sound financial and technical footing in order to implement the Record of Decision. Given prior egregious misestimations and escalation and the fact that the project now is estimated to involve hundreds of millions of dollars, a thorough independent review of both accounting and engineering aspects needs to be carried out before any cost increases are granted.

2. The waste in all three silos should be more thoroughly characterized. Development of vitrification techniques for the waste in Silos 1 and 2 should proceed along a focused, targeted effort in the 1-2 year time frame. Specifically,

    - further work should be done using several small experimental melters to address the feasibility, processing rate, and economics of treating the mixture of sulfates and lead in Silos 1 and 2;
    - a careful review of Oak Ridge National Laboratory's experience with developing a melter that handles molten lead might be useful in designing Silo 1 and 2 vitrification;
    - stirred glass melters and cold crucible melters should be evaluated for their ability to address surface layer problems and high temperature problems;
    - greater efforts need to be made to incorporate European experience and the experience in the rest of the DOE in experimental and design phases of the project;

3. Vitrification of Silo 3 waste, the remedy selected in the Record of Decision, should be placed ahead of any other technical approaches to stabilization of Silo 3 waste. A decision to change treatment of the waste in Silo 3 should be taken only after sufficient experimentation and evaluation of Silo 3 vitrification has been carried out.

4. A modular approach to vitrification, which would allow for operating flexibility in order to treat a potentially heterogeneous waste feed, is advisable.

5. DOE should not rush into alternative treatments, such as cementation, given DOE's own evaluation of problems and difficulties with such technologies.

6. "Privatization" is not an appropriate contracting mechanism for the remediation of the waste in the silos. Privatization would reduce the ability of DOE to oversee the contractor and might result in less accountability to regulators and the public (see the Pit 9 discussion in the TRU case study).

7. The demonstration of vitrification as a viable technology for radioactive waste is an important goal for the rest of the DOE complex. Demonstration of the ability to treat the radioactive and hazardous waste in the silos by vitrification is important to dealing with the vast environmental legacy of nuclear weapons production. Many sites across the United States, as well as other countries, have waste that needs to be treated to reduce their mobility in the environment and the health and environmental hazards that they pose. Some of the waste may be candidates for treatment by vitrification.

8. To address the contingency that vitrification may be found to be inappropriate after further experimental and pilot program work, DOE should also research other approaches that would simultaneously reduce waste volume, toxicity, and mobility to levels that are comparable to or better than those anticipated for vitrification.

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Appendix A: Clean-up Standards

The DOE is now operating the largest environmental remediation program without any overall clean-up standards. It has been operating under ad hoc self-promulgated rules, that can change from site to site and job to job. In December 1996, the DOE derailed a process by which the EPA was setting up clean-up standards for the nuclear weapons complex. A brief letter from the Assistant Administrator of the EPA simply announced that a process in which so much time, public energy, and environmental hope and been invested would be abandoned, without any plans for its resumption.

There are not even EPA standards for low-level waste disposal. DOE has opposed their promulgation since the late 1980s. DOE's self-regulation and *ad hoc* approach to environmental management is not an appropriate way to manage a program that spends $5 to 6 billion per year of taxpayer money. As is demonstrated by the case studies in this report and much other evidence, the return on this money has been very low indeed. It is routine for projects to go wrong, be delayed by long time periods, and to be repeatedly over budget. Not all of these ills can be cured or even addressed by clean-up standards.

In 1993, the US Nuclear Regulatory Commission (NRC) and EPA embarked on a process to create consistent national decommissioning and clean-up standards that would apply to the whole nuclear industry, and indeed to all industries that were creating radioactive pollution. The idea was to have rational, consistent, and, hopefully, conservative standards for remediation of contaminated sites and for protecting future generations from today's contamination problems. Simultaneously, the EPA also began to create standards for radioactive waste disposal for those wastes not previously covered by regulations. This process has fallen apart. The EPA has abandoned the effort to create standards, though it reserves the right to begin the process again. EPA's letter to this effect is attached at the end of this report.

For now, DOE is proceeding on an ad hoc basis. For example, at the Rocky Flats site, DOE has proposed 'Soil Action Levels' that would result in a dose for a residential land use scenario of 85 millirem per year. The Rocky Flats Citizens Advisory Board has asked for an independent, unbiased, and scientifically-based review of this proposal. The Advisory Board notes the inappropriate way in which DOE is proceeding:

> The Rocky Flats Citizens Advisory Board, in its recommendations on the Soil Action Levels, stressed the need to have national standards in place before setting site-specific standards at Rocky Flats. The Soil Action Levels at Rocky Flats now set a precedent for the rest of the country. We do not feel that this is the proper manner in which to set a national standard.[634]

[634] Marshall, 1997.

In May 1997, the NRC approved regulations that could in time apply to DOE sites. (A Working Group appointed by former Secretary of Energy Hazel O'Leary recommended in December 1996 that DOE self-regulation be ended and the NRC one of the external agencies to take over regulate the DOE over a period of time.)[635]

The deficiencies in the new NRC decommissioning rules are particularly troublesome as they come in the context of the DOE having pressured the EPA into abandoning the process for certain rules that would apply to the DOE. While the EPA has formally retained the option of resuming the process of setting the rules. absent a real push for them from outside the both the EPA and the DOE, there is little prospect that the EPA will exercise that prerogative. Thus the NRC rules are likely to become one non-binding guide for the DOE as it proceeds with its environmental management program.

We are providing here a detailed analysis of the NRC rule in order to (i) help the EPA do better in its own rule, (ii) assist the NRC in rethinking the parts of the rule that poorly serve future generations) and (iii) help the DOE design guidelines consistent with sound clean-up regulations, should they ever be developed by the EPA. In what follows, for purposes of analyzing the NRC rule we will use the terms "license termination" by the NRC and "completion of clean-up" by the DOE equivalently.

The NRC regulations are deficient on a number of grounds.

1. They neglect to consider issues central to risk minimization. Specifically, they do not integrate cancer risks from non-radioactive and radioactive hazardous materials. Methods for coordination of decommissioning with the EPA (which has responsibility for limiting exposure to non-radioactive materials) are not established within the rule. There are no mechanisms to ensure that adequate financial resources will be available to meet both NRC requirements for radioactive components while also complying with EPA requirements on toxic materials. The regulations also do not give due consideration to non-cancer risks, especially from non-radioactive hazardous materials.

2. The regulations also ignore a position generally agreed upon by the committee on radiation clean-up standards of the National Advisory Committee on Environmental Policy and Technology of the EPA that risks from waste disposal be considered together with those from residual radioactivity.

3. The requirement that doses should be kept as low as reasonably achievable (ALARA) has no numerical guideline incorporated within the regulation itself.

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[635] DOE, 1996f. The implementation of the recommendations of the Working Group in regard to external regulation by the NRC would require new legislation to be passed by Congress and singed into law by the President.

This is an unacceptable relaxation of well-established norms in the nuclear industry in the United States and elsewhere.

4. The exposure limits are too high. The limit of 25 millirem per year with a suggested 'as low as reasonably achievable' (ALARA) dose of 3 millirem per year are, for instance, above the corresponding British limits of 10 millirem and 2 millirem. There is no explicit requirement for remediation to background when this is technically and economically achievable.

5. The regulations do not require as a condition of license termination that the licensee make public all relevant documents about environmental releases and contamination that occurred during the period of facility operation and the period of decommissioning. Since the cancer and other adverse health risks from future exposure add to risks from past exposure, it is imperative that all documents relating to past and potential future exposures be made public as a part of license termination.

6. The regulations do not require licensees to establish a fund for environmental monitoring and public education whenever there is residual radioactivity at the time of license termination if this residual would produce doses lower than the maximum limits. So long as doses are in addition to natural background, there must be a fund for monitoring and public education. The rule only requires a fund be established in case the limits of the rule cannot be met. This is grossly inadequate.

7. The rule is unacceptable because it does not require strict compliance with the 40 CFR Part 141 standards for protection of groundwater supplies. It is simply insufficient to say only that the "licensee shall demonstrate a reasonable expectation that residual radioactivity" will not violate drinking water standards from groundwater.

We recommend that the following changes be made at a minimum to the decommissioning standards and that DOE adopt the approach that we outline below:

- For each facility explicit technical and economic analysis of remediation to background should be mandated by the rule in order to assure compliance with the ALARA standard.
- A guideline of a cancer risk of one in a million per year should be set under the rule of keeping exposures ALARA. This limit should include all cancer risks from residual radioactivity, residual carcinogenic non-radioactive materials, and on-site waste disposal. If contamination is due to radionuclides alone, then the annual radiation dose corresponding to this risk would be about 2 millirem per year. This is the ALARA level in British standards. Chemicals known to pose non-cancer risk, such as risk of damage to the reproductive system, should

be explicitly listed in the regulations as being of special additional concern. Specific plans should be required to eliminate such risks to the extent technically feasible as part of decommissioning activities.

- All plant documents relating to health and environmental issues from the licensees' (or DOE's) operations as well as from decommissioning activities should be required to be made public prior to license (or DOE remediation) termination.
- A fund for environmental monitoring and community education controlled by the community (for example by the local government) should be required in all cases where there is demonstrable residual contamination above background, even if such contamination corresponds to levels that are below maximum limits for set for unrestricted use of the site after decommissioning is complete. This will put in place a mechanism to detect problems such as unexpected migration of residual radioactivity or chemicals. NRC technical resources and staff should remain available to the community after license termination in all cases when there is residual contamination.
- Compliance with protection of groundwater supplies as specified in 40 CFR Part 141 should be required as a condition of license termination. We believe that the NRC does not have the authority to waive the standards of other governmental agencies.

We will now consider some of these points in more detail.

A. Risk Minimization

Both the NRC and DOE have "the statutory responsibility for protection of health and safety related to the use of source, by-product and special nuclear material under the Atomic Energy Act." (Emphasis added.) The NRC has neglected this responsibility in the radiological criteria for decommissioning. Specifically, the NRC criteria are deficient in three broad areas:

- Overall risk minimization from radioactive as well as non-radioactive materials is not addressed;.
- The risks associated with management of wastes from decommissioned facilities (waste disposal, on-site stabilization and possible recycle of materials) are not integrated with those from residual radioactivity.
- Non-cancer risks from residual toxic materials (radioactive and non-radioactive) are not evaluated.

1. Non-radioactive Hazardous Materials

Hazardous non-radioactive materials are an integral part of many operations associated with licensed activities at nuclear fuel-cycle facilities, such as at uranium hexafluoride plants, uranium enrichment plants, and uranium mill facilities. In such

cases, the protection of health and safety related to use of NRC licensed material necessarily involves non-radioactive hazardous materials that are required for processing the nuclear materials. While we recognize that non-radioactive materials are regulated under laws other than the Atomic Energy Act, the NRC has stated that the development of the decommissioning criteria is being done in collaboration with the Environmental Protection Agency. Since the EPA has the responsibility for health and environmental protection for these non-radioactive constituents, it is a glaring lapse that the NRC proposed regulations only addresses this issue in a cursory manner. In particular the NRC "has refrained from extending its reach to address non-radiological hazards."[636] While we appreciate the jurisdictional issues, it is incumbent upon the NRC to address the problem of coordinating with the EPA the responsibility for the remediation of NRC-licensed facilities.

By not clearly defining how the responsibility for oversight of decommissioning will be shared and coordinated at those NRC sites contaminated with non-radioactive hazardous materials, the NRC has not produced a rule that will result in "protection of health and safety related to the use of source, by-product and special nuclear material." In particular, the rule does not require that termination of the NRC license be dependent upon the licensee fulfilling other regulatory agencies' obligations.

The interactions between the NRC and EPA during decommissioning have not been carefully defined in the rule. This is likely to result in costs and risks to workers and communities in excess of what could be achieved with well coordinated efforts. For instance, the presence of solvents can increase the mobility of radionuclides, and hence the dose from a given level of contamination.

The Generic Environmental Impact Statement (GEIS) associated with the NRC rule is fundamentally deficient since it omits serious consideration of non-radioactive hazardous pollutants. The question of adequacy of funds for decommissioning is another crucial issue that is not considered, even though resources are needed for dealing with both radioactive and non-radioactive contamination. Further, resources will be wasted if separate characterization plans are prepared for the two types of pollutants. A single characterization and decommissioning plan, fully funded, with clear risk minimization goals must be a basic provision in the NRC's regulations. An explicit method for coordinating the work of the NRC and EPA must be a part of the rule. If not, a waste of scarce resources, poor remediation, unnecessarily large residual risks, and inadequately funded clean-up are likely to be an outcome at many sites.

The NRC's general statement that it would "require that the licensee, when determining ALARA for a specific decommissioning, consider all significant radiological and non-radiological risks resulting from residual radioactivity and from the decommissioning process itself (including transportation and disposal of radioactive

[636] 58 Fed. Reg. at 43204.

wastes generated in the process)"[637] is insufficient, especially since the NRC itself has neglected to fully consider waste disposal options in its GEIS.

One example of the inadequacy of the regulatory framework for decommissioning is provided by the proposed decommissioning of the uranium hexafluoride plant near Gore, Oklahoma owned by the Sequoyah Fuels Corporation (SFC). The uncoordinated regulation of decommissioning of the same facility by the EPA and NRC is adding to the uncertainty as to what sort of decommissioning will be accomplished at SFC. For example, SFC has committed to the EPA to pay for chemical waste remediation with the same inadequate source of funds that has already been committed to the NRC for radioactive waste remediation. As a result, neither agency seems to have an accurate picture of the true cost of remediation or of the likelihood that adequate resources will be available to complete the decommissioning.

In the context of this example, it is curious to note that the NRC has made inconsistent use of reference facilities. The reference facility for the uranium hexafluoride facility used in the GEIS is Kerr McGee (Sequoyah Fuels) plant, yet a different type of facility (Portsmouth gaseous diffusion facility) is used to describe the soil contamination.[638] While the Portsmouth facility did manufacture UF_6, it only did so for a limited time. Since the processes and materials used are different at these two types of facilities it is not appropriate to use a gaseous diffusion facility as a reference facility for soil contamination at a uranium hexafluoride conversion facility. The use of Portsmouth as reference facility for soil contamination is especially misleading since UF_6 and UO_2F_2 are soluble, while intermediate and raw material materials at SFC (UO_2 and U_3O_8) are not.

In sum, the NRC rule does not:

- make explicit provision for minimizing overall risks from all residual contamination;
- properly coordinate decommissioning with the EPA;
- ensure that licensees meet all obligations for site clean-up prior to license termination, including provision of funds needed for non-radioactive contamination removal.

We suggest that an ALARA guideline for overall cancer risk from residual contamination as well as on site waste disposal be 1 in a million per year.

2. Waste Management and Decommissioning

Health and environmental effects and costs arising from management of contaminated materials and from waste disposal could be a large part of decommissioning impacts in many cases. But the NRC has largely punted on this issue.

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[637] 59 Fed. Reg. at 43208.
[638] NUREG-1496, volume 2, pages C.4.10 and C.5.19.

For instance, the NRC states that it will "consider separately the issues of how to deal with cases where the licensee proposes to release material containing residual radioactivity intentionally for reuse or recycle." Further, until it promulgates a comprehensive policy in this regard, the NRC proposes to "continue to review these actions on a case-by-case basis." The NRC has stated the "costs and impacts associated with recycle of such material can be addressed on a separate basis without affecting the NEPA analysis of this GEIS."[639] We find this statement to be too sweeping and without proper supporting evidence. The EPA is also separately considering the issue of recycling contaminated metals though it has abandoned the pursuit of clean-up standards.

One important purpose of issuing regulations for decommissioning is to stop doing things on a case-by-case basis. Such an approach to recycle of contaminated materials would result in the *de facto* institutionalization of a policy without any formal regulatory proceedings. It would also condone DOE's current practice of releasing contaminated materials, which is now happening without external oversight. Even worse, previous NRC efforts to allow the release of certain contaminated materials into waste streams as being "below regulatory concern" (BRC) were roundly rejected by the public and eventually abandoned by the NRC itself. This back door way of re-introducing the concept of BRC is unacceptable. Explicit discussion of the impacts of recycle of materials must be part of the decommissioning rule.

The GEIS also did not consider the impacts of on-site disposal of decommissioning wastes. The Commission contemplates that on-site stabilization and disposal at "several existing licensed sites (no more than a few tens)"[640] will be the most protective decommissioning option for these sites. Since the NRC did not evaluate the environmental impact of this option in the GEIS, it has not demonstrated that this conclusion has an adequate foundation or indeed is warranted at all.

The NRC should provide specific examples of real facilities where it considers on-site disposal to be the most desirable option. In its evaluation the NRC should clearly demonstrate what it considers a "comprehensive analysis of risks and benefits of all viable alternatives including remediation of the site."[641] The estimate of dose to the critical group should include that from residual contamination and from on-site waste.

The waste disposal implications of delayed decommissioning are also not addressed in the rule. For instance, in the case of sites predominantly contaminated with short-lived radioisotopes, the risks associated with remediation might be substantially reduced by delaying decommissioning enough to allow for radioactive decay. In other instances, delaying certain aspects of decommissioning could increase risks, for instance, by allowing contamination to spread in groundwater. Evaluation of the risks and

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[639] Ibid, volume 2, page E-15.
[640] 59 Fed. Reg. at 43217.
[641] 59 Fed. Reg. at 43217.

benefits of decommissioning in phases should be required in the rule as part of the preparation of decommissioning plans for all facilities.

c. Non-cancer Risks from Residual Toxic Materials

Both non-radioactive and radioactive chemical contaminants involve non-cancer risks which need to be taken into account. For instance, uranium is toxic to the kidney as a heavy metal. Exposure to radioactivity can cause genetic defects. Some non-radioactive toxic materials cause reproductive damage. More broadly, these is accumulating evidence certain kinds of chemicals such as PCBs, known as endocrine disrupters, may pose risks that are greater and more varied than the cancer risks of these same chemicals. Some of these chemicals are contaminants at DOE facilities. There may also be synergisms between radioactive and non-radioactive materials. If there is a lack of sufficient knowledge about some of these effects for certain chemicals, as happens to be the case, then the regulations must explicitly acknowledge this uncertainty and be appropriately conservative as regards the potential exposure limits.

B. ALARA requirements

The NRC claims that the objective of the radiological criteria for decommissioning is to reduce residual radioactivity so that the concentration of each radionuclide that could contribute to residual radioactivity is indistinguishable from the background concentration for that radionuclide. We share this objective. But the NRC has not laid out a rule that would achieve it.

Specifically, a guideline for ALARA dose limit is not incorporated in the rule; rather it is mentioned in the accompanying guidance documents that are not a part of the rule. This leaves open the real possibility that the maximum dose limit of 25 millirem will in practice be treated as an ALARA guideline as well. This would be most inappropriate.

The pre-draft rule had an ALARA guideline of 3 millirem per year within the rule. We believe that a quantitative ALARA guideline should be specified within the rule itself. We do not agree with the reasoning that states that the variation in natural background dose is equal to or greater than 3 millirem/year to a member of the critical group and that therefore a specific dose limit should not be provided as an ALARA guideline.

Doses from contamination due to man-made radionuclides such as cesium-137 and other fission products, as well as transuranic elements such as plutonium-239 can be estimated to levels less than 3 mrem/year. It is noteworthy that doses from fallout deposition of such isotopes are, in general, currently below levels that would produce individual doses of 3 millirem per year.

Doses due natural radionuclides, such as isotopes of uranium, can also often be calculated to within 3 mrem/year or less. The calculation of doses from man-made contamination from these radionuclides depends on determination of their natural background levels. Using sensitive means of detection and analytical procedures such as measurement of ratios of uranium-238 to its decay products thorium-230 and radium-226, one can often separate natural background levels of uranium-238 to within 1 picocurie per gram, sometimes even less. A blanket elimination of a quantitative ALARA goal is technically insupportable and poor policy from the point of view of public health protection.

The NRC should reinstate a quantitative ALARA guideline in the rule. We suggest that this guideline should be 2 millirem per year, in cases where there is no contamination with non-radioactive hazardous materials. This corresponds to a risk of fatal cancer of slightly less than in one in a million per year.[642] It is also the British ALARA guideline. The ALARA guideline should be lower when there are additional risks from residual non-radioactive hazardous materials. Explicit provision also should be made in the rule for evaluating the risks, costs, and benefits of remediation below such ALARA guidelines all the way to background. Such remediation should be carried out in cases where it is environmentally appropriate and technically feasible to do so, and would not impose economic burden greatly in excess of meeting and ALARA limit of 2 millirem dose per year. A provision can be included in the rule for cases where detection problems make such goals impossible to achieve, but the burden of proof should be on the licensee.

C. Fund for Environmental Monitoring

Whenever there is demonstrable residual contamination, including those cases where decommissioning criteria have been met, the communities have the right to be empowered enough to continually monitor and evaluate their situation. Uncertainties in characterization of contamination, calculations of doses, health effects of many chemicals, and synergistic effects of radioactive and non-radioactive materials are so great that communities need a means to be able to monitor their situation after license termination. Further, there was in many or most instances no substantial disclosure of these long-term risks to communities in an accessible public participation process when these plants were built. The historical promotion of nuclear industrial activities at the expense of health and environmental protection, especially in the first quarter of a century after World War II, has created widespread distrust of the nuclear industry and even of regulatory agencies. Community empowerment after license termination, or in the case of DOE, after "clean-up" is declared to be complete, is essential both as practical environmental safeguard and as a policy measure to rebuild trust between regulatory

[642] This risk calculation uses the risk factors for fatal cancers in BEIR V with a dose rate reduction factor of 2 -- that is it assumes, as is common in regulatory practice that low doses delivered at low rates are a factor of two less harmful than the same overall doses delivered suddenly.

institutions and communities. In cases of residual contamination, DOE should provide the community with the resources to:

- evaluate past contamination and exposures;
- perform continuing environmental monitoring;
- disseminate information and documents about monitoring results, past exposures and contamination;
- perform community education about the interpretation of monitoring results, documents, and analyses.

Creating such a fund should be an essential part of the process of terminating the clean-up. The size of the fund could depend on the size and character of the residual radioactive and non-radioactive hazardous contamination of land, remaining structures, surface waters, river beds, and groundwater, as well as the total amount of radioactivity and non-radioactive hazardous material left in disposal areas on site. This fund part of the financial assurance requirements for decommissioning. In no event should the licensee have any direct or indirect control of, or interest in, such a fund.

Further, the NRC and DOE should make their technical resources, including staff, available to communities after license (or clean-up) termination in all cases where there is residual radioactivity.

Appendix B: Waste Classification System

The waste created by nuclear production activities present many special hazards. Some radioactive wastes emit radiation that can penetrate storage canisters and require remote handling operations. Some wastes are radioactive for hundreds of thousands of years. Some wastes contain hazardous chemicals and toxic metals. Often, particular wastes contain a mixture of these types of contaminants.

The major waste classifications in the US and their regulatory status are described in the table below. Some of the fundamental inadequacies of the present environmental remediation, management, and disposal of waste resulting from nuclear production activities stem from the confused and incomplete regulatory structure shown in Table 41.

Table 41: Regulatory Status of Waste Generated in the US Nuclear Fuel Cycle

TYPE OF WASTE	CHARACTERISTICS	REGULATORY STATUS	COMMENTS
High-Level Waste			
Spent Nuclear Fuel	Consists of irradiated fuel rods discharged from a reactor. Includes fuel from DOE reactors and commercial power reactors. Total weight = 34,600 metric tons of initial heavy metal for DOE and commercial spent fuel. Contains over 95% of all the radioactivity in current nuclear waste inventory.	- storage: NRC - disposal: NRC technical regulations; EPA regulations for all repositories except Yucca Mountain	
Reprocessing Waste	Supernate, sludge, "salt cake," and some vitrified waste. Almost all wastes from chemical separation (reprocessing) of spent nuclear fuel for military plutonium. Contains about 3% of all the radioactivity in current nuclear waste inventory.	- DOE: self-regulation - long-term regulations as above	
Low-level Waste			
Class A	Booties, gloves, some medical waste, etc. May contain some long-lived radionuclides.	- A, B, C, GTCC classification applies to NRC licensees - DOE has own classification system - EPA effort to regulate has been abandoned.	Shallow land burial allowed. Can contain short-lived and long-lived radionuclides.
Class B	Reactor filter resins, etc. Some waste has high radiation levels. May contain some long-lived radionuclides.		
Class C	Irradiated reactor parts, some instruments, etc. Very radioactive.		
Greater than Class C	The most radioactive irradiated reactor parts and some instruments.		DOE is supposed to dispose of GTCC in a repository, according to the NRC, but DOE has no repository to take it and no active plans to do so.

TYPE OF WASTE	CHARACTERISTICS	REGULATORY STATUS	COMMENTS
Mixed Low-Level Waste	Generated mainly from nuclear weapons production; includes organic and inorganic toxics, heavy metals, and radioactive materials.	- DOE: Federal Facilities Compliance Act, agreements with states; RCRA - NRC licensees: NRC for radioactive portion; RCRA for non-radioactive portion	Management of toxics can complicate management of radionuclides.
Transuranic waste (TRU waste)	Exists in many forms and contains a broad spectrum or hazardous chemical constituents. Largest volumes from reprocessing, weapons component fabrication, research, development, and testing	- DOE: self-regulation - some EPA regulations apply for mixed TRU -EPA standards for TRU repository disposal	Repository slated for New Mexico (Waste Isolation Pilot Plant) but problems confront it. Two-thirds of characterized waste is mixed TRU waste.
Uranium mill tailings and 'byproduct' (11e2) material	Large volume; includes radium-226, thorium-230, and toxic heavy metals such as arsenic, molybdenum, vanadium, etc.	- Uranium Mill Tailings Remediation Act - Uranium Mill Tailings Radiation Control Act	200 to 1,000 yr. regulation time far less than 75,000 yr. half-life of thorium-230. Institutional control assumed after 1,000 years
Depleted uranium	By-product of uranium enrichment; radioactivity levels from alpha radiation similar to TRU waste.	- not yet formally classified as a waste. - DOE considering regs. - NRC regulates minor quantities	95.2% of depleted uranium stocks are in depleted uranium hexafluoride chemical form
Naturally Occurring Radioactive Material (NORM)	Large volume; includes radioactive waste from mining and refining of non-radioactive materials, such as copper; includes many radium-contaminated oil fields.	- mostly unregulated - some state regulations	EPA was considering regulations but effort was abandoned.
Uranium mine waste	Large volume, comparable to mill tailings; part of NORM wastes.	- unregulated	
Decommissioning and remediation waste	Structural components contaminated in varying degrees, contaminated soil, etc.	- NRC has published regulations - DOE has *ad hoc* approach	Large volume, and growing

DOE: Department of Energy
EPA: Environmental Protection Agency
NRC: Nuclear Regulatory Commission
RCRA: Resource Conservation and Recovery Act

The problem of environmental management of sites contaminated by nuclear weapons production and testing has two long-term components affecting health and the environment:

1. The standards for individual site remediation, which determine how clean the site will be, and which may restrict the kinds of uses to which the land and underlying water may be put in the future.
2. The way in which long-lived radioactive and hazardous wastes (some of which may be produced by remediation activities) are managed, which limits land and water use in disposal areas, if shallow and deep land disposal are the ways chosen for management.

The term remediation addresses only the first of these two: the digging and scraping of dirt, the dismantling and removal of contaminated equipment and buildings, or the extraction of groundwater (when possible). But these questions do not address the question of waste management and disposal: what to do with the radioactive, hazardous, and mixed wastes that have been created by weapons production and that will be generated by remediation activities? Seen from the perspective of radioactive wastes, there really is no "clean-up" of the complex as a whole (in the sense that the waste is ultimately gotten rid of). Rather, the problem gets transformed into long-term waste management -- containment of the Cold War mess.

A principal connection between these two aspects of environmental management is that if the wastes are not managed properly in the short-term, they will wind up as the environmental problems of the future. Some of the most serious remediation and waste management issues of today -- such as the Hanford, Washington high-level radioactive waste tanks, the West Valley, New York dumps, the Maxey Flats, Kentucky low-level waste dump, and uranium mill tailing sites -- are the result of past irresponsible waste management and disposal practices dominated by short-term expediency.

IEER's 1992 study, *High-Level Dollars, Low-Level Sense,* examined DOE's approach to waste management. Four key findings of that report are discussed below.[643]

1. Radioactive waste is inappropriately defined.

Classification of radioactive wastes in the United States is fundamentally flawed in that waste categories are based on the origin of the waste, not on the physical or chemical properties that determine the hazards of the waste, and hence its safe and proper management. For example, "high-level waste" is defined as irradiated fuel from commercial nuclear power plants, or waste resulting from reprocessing.[644] "Low-level

[643] IEER, 1992.

[644] Reprocessing is the chemical treatment of irradiated reactor fuel to separate it into its constituent parts: plutonium, uranium, and fission products. It was used throughout the Cold War primarily to recover plutonium for use in nuclear weapons.

waste" is a catch-all category, defined as any waste that is not high-level waste, transuranic waste, or uranium mill tailings.

A major problem of this classification system is that it does not systematically take into account actual radioactivity levels of waste either overall or per unit volume. Examples are shown in Table 42. Thus, so-called "low-level waste" can contain materials more radioactive than those classified as "high-level waste." For example, the radioactivity in the most radioactive portion of commercial low-level wastes (300 curies per cubic foot[645]) is actually three times more radioactive than the average radioactivity in high-level wastes from nuclear weapons production activities.

Table 42: Radioactivity Content of Various Waste Classifications

Waste Characteristics		
	Average Concentration (curies/ft^3)	Selected Samples (curies/ft^3)
Low-Level Waste		
Class A	0.1	
Class B	2	4.4 (Cintichem facility, New York)
Class C	7	160 (average waste from commercial reactors in New York)
Greater-than-C	300 to 2,500*	
Transuranic Waste		
Contact-handled	0.57	
Remote-handled	47	
Military High-Level Waste	100	3.7 (Hanford salt cake) 920 (SRS sludge) 7,110 (SRS glass, projected)
Commercial Spent Fuel	73,650**	

* The 300 figure is based on the 1985 inventory. The higher figure represents anticipated inventory in 2020, including some decommissioning wastes.
** Based on average activity in all spent fuel at the end of 1989 and on overall fuel assembly dimensions.

Source: IEER, 1992, page 26.

[645] A curie is a unit of radioactivity equal to 37 billion disintegrations per second. If a radioactive element is present in the amount of one curie, it means that 37 billion nuclei of that element undergo radioactive decay in one second, and thereby become transformed into another element.

This skewed classification system poses serious problems for waste management and disposal. "Low-level" waste is routinely disposed of by putting it in wooden boxes or 55-gallon drums and burying it in shallow trenches. Cardboard boxes have also been used. As a result, some wastes which are significantly more radioactive than high-level or transuranic wastes (which are slated for deep geologic burial) are disposed of in shallow pits. Another problem is that waste classification is determined without reference to the longevity of the radionuclides in the waste. Both high-level and "low-level" wastes can contain short- and long-lived radionuclides.

2. Existing regulations and plans for long-lived radioactive waste management and disposal are irrational and incoherent.

Regulations for disposal of long-lived radioactive wastes are internally inconsistent and scientifically unsound, raising serious doubts about their ability to adequately protect public health and the environment.

Currently, NRC regulations for Class A and B wastes (see table of waste categories) require institutional controls at low-level waste disposal facilities for up to 100 years because, according to the NRC, after this time, these wastes will have decayed to levels that would pose an "acceptable hazard" to an intruder. But even many of the so-called "short-lived" wastes in these classes are allowed in concentrations that will not have decayed to NRC-defined acceptable levels after this 100-year period.

For example, as shown in Table 43, Nuclear Regulatory Commission waste concentration limits allow wastes contaminated with nickel-63 in concentrations up to 70 curies per cubic meter to be buried as Class B waste. At this concentration, after 100 years (the half-life of nickel-63) this waste will have decayed to 35 curies per cubic meter -- 10 times higher than the Class A concentration limits (3.5 curies per cubic meter). If this waste were to be retrieved from the disposal site and re-buried, it would still be classified as Class B waste, requiring the 100-year institutional control all over again. Even after more than 400 years, it would only have decayed to Class A concentration levels, at which point NRC regulations would still define it as hazardous for another 100 years.

Table 43: NRC Limits Defining Class A, B, and C Low-Level Waste

	Half-life (years)	Concentration limit (curies per cubic meter)		
A. "Long-lived radionuclides"				
		Class A	Class B	Class C
Carbon-14	5,700	0.8	N/A	8.0
Carbon-14 in activated metal	5,700	8.0	N/A	80.0
Nickel-59 in activated metal	75,000	22.0	N/A	220.0
Niobium-94 in activated metal	30,300	0.02	N/A	0.2
Technetium-99	213,000	0.3	N/A	3.0
Iodine-129	15,700,000	0.008	N/A	0.08
Alpha-emitting transuranics with half-lives greater than 5 years:	-	10.0*	N/A	100*
Plutonium-241	14	350.0*	N/A	3,500*
Curium-242	163 days	2,000*	N/A	20,000*
B. "Short-lived radionuclides"				
Tritium	12.3	40	no limit	no limit
Cobalt-60	5.3	700	no limit	no limit
Nickel-63	100.1	3.5	70	700
Nickel-63 in activated metal	100.1	35	700	7,000
Strontium-90	28.5	0.04	150	7,000
Cesium-137	30	1	44	4,600
Total of all nuclides with less than 5 year half-lives	-	700	no limit	no limit

Source: NRC 1988 (10 CFR Part 61.55).
* Units are nanocuries per gram. (Note that Pu-241 and Cm-242 have long-lived decay products. Quantities given decay to approximately 100 nanocuries per gram of Am-241 and Pu-238, respectively.)
** There are no limits established for these elements in Class B or C wastes. If waste is contaminated with these radionuclides in concentrations greater than their Class A limits, the waste is Class B, unless the concentrations of other radionuclides determine the waste to be Class C or above independent of these nuclides.

NRC regulations explicitly acknowledge that some "low-level" wastes will remain hazardous well beyond the time that the institutional and physical controls set forth in its regulations will be effective. The regulations state that:

> consideration must be given to the concentration of long-lived radionuclides... whose potential hazard will persist long after such precautions as institutional controls, improved waste form, and deeper disposal have ceased to be effective. These precautions delay the time when long-lived radionuclides could cause exposures.[646]

[646] Nuclear Regulatory Commission, 1988.

Thus the NRC admits that the regulatory controls for low-level waste merely push the hazards posed by long-lived radioactive waste into the future, rather than assure that the public and the environment are adequately protected from exposure.

Another category of waste is transuranic (TRU) waste, which largely consists of waste resulting from plutonium production and processing, mostly for weapons purposes. Although TRU wastes are not classified by their source, there are problems with how they are categorized and managed. The following box discusses one aspect the confusing and illogical federal regulations that currently govern TRU waste management.

The Curious Case of Curium-242, Curium-244, and Plutonium-241

One illustration of the problems in the current waste classification system is the inconsistency between the definition of transuranic waste used by the Nuclear Regulatory Commission (NRC) on one hand, and the Environmental Protection Agency (EPA) and DOE on the other.

The NRC's implicit definition of transuranic (TRU) waste as that which contains alpha-emitting transuranic radionuclides with half-lives greater than 5 years in concentrations greater than 100 nanocuries per gram.[647] It also has separate definitions for two important transuranic radionuclides that do not qualify as TRU waste, but which have decay products that do: plutonium-241 and curium-242.

Plutonium-241 has a half-life of 14.4 years, but its main decay mode is beta, not alpha radiation. However, it decays into americium-241, which is an alpha-emitting radionuclide with a half-life of 432 years, and which does fall into the TRU waste category. Hence the NRC defines waste containing more than 3,500 nanocuries per gram of plutonium-241 as equivalent to TRU waste because it decays into waste containing slightly above 100 nanocuries per gram of americium-241.

Similarly, waste containing more than 20,000 nanocuries per gram of curium-242 (half-life 163 days) decays into waste containing about 100 nanocuries per gram of plutonium-238 (half-life 87 years). Hence, this is also treated as equivalent to TRU waste.

The EPA and DOE definitions of TRU waste, however, include only elements containing alpha-emitting TRU elements with half-lives greater than *twenty* years in concentrations greater than 100 nanocuries per gram (see Table 4). The EPA-DOE definition is far less stringent than the NRC definition on several grounds:

[647] The NRC defines Greater-Than-Class-C (GTCC) waste as that which exceeds low-level waste limits and which must be disposed of in a repository. Therefore, NRC's definition of GTCC waste with only TRU elements should be the same as EPA's TRU waste definition (EPA requires repository disposal for TRU waste).

- It excludes curium-244, which is an alpha-emitter with an 18-year half-life.[648]
- It does not take into account the fact that high concentrations of plutonium-241 and curium-242 decay into transuranics that meet all EPA-DOE criteria for TRU waste.

This means that waste defined as "low-level" by the DOE (because it contains TRU elements with half-lives less than 20 years) could be disposed of in shallow pits. But after several years or decades of storage, some of these wastes could be classified as TRU wastes due to the build up of americium-241 and/or plutonium-238, and hence require deep geologic disposal!

In sum, not only is the TRU waste classification system inconsistent between various bureaucracies, but the contradictions are such that they also imply serious differences in how the same wastes would be managed depending the jurisdiction in which they were created, and the time which is allowed to elapse before disposal.

An additional inconsistency in regulations for waste classification is that NRC lowers the 100 nanocurie per gram limit when other radionuclides are present and DOE does not. The DOE definition is thus operationally much more lax than the NRC definition, since DOE TRU wastes are often mixed with fission productions and other non-TRU radionuclides. This is another reason to combine management of TRU waste in shallow pits and trenches with associated "low-level" waste that contains TRU radionuclides.

3. DOE's management of the repository program for long-lived radioactive wastes is exacerbating these problems.

DOE is responsible for developing geologic repositories for high-level and transuranic wastes. Its high-level waste repository program is at Yucca Mountain, Nevada, and its transuranic waste disposal project, the Waste Isolation Pilot Plant (WIPP), is located in southeastern New Mexico about 25 miles from the town of Carlsbad. Both of these sites have significant scientific, technical, managerial and environmental problems. Timetables for both programs have slipped repeatedly and costs have escalated.

a. WIPP

The geology and hydrology of the WIPP site cause concern about its suitability as a repository for transuranic waste. Water leakage, cracks in the ceilings and floors of waste storage rooms caused by brittle rock that could also serve as a passageway for waste movement, falling ceilings in underground rooms, the presence of natural gas and oil reserves below the site (which invites future intrusion), and active mining and drilling

[648] It also excludes another alpha-emitting transuranic, californium-250 (half-life 13 years). This may be an issue with some wastes at Oak Ridge National Laboratory (and elsewhere?).

immediately surrounding the site which can cause fluid injection that could run through the waste rooms raise serious questions about the ability of WIPP to safely contain wastes that will remain hazardous for thousands of centuries.

The 1992 Land Withdrawal Act requires that DOE comply with EPA regulations for permanent disposal of waste. But DOE and its contractors successfully lobbied to water down the requirements of the EPA compliance criteria. DOE's subsequent Compliance Criteria Application was found to be incomplete for seven months and EPA is still requesting further information and verification that WIPP can comply with EPA's disposal regulations. Even if WIPP opens, DOE does not plan to use the site to dispose of existing buried TRU waste or transuranic contaminated soil, which together pose the greatest environmental risk and make up the bulk of TRU wastes. Table 11 shows the range of volume estimates for these wastes.

DOE has spent $2 billion on WIPP over the last 20 years, and the project has cost $14 to $15 million per month since the late 1980s, even though no waste has been put in the repository.

b. Yucca Mountain

Like the WIPP site, the Yucca Mountain site has significant technical problems that may make it undesirable as a high-level waste repository. The site is located on or near 32 active fault lines, including one which intersects the underground storage rooms; it cannot be certified to meet EPA radiation release limits for high-level waste for carbon-14; there is a potential for volcanic activity in the area; and rainwater percolation into the site is a concern, as is the possibility of the water table itself rising and flooding the repository. Finally, though proponents of the Yucca Mountain repository imply it is a suitable site by describing it as a "remote desert location," the land around Yucca Mountain is used as a source of food and water: Yucca Mountain is located on land claimed by the Western Shoshone people, and there is a farming community 20 miles from the site.

Rather than recognize that the problems with the site may pose unacceptable exposure risks if used for high-level waste disposal, DOE and much of the nuclear industry have chosen to argue for more lax disposal standards and repository suitability criteria. After it appeared that the Yucca Mountain site could not meet the EPA carbon-14 standard, Congress passed a law signed by President Bush exempting Yucca Mountain from this high-level waste standard applicable to all other repositories. In another example of sidestepping Yucca Mountain's technical deficiencies, in 1996 an *ad hoc* committee of the National Research Council of the National Academy of Sciences made a recommendation for standards setting that would result in the abandonment of explicit groundwater protection, and could exclude from consideration those individuals at risk of receiving the highest radiation dose.

4. Taken as a whole, current policies entail high risks in terms of both economics and environmental protection.

DOE's cost estimates for disposal programs have continually escalated though little has actually been done to properly manage and dispose of radioactive wastes. For instance, high-level waste repository costs in constant dollars increased by about 80 percent from the time work under the 1982 legislation began to 1990. At WIPP, DOE's estimates of operation costs for the first 5 years have jumped from $531 million in 1989 to roughly a billion dollars in 1996.[649] DOE estimates WIPP's lifetime cost at $8.4 billion.[650]

Hundreds of millions of dollars have been wasted in searches for low level waste facilities under legislation from the 1980s that transferred responsibility for low-level waste disposal to the states. Billions more are being spent to stabilize uranium mill tailings, and to fix the problems caused by past shallow land burial of low-level and transuranic wastes at commercial and military sites. DOE estimates the total cost for environmental remediation and management of waste generated by nuclear weapons production activities alone will be $227 billion over 75 years.[651]

Given the illogical waste management regulations, technically-flawed repository sites, inadequate provisions for disposing of TRU waste inventories and DOE's history of mismanagement of repository programs, it is unlikely that current radioactive waste management policies will result either in minimization of risk to future generations or wise use of financial resources.

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[649] DOE, 1996c, p. 79, New Mexico section.

[650] Ibid, New Mexico section. This estimate does not include transportation costs or waste treatment costs. Furthermore, it excludes costs for 68 of the 100 years of active institutional controls to be employed at the facility after its scheduled decommissioning in 2038. See "Reader's Note" page New Mexico-82.

[651] DOE, 1996c, p. 4-1.