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Shifting Radioactivity Risks:

**A Case Study of the K-65 Silos and Silo 3 Remediation and Waste
Management at the Fernald Nuclear Weapons Site**

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As always, we, as the authors, remain solely responsible for the contents of this report, its conclusions and recommendations, and any omissions or errors.

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Main Findings and Recommendations

The Feed Materials Production Center near Cincinnati, Ohio, often called the Fernald Plant or simply Fernald, was the largest producer of uranium metal for the nuclear weapons complex during the Cold War. Its processes for uranium production ranged from ore processing, to conversion of uranium into various chemical forms, to scrap recovery, to machining of uranium metal. Fernald also processed thorium-232, but in much smaller amounts.

A large volume of radioactive waste was created at Fernald. Fernald also received radioactive wastes dating from the World War II Manhattan Project, which created the bombs that were used to destroy Hiroshima and Nagasaki. These wastes resulted from the processing of very high grade uranium ore from the Belgian Congo, called pitchblende, at the Mallinckrodt Chemical Works in St. Louis, Missouri. Fernald also processed some Belgian Congo pitchblende. Since pitchblende had very high uranium content, it also had a high concentration of the decay products of uranium-238 and uranium-235. The decay products include thorium-230 and radium-226 from the U-238 decay-chain and protactinium-231 and actinium-227 from the U-235 decay chain. Some other high grade ores were also processed at Fernald.

The wastes from processing of high grade ores were called K-65 residues and were stored in two silos at Fernald, called Silos 1 and 2. These silos contained most of the radioactivity in the waste at Fernald, at concentrations that far exceed those found at mill tailings sites across the United States. The waste from processing uranium ore concentrates was known as “cold metal oxide” waste. It was relatively low in radium-226 but had high thorium-230 content. It was stored in Silo 3.

The wastes in these three silos are very long-lived (thorium-230 has a half life of about 75,000 years). Given the high concentration of thorium-230 in all three silos, as well as the large volume of the wastes, the wastes presented rather unique challenges for processing and off site disposal as well as for the long-term stewardship of the disposal sites.

This report provides a case study of the emptying of the K-65 silos of their waste, the processing of those wastes for long-term storage or disposal, and the long-term radiological consequences of how the Department of Energy (DOE) has approached those responsibilities. We have chosen to study the significant problems and failures associated with the management of these wastes because they illustrate problems in remediation and long-term stewardship that hold lessons for other sites. The analysis here is not meant in any way to detract from the performance of the Department of Energy and its contractors and the many stakeholders who assisted them in successfully decommissioning scores of contaminated buildings and sites at Fernald over the last 17 years.

We also looked at some other aspects of long-term stewardship at the Fernald site, notably in regard to the commitments that had been made to the community and to the State of Ohio for long-term stewardship. Specifically, we looked at the fate of an educational program to maintain institutional memory of the on-site waste cell and other residual contamination that will likely remain in the Fernald neighborhood for thousands of years.

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Main Findings

1. Mismanagement and design flaws led to the failure of the vitrification program for silo wastes at Fernald. Instead of fixing the management and design, the DOE decided to change the waste forms, thereby significantly degrading the expected long-term performance.

The remediation strategies finally used for Silos 1, 2, and 3 were considerably inferior to those in the initial Record of Decision. The original ROD envisioned vitrification of the waste in all three silos. This significant degradation of performance has been allowed to occur despite the marginal overall cost differences between the option implemented for Silos 1 and 2 and vitrification of the waste.

Poor design of the pilot plant, a failure to take into account the differences in the composition between Silos 1 and 2 waste on the one hand and Silo 3 waste on the other, and several other problems led to a failure of the pilot plant. The melter failed even before any radioactive waste was processed in it.

Vitrification of Silos 1 and 2 waste would have created a waste form that would be far more resistant to degradation over the long-term than the solution the DOE finally adopted – grouting the waste. Interestingly, the bonuses for completing treatment of the waste rapidly were not tied to long-term waste performance. Expediency rather than long-term health and environmental protection dominated the decision-making.

Silo 3 waste has been packaged in large plastic bags and disposed of in the radioactive waste disposal facility in Utah known as Envirocare.¹ The long-term performance of this waste is expected to be poor. Our dose calculations indicate that NRC radiation dose standards will be greatly exceeded in the long-term.

2. The changes in waste form and expected performance have resulted in an uncertain future for the processed wastes from Silos 1 and 2. If the grouted waste is disposed of by shallow land burial, the long-term estimated doses will be far in excess of the allowable regulatory limit of 25 millirem per year.

We have evaluated long-term doses using RESRAD, which is the approved model for estimating doses from residual radioactivity. Even under assumptions favorable to low doses at sites with low rainfall, the erosion of the cover of the buried waste will result in high long-term doses, especially external doses from radium-226. Since thorium-230 has a half life of about 75,000 years and since it is the parent radionuclide for radium-226, the waste will have a relatively high specific activity for tens of thousands of years. Over such periods of time, no shallow land burial arrangement can be expected to endure; nor can the grout be expected to remain intact.

¹ Envirocare is now part of a larger company known as EnergySolutions that has a variety of facilities across the United States. This report refers only to the radioactive waste disposal facility near Clive, Utah, commonly called Envirocare.

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The initial plan was to send the vitrified waste for disposal at the Nevada Test Site. The change in the waste form to grout for Silos 1 and 2 and to plastic bag packaging for Silo 3, resulted in the rejection of the waste by the State of Nevada because the waste no longer met the state's Waste Acceptance Criteria. There is no clear final disposal option for Silos 1 and 2 waste. It has been shipped to the Waste Control Specialists (WCS) site in Texas for temporary storage. However WCS does not have a license to dispose of the waste. IEER's analysis of WCS's qualifications indicates that it is unqualified to accept large amounts of radioactive waste, much less handle them and dispose of them. WCS documents show a lack of understanding of the basic radiochemical properties of uranium, for instance. The Texas Commission on Environmental Quality has been critical of some aspects of the WCS's low level waste disposal license application. The same technical issues criticized in this application would also apply to the byproduct license application for disposal of the Silos 1 and 2 waste. As of mid-June 2006, it is unclear whether WCS will succeed in getting any license and what the fate of the waste will be if it does not. The specific activity of the waste is too high for it to be disposed of at the Envirocare site in Utah, where the radium-226 concentration is limited to 4,000 picocuries per gram.

3. Silo 3 waste is estimated to produce radiation doses in the long term that would be far in excess of legally allowable limits, even though the waste is far less radioactive than Silos 1 and 2 waste. The long-term build-up of radium-226 to high levels (far higher than allowed in waste at the time of disposal at Envirocare) is a significant part of the problem.

Silo 3 waste was packaged in plastic bags and shipped to the Envirocare site in Utah for disposal. The site has a license for byproduct material disposal. Radium-226 is limited to 4,000 picocuries per gram. While the waste meets this criterion at present, radium-226 will build up to more than this level in less than a hundred years. This is because thorium-230, which is present in high concentrations (about 60 nanocuries per gram) decays into radium-226. Since thorium-230 has a very long half life (about 75,000 years), radium-226 will rise to approximately equal the thorium-230 level in a few thousand years and then decline at the same rate as thorium-230. Hence radium-226 will build up to far higher levels than allowed in the acceptance criteria for waste at Envirocare and indeed to levels that would exceed allowable dose limits by up to thousands of times, depending on the length of occupancy of the site.

4. The large increases in the cost of disposal, despite the significant degradation of performance, do not appear to have any readily identifiable engineering basis. The cost changes made by the DOE and its contractor were not transparent in their technical justifications.

The failure of the vitrification program for silo wastes led to a much more low-tech approach to waste handling and processing. Instead of being vitrified, Silos 1 and 2 wastes were simply grouted. Instead of being vitrified, Silo 3 waste was simply packaged into large plastic bags with the addition of a chemical agent to reduce dispersability. Yet, the cost estimates increased simultaneously with the downgrading of processing technology level. We have been unable to identify any technical reasons for the increases, in the documents that we have examined. Nor

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have we been able to identify any valid reasons for the cost escalations that have an engineering basis.

5. Expediency and short-term gain have driven the process of decision-making about the waste form, resulting in the sacrifice of long-term performance. The DOE's failure to include long-term waste form performance in its decision-making for bonuses created a perverse incentive to finish rapidly at the expense of long-term health and environmental protection.

According to the various cost revisions, overall, the cost difference between vitrifying and grouting the waste would have been about \$50 million, or about one-and-a-quarter percent of the four billion dollar cleanup cost of the Fernald site. While vitrification may have taken some more time, the increased time was trivial in comparison to the deleterious long-term risks that grouting has created. The one clear incentive for grouting versus vitrification is that the former met the rushed, artificial deadline for completion of site closure by 2006 (with an attendant bonus of up to \$288 million for the contractor). In other words, the bonus created perverse incentive to rush the job even if the interests of future generations were compromised.

6. The DOE altered and loosened the standard for uranium contamination of groundwater after remediation commenced.

In the initial Record of Decision the DOE committed to a maximum contaminant limit (MCL) for uranium of 20 micrograms per liter. At that time, in the 1990s, there was no federal standard for uranium in water. In the year 2000, the United States Environmental Protection Agency (U.S. EPA) promulgated a standard of 30 micrograms per liter. Instead of sticking to its original agreement with the community and the ROD, the DOE relaxed its MCL to 30 micrograms per liter, providing one more instance of its failure to keep its cleanup commitments.

7. The Department of Energy has abandoned its commitment to the community to provide guaranteed funding for an education program for the community as part of its Natural Resource Restoration Plan. This has been regarded as essential, since the community accepted that a very large volume of low level radioactive waste could be disposed of in an on-site waste cell. This backtracking on long-term stewardship parallels the degradation of waste form choice for the silo wastes.

The DOE initially committed to fund an education program to the tune of \$5 million, but in April 2005 it eliminated this money entirely from its Natural Resource Restoration Plan. The Attorney General of the State of Ohio has protested this deletion. The State of Ohio and the DOE were in negotiations regarding the education program funding as of mid-June 2006.

The State of Ohio as a Natural Resource Trustee under the Superfund law has considerable leverage over the DOE in regard to funding commitments made pursuant to that law. In view of the other changes that DOE made both at Fernald and at other sites where commitments were not kept or where expected environmental performance from cleanup was significantly degraded, it is questionable whether the DOE would even negotiate regarding money for an education program were it not for the legal leverage possessed by the State of Ohio.

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8. The Waste Acceptance Criteria for the On-Site Disposal Facility at Fernald were not subjected to adequate quality assurance.

The Waste Acceptance Criteria contain a physically absurd value in regard to one radionuclide. The maximum allowable concentration of neptunium-237 is so high that it amounts to over 4 grams of neptunium-237 per gram of waste. This is, of course, physically impossible. This quality assurance is indicative of the lack of due care in preparing environmental documents. IEER has not done an audit of the entire ROD or other RODs that were produced at about the same time using similar methods. It is therefore unclear whether there are any serious errors that have compromised the quality of the waste cells in OU5 or the understanding of what actually has been put into them. The existence of a literally impossible value also points up the need for external oversight and independent scientific audits of environmental remediation programs. This is not the only case in which IEER has found physically absurd values in regard to radionuclides in waste from the DOE, indicating that there may be more pervasive problems in the preparation of remediation documents with unknown long-term consequences for the environment.

Recommendations

1. Contractor bonuses should not be tied to schedule alone. Long-term radiation dose consequences for all communities affected by the waste, including those to which waste is shipped, should be central to the contracting process.
2. State and local governments and communities should have stronger legal leverage to prevent the DOE from degrading performance or cleanup goals, once an ROD is issued.
3. Shallow land burial of Silos 1 and 2 waste should not be permitted. This waste should be disposed of in a deep geological repository. It can be co-disposed of with the depleted uranium waste resulting from historical uranium enrichment operations, which also need a geologic disposal repository. Since the volume of the Silos 1 and 2 waste is far smaller than the depleted uranium and the specific activities are comparable, the silo waste is unlikely to significantly add to radiation doses resulting from DU disposal.
4. The DOE should be required to create a permanent fund for monitoring and education that is large enough that the interest will be sufficient to cover annual costs for these programs. The Federal government must disburse the principal amount to state and local governments up front, with provisions for openness and community participation built into the initial grant.
5. The federal government should be liable for the costs of legal proceedings including litigation arising from a demonstrated failure of the DOE to live up to its cleanup or long-term stewardship commitments.
6. An independent quality assurance program for computer programs and for the calculations done using those programs, including input parameters and software logic is needed to ensure that cleanup decisions are technically sound. Specifically, the computer program and the input

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parameters done to estimate the total burden of radionuclides that can be put in waste cells and still be in compliance with regulations and the maximum residual radionuclide concentrations need intensive verification. There is very likely to be at least one major error in the software that needs correction. A new performance assessment for the Fernald On-Site Disposal Facility should be performed once this independent quality assurance is done.

7. The state of Utah should tighten the rules for waste acceptance so that the total amount of radium at any time remains less than 4,000 picocuries per gram after its in-growth from thorium-230 has been taken into account.

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1. Introduction

This report is an evaluation of the remediation of two aspects of the waste generated or stored at the Feed Materials Production Center (FMPC), now called the Fernald Closure Project Site. It is more commonly called the Fernald Plant or the Fernald Site or simply Fernald.² The Fernald Plant, which mainly produced uranium metal for the U.S. nuclear weapons program, is now decommissioned. It has belonged to the Department of Energy or its predecessor agencies for its entire history. It has been operated by the following prime contractors: National Lead of Ohio until the end of 1985, Westinghouse until late 1992,³ and Fluor Fernald⁴ from late 1992 until the date of this report (June 2006).

This report is mainly focused on two aspects of Fernald:

1. Waste from uranium ore processing stored in three silos, called Silos 1, 2, and 3.
2. The On-Site Disposal Facility (OSDF) and the monitoring, surveillance, and education associated with the long-term stewardship of the site.

We chose to study the first item because it concerns the most radioactive waste, in terms of radioactivity per gram, among the large volumes produced or stored at Fernald. It is a case study in remediation. Specifically, it is a case study in remediation gone wrong, where costs have escalated, performance has deteriorated, and long-term costs are likely to be high if environmental standards are to be met. In other words, even though the Silos 1, 2, and 3 waste has been removed and shipped offsite⁵, the issue of long-term stewardship and legacy management is far from resolved. It has been shifted from Fernald to two different locations. The post-closure costs at these other sites are not yet fully accounted for in the official calculations because no final disposal system has been designated, much less implemented, for the wastes from Silos 1 and 2.

Our study of the second item provides an examination of whether the DOE can be relied upon to fulfill its post-closure agreements and especially the financial aspects of these agreements. The ability to carry out monitoring and surveillance at sites that have radioactive waste disposal cells is an essential part of the long-term protection of the community.

The Fernald site covers 1050 acres situated 18 miles northwest of Cincinnati, Ohio. From 1952 until 1989 the plant processed a wide variety of uranium bearing materials (depleted, normal, and enriched) into high grade uranium metals to support the U.S. nuclear weapons program.⁶ Some of these uranium metals were fabricated into reactor fuel or target elements for plutonium production in reactors at the Hanford and Savannah River sites. Others were shipped to the Y-12

² Unless otherwise mentioned, basic facts about Fernald are from the Fernald Closure Project website, www.fernald.gov.

³ Called Westinghouse Materials Company of Ohio and then Westinghouse Environmental Management Company of Ohio (NAS/NRC 1994, page 5 and Fluor 1999).

⁴ Fluor 1999, Fluor 2000, and DOE 1994. Fluor Fernald was previously called Fernald Environmental Restoration Management Restoration (FERMCO) and then Fluor Daniel Fernald.

⁵ Fernald 2006h and Fernald 2006.

⁶ Fernald 2005d and Fernald 2006c

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facility at the Oak Ridge Plant and to the Rocky Flats Plant where they were manufactured into nuclear weapons components.⁷

In all, Fernald produced over 500 million pounds of uranium metal.⁸ Smaller amounts of thorium-232 were also processed at Fernald. Fernald was also designated as the storage location for thorium that was produced on site as well as offsite.⁹ In these processes, large amounts of wastes were generated that were put into pits, settling ponds, or discharged to the air. Fernald's emissions and discharges contaminated the soil, the water, and the air, on site as well as offsite. During production, the uranium released to the air settled down to contaminate the waters and soils both on site and offsite.

As the Cold War came to an end and environmental and waste controversies mounted, production at Fernald FMPC was suspended in July 1989. In other words, the decrease in demand for uranium metal came at the same time as the increase in the demand for environmental restoration. A lawsuit filed by neighbors of the Fernald plant against National Lead of Ohio was settled by the U.S. government on the contractor's behalf for \$78 in mid-1989.¹⁰ In October 1990 the Department of Energy (DOE) transferred its responsibility from the Office of Defense Programs to the Office of Environmental Restoration and Waste Management (later to become the Office of Environmental Management).

The wastes produced included radioactive "low level" waste, non-radioactive toxic waste, mixed waste (a mixture of radioactive and non-radioactive hazardous waste), water treatment sludge, fly ash, and general waste. During production various waste streams were (i) disposed of in six pits, (ii) stored in Silos 2 and 3 or in drums, or (iii) sent to scrap piles.¹¹ The silos in which the wastes were stored were Silos 1, 2, and 3. Silo 3 contained waste produced only at the Fernald site. Silo 2 contained waste produced at the Fernald site as well as waste produced off site and Silo 1 contained waste produced only off site.¹²

The migration of the radionuclides in these wastes has also contributed to the contamination of the soils and waters of the site.

After 37 years of operation the contamination on and off the site was extensive:

- About 170 acres of the Great Miami Aquifer were impacted with uranium at concentrations above 20 micrograms per liter ($\mu\text{g/L}$), which was the maximum contaminant level (MCL) used as the site's initial cleanup goal prior to the year 2000. This was a site specific standard, since there was no national MCL for uranium until that year. Significant levels of contamination were found in various locations. The highest measurement was 2,100 $\mu\text{g/L}$ beneath a solid waste disposal area.¹³ While the onsite

⁷ DOE 1996, Chapter 2

⁸ Fernald 2006d

⁹ ORAU team 2004, Section 2.1.1

¹⁰ ROD OU5 1996, Section A.2.1 (page 149 of pdf)

¹¹ Makhijani, Hu, and Yih 2000, page 212

¹² ROD OU4 1994, Section 2.2 (pages 19 and 20 of pdf)

¹³ ROD OU5 1996, Section 5.1.2.2 (page 28 of pdf)

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contaminated water was not ever used for drinking, the MCL for drinking water provides a useful point of comparison for long-term stewardship – that is, when site control is lost. The U.S. EPA set the MCL for uranium in drinking water at 30 µg/L as a national standard in the year 2000,¹⁴ which led to the relaxation of the Fernald MCL goal to this level.¹⁵

Within the boundary of the site, soils were contaminated with uranium with concentrations ranging from 10 milligrams per kilogram (mg/kg) to 100 mg/kg (about 7 to 70 picocuries per gram). The background level in the area is about 3.7 mg/kg (about 2.5 picocuries per gram). Offsite soils were also contaminated with uranium at concentrations ranging from 5 to 6 mg/kg. All together the impacted soils, on site and offsite, covered 7,907 acres. Depending on the level of remediation sought in the preliminary plans, the volumes of soil to be removed ranged from 1,750,000 yd³ (1,338,000 m³) to 9,350,000 yd³ (7,149,000 m³).¹⁶ As of March 2006, 2.75 million yd³ (1.9 million m³) of soils with levels of contamination low enough to be disposed on site in a 2.94 million yd³ lined and capped facility had been excavated¹⁷ and an additional 140,212 tons of materials (soils and debris) that include the soils that were too contaminated to remain on site had been shipped offsite.¹⁸

2. Legal framework and DOE's remediation commitments

In 1985 the United States Environmental Protection Agency (U.S. EPA) issued a notice of noncompliance to the DOE “identifying potential environmental impacts associated with the plant’s operations.”¹⁹ This notice was the first of several key milestones that would set the regulatory framework for the remediation program at Fernald:

- In July 1986, a Federal Facilities Compliance Agreement was entered between the two agencies. It is a “legally binding agreement...to ensure Fernald’s compliance with...the Clean Air Act, the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).”²⁰
- In 1989, the Fernald site was put on the EPA’s National Priorities List, better known as “Superfund.”²¹ Superfund was created by CERCLA.
- In 1990, the DOE and EPA signed a Consent Agreement (amended in 1991) that grouped various locations with similar characteristics into five “Operable Units” (OUs).²² A

¹⁴ EPA 2000

¹⁵ ESD OU5 2001, page 4

¹⁶ ROD OU5 1996, Section 5.1.1 (pages 21, 22, and 25 of pdf)

¹⁷ Fernald 2006f

¹⁸ Fernald 2006e

¹⁹ Fernald 2005c

²⁰ Fernald 2005c

²¹ EPA 2005

²² ROD OU4 Amendment 2000, page 2-3

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“Remedial Investigation”²³ (RI), followed by a “Feasibility Study”²⁴ (FS), was carried out for each Operable Unit to form the basis of a remediation program.

- Between 1994 and 1996, the DOE produced five legally binding Records of Decision (RODs), described in Table 1, providing the justification for the chosen remedial actions.

A detailed description of the five operable units and the actions applying to each one of them are given in Table 1, which is adapted from Table 36 in IEER’s 1997 report, *Containing the Cold War Mess*. (See next page)

²³ The remedial investigation consists in gathering information and data to determine the nature and the extent of the contamination, set environmental remediation criteria, and identify preliminary remedial alternatives based on various techniques and costs analyses.(EPA 2005b)

²⁴ The feasibility study, often conducted at the same time as the remedial investigation, evaluates the various alternatives. The combined study is often referred to as an RI/FS. (EPA 2005b)

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Table 1: Overview of Operable Units for Fernald Site

Operable Unit	Description	Actions	Status of remediation (end of June 2006)
1: Waste Pit Area	Low level radioactive waste in six pits of sludge, soil, rubble/debris, and contaminated wastewater. Soil around and underneath the pit to be remediated. According to the DOE, there are 35 “constituents of concern,” including radioactive, organic, and inorganic materials.	Record of Decision signed March 1995. Low level waste was to be dried and transported off-site to a commercial disposal facility.	Complete
2: Other Waste Areas	Low level radioactive waste of sludge, soil, rubble/debris, and contaminated ash. Five main areas include: Solid Waste Landfill, Lime Sludge Ponds, Inactive Flyash Pile, South Field, Active Flyash Pile. According to the DOE, there are 28 “constituents of concern,” most notably uranium and lead.	Record of Decision signed in 1995. Most waste was to be excavated and disposed of in an onsite disposal cell. Some waste above the disposal cell acceptance criteria was to be disposed off site.	Complete
3: Former Production Area	Covers 128 buildings and 72 miscellaneous facilities and almost 8,000 metric tons of uranium bearing materials. According to the 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 was to be sold to manufacturers; remaining uranium materials was to be sent to other DOE facilities. Most waste was to be disposed of on site.	Complete
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; amended July 2000. Silo contents were to be vitrified and disposed of off site.	Near completion. The silos have been emptied and the waste has been shipped off site. Silos 1 and 2 waste has been grouted and Silo 3 waste has been put in plastic bags with minimal treatment. Shut down work is in progress.
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 to include excavations of soil and disposal on site. Treatment of contaminated process water, stormwater runoff, and groundwater.	Remediation of groundwater to continue after site closure. Surveillance and monitoring of the contamination left on site.

Adapted from Fioravanti and Makhijani 1997, citing ROD OU1 1995, ROD OU2 1995, ROD OU3 1996, ROD OU4 1994, ROD OU5 1996. Source for column 4: <http://www.fernald.gov/>.

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Citizens groups played an important role, contributing to the elaboration of the remediation program, seeing that choices were adopted that minimized harm to the public and the environment, and pressuring DOE to live up to its commitments.

The Fernald Citizens Task Force, later to become the Fernald Citizen Advisory Board, was formed in 1993 to advise the DOE, the U.S. EPA, and the Ohio Environmental Protection Agency (Ohio EPA) on environmental remediation issues at the Fernald site and came up with recommendations on the following questions:

- “What should be the future of the Fernald site?
- What residual risk and remediation levels should remain following remediation?
- Where should the waste be disposed?
- What should be the priorities among remedial actions?”²⁵

3. Status of the remediation and potential long-term contamination problems

In order to implement the selected remedies of the five RODs, the tasks were divided into five projects. The original RODs were amended as problems arose. In the case of the silo wastes, the performance goals of the revised remediation decisions were greatly weakened. The latest versions of these projects are itemized below with the corresponding descriptions of the progress made as of the end of June 2006.

- Silos 1 and 2 (OU4). The waste has been grouted, put in carbon steel containers and shipped by tractor trailer to the Waste Control Specialists LLC (WCS) site in Texas.²⁶
- Silo 3 (OU4). The waste has been put in “soft-sided packages” and shipped by trucks to the Envirocare facility in Utah.²⁷
- Waste pits (OU1). The project was completed in August 2005. Almost one million tons of wastes were excavated from the six waste pits and shipped to the Envirocare facility in Utah.²⁸
- Soil and disposal facility. The cleanup remedy consists of excavation of contaminated soils (OU2 and OU5), certification that the remaining soils meet the EPA cleanup standards (OU5), building of an On-Site Disposal Facility (OSDF) and filling it with contaminated soils (OU2 and OU5) and debris (OU5). Shipping off site the soils that do not meet the cleanup standards (OU2).²⁹
- Decontamination and demolition (OU3). Most of the waste is being placed in the On-Site Disposal Facility. The OSDF cells are scheduled to be closed in June 2006.³⁰ The rest of the waste has been shipped to Envirocare (Utah) and the DOE’s Nevada Test Site.

²⁵ FCAB 2005b

²⁶ Fernald 2006h

²⁷ Fernald 2005p and Fernald 2006

²⁸ Fernald 2005

²⁹ Fernald OSDF Fact Sheet

³⁰ Fernald 2006f

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- Aquifer restoration (OU5). The project will continue after site closure.³¹
- Waste management (OU3). The project was completed in 2005.³²
- Nuclear materials disposal. The project was completed in 2002.³³

In summary, the remediation of Operable Units 1, 2, and 3 is complete; the remediation of Operable Unit 4 is nearing completion as of late June 2006; while some aspects of Operable Unit 5's remediation will continue after closure. The remediation of the Great Miami Aquifer will continue after closure and the placement of soils and materials in the On-Site Disposal Facility is scheduled to be completed by the end of 2006.

The expected date for the closure of the site is 2006,³⁴ in accordance with the time set by the DOE in its 2002 Top to Bottom Review of the EM Environmental Program.³⁵ In that document the DOE moved up the original closure time for the Fernald site to 2006, from its previous deadline between 2006 and 2010. The DOE's rationale for the accelerated cleanup program is that, by removing radioactivity in a timely manner, this action will be protective of the environment and human health and that it will also cut costs.³⁶

Remediation in a timely manner is crucial to addressing serious contamination problems that have the potential to result in more prolonged and severe threats to the environment and human health. For example, the timely removal of contaminated waste dumped in unlined trenches is crucial to preventing migration of radionuclides into groundwater. However, this must be done in a manner that is compatible with the long-term goal of protection of the environment, safety, and health overall. Lowering short-term risks in a way that could aggravate long-term problems shifts the burden to future generations. Long-term stewardship goals and short-term risk reduction need to be harmonized. The problems that have arisen when these two goals are not addressed together throughout the process of remediation are illustrated by the technical history of Operable Unit 4 at Fernald, which is the main focus of this report.

4. Operable Unit 4

Operable Unit 4 consists primarily of the three silos that contain the waste from the processing of uranium ore:

- Silo 1 contains the radium-rich waste streams from the processing of high-grade uranium ore from the Belgian Congo known as pitchblende. This had uranium oxide content as high as 65 to 70 % – that is uranium content of ~50 %.³⁷ The waste in Silo 1 was shipped

³¹ Fernald 2006g

³² Fernald 2005l

³³ Fernald 2005m

³⁴ ESD OU4 2004 Draft, page 11

³⁵ DOE 2002, page IV-2

³⁶ DOE 2002, pages IV-1, IV-2, and ES-3

³⁷ Mallinckrodt 2005, page 6 of pdf

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to Fernald from the Mallinckrodt Chemical Works in St. Louis, Missouri, where large-scale uranium ore processing and uranium metal production began during the World War II Manhattan Project. The radium-226-rich wastes from Belgian Congo pitchblende processing are called “K-65 residues” (see below).³⁸

- Silo 2 also contains a radium-rich waste stream, which is a mixture from ores processed both at Mallinckrodt and at Fernald. These ores originated in the Belgian Congo, with a small amount from two Australian mines.³⁹ These are also referred to as K-65 materials.
- Silo 3 waste has much lower specific activity⁴⁰ and consists of waste only from relatively low grade ores processed at Fernald.

The health and environmental risks posed by the contents of the three silos, forming Operable Unit 4 (OU4), are described in section 4.4. A fourth silo was built, but it remained empty and will not be considered in this report. Non-silo wastes are not addressed in this report.

The 1994 Record of Decision for Operable Unit 4 (ROD OU4) explored several alternatives for reducing the risks associated with the radiological and chemical content of the wastes. Vitrification of the wastes – that is, turning it into a glassy material by heating to a very high temperature – was selected as the remedy that would best reduce the short-term risks and produce a waste form that would have the lowest risk of long-term contamination at the disposal site. Other options were also regarded as short-term risks according to the OU4 ROD. This concern is clearly expressed in the 1994 ROD:

Actual or threatened releases of hazardous substances from Operable Unit 4, if not addressed by implementing the response action selected [vitrification] in this ROD, may present an imminent and substantial endangerment to public health, welfare, or the environment.⁴¹

A detailed description of the origin and composition of the wastes is given in *Containing the Cold War Mess*.⁴² Tables 2 and 3 summarize this information. The main differences between Silos 1 and 2 and Silo 3 reside in the composition of the physical form of the waste as shown in Tables 2, 3 and 4.⁴³

³⁸ Fernald Feasibility Study 1994

³⁹ Fernald Feasibility Study 1994, Section 1.4.3.2

⁴⁰ The specific activity of the waste refers to its radioactivity per gram.

⁴¹ ROD OU4 1994, page 2 of pdf

⁴² Fioravanti and Makhijani 1997, Chapter 4; especially pages 213-224

⁴³ Please note that the combined waste volumes for Silos 1 and 2 sometimes vary according to the source cited. As explained below, a layer of bentonite was added to Silos 1 and 2. In some sources it is taken into account, in others not. There sometimes also exists, between two sources, a small discrepancy between the volumes of Silos 1 and 2 without the bentonite layer. This is also true for the volumes with the bentonite layer.

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Table 2: Generation of Waste

	Silo 1	Silo 2	Silo 3
Generating facility	Mallinckrodt Chemical Works, St. Louis, Missouri	Mallinckrodt Chemical Works, St. Louis, Missouri, and Fernald	Fernald
Activity of the generating facility	Processing of high uranium content ores (Note 1)	Processing of high uranium content ores	Processing of high uranium content ores and uranium ore concentrates
Type of waste	K-65 residues (Note 2)	K-65 residues	Cold metal oxide waste (Note 3)

Source: Fioravanti and Makhijani 1997

Note 1: The uranium content of the ore was on average 40 to 50%. (Fernald 2005o)

Note 2: The term “K-65” refers to a particular waste stream with high radium content. This waste stream, or “hot” (because highly radioactive) raffinate (as waste product from a refining process), was passed through a filter that trapped the radium, and thus a major portion of the radioactivity. The rest of the raffinate contained some metal oxides in solution. At Fernald this liquid was evaporated and calcined (that is, heated) to produce a dried and fine powder of “cold” (because less radioactive than the K-65 residues) metal oxides and sent to Silo 3.

Note 3: Waste left after the filtration of K-65 raffinates and the processing of uranium ore concentrates

Table 3: Estimated Radionuclide Content of Silos 1, 2, and 3

Radionuclide	Mean Concentration, picocuries per gram		
	Silo 1 (3,240 m³)	Silo 2 (2,845 m³)	Silo 3 (3,890m³)
Actinium-227	5,960	5,100	618
Protactinium-231	(not listed)	2,350	487
Lead-210	165,000	145,000	2,620
Polonium-210	242,000	139,000	(not listed)
Radium-226	391,000	195,000	2,970
Thorium-230	60,000	48,400	51,200
Uranium-234	800	961	1,480
Uranium-238	642	912	1,500

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 is 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 (ROD OU4 1994, Section 1.1 (page 15 of pdf)).

Adapted from Fioravanti and Makhijani 1997, page 224, citing source: D. Paine (Silos Project Manager), *Operable Unit 4: Project History and Status Presentation*, Fernald, OH: Meeting of Independent Review Team, November 14 1996, pages 8 and 11.

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Table 4: Total Radioactivity of Silos 1, 2, and 3

Radionuclide	Silos 1 and 2 combined	Silo 3
Radium-226	3,700 curies	26 curies (Note 3)
Thorium-230	600 curies	450 curies (Note 2)
Lead-210	1,800 curies	4 curies (Note 3)
Uranium	28 metric tons (Note 1)	

Source: ROD OU4 1994, pages 25 and 26 of pdf.

Note 1: 28 metric tons of natural uranium correspond to less than 20 curies.

Note 2: The high value for thorium-230 in Silo 3 comes from the processing of uranium ore concentrates.

Note 3: ROD OU4 1994 does not give values for radium-226 and thorium-230 in Silo 3. The value for radium-226 is from NAS/NRC 1995, Table 3, and the value for lead-210 is calculated using values from Table 3 of this report and Table 3 of NAS/NRC 1995.

Table 5: Physical Form and Non-Radioactive Chemicals of Concern for Silos 1, 2 and 3

	Silo 1 (3,240 cubic meters)	Silo 2 (2,845 cubic meters)	Silo 3 (3,890 cubic meters)
Material	Silty, claylike	Silty, claylike	Dry, powdery
Heavy metals above RCRA TCLP limits	Lead	Lead	Arsenic, cadmium, chromium, selenium
Organic compounds	Yes	Yes	No

Source: ROD OU4 1994, Section 5.2.2 (pages 25 and 26 of pdf). TCLP stands for Toxicity Characteristic Leaching Procedure and RCRA stands for Resource Conservation and Recovery Act.

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 (ROD OU4 1994, Section 1.1 (page 15 of pdf)).

Volumes from Fioravanti and Makhijani 1997, page 224, citing: D. Paine (Silos Project Manager), *Operable Unit 4: Project History and Status Presentation*, Fernald, OH: Meeting of Independent Review Team, November 14 1996, pages 8 and 11.

4.1. Waste classification and disposal issues

The silos' waste is classified as byproduct material resulting from the processing of uranium or thorium ores as defined in section 11e.(2) of the Atomic Energy Act.⁴⁴ But this classification does not reflect the level of dangers posed by this waste.

This classification normally refers to the tailings of uranium and thorium mills that are generally left on site. The criteria that regulate their disposal are specified in Appendix A of 10 CFR 40. They broadly consist in "permanent isolation of tailings and associated contaminants by minimizing disturbance and dispersion by natural forces, and to do so without ongoing maintenance." Appendix A also specifies that provisions must be made to protect water resources, in particular groundwater, and to ensure that radon-222 emissions to the atmosphere

⁴⁴ AEA, Volume 1, page 1-11 gives the following definition for byproduct material: "the tailings or waste produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content."

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do not exceed 20 picocuries per square meter per second on average.⁴⁵ This type of waste is exempt from RCRA regulations for hazardous solid waste.⁴⁶ However, because the Fernald silo waste exceeds the Toxicity Characteristic Leaching Procedure (TCLP)⁴⁷ limits for a number of metals, certain RCRA conditions for disposal still apply.⁴⁸

The 11e.(2) classification, even with the TCLP conditions, falls far short of addressing the potential hazards posed by the silo wastes. Indeed, the National Research Council suggests that the K-65 silo wastes (Silos 1 and 2) should be treated on a par with transuranic waste since the radium-226 level exceeds 100 nanocuries per gram.⁴⁹ It states that:

Although radium is not a transuranic, the K-65 wastes produce a substantial external dose due to gamma-ray emission and the risks they pose may even exceed those posed by some transuranic wastes and are at least similar based on the intrinsic toxicity of the isotopes involved.⁵⁰

Transuranic wastes are slated to be disposed of in a deep geologic repository. We will discuss in detail this waste classification issue in Section 4.3 and review disposal options that are based on scientific evidence.

The waste from Silos 1 and 2 has been sent by trucks to Waste Control Specialists (WCS) in Texas, a facility licensed only to process and temporarily store radioactive materials.⁵¹ On September 30, 2005, the Texas Department of State Health Services received from WCS a byproduct license application that, if granted, would allow for the permanent disposal of the K-65 waste at the site.⁵²

The apparent rationale for disposing of K-65 waste in a shallow land burial site is that the process that produced the Fernald waste is similar to the process that created uranium mill tailings, which are known as 11e.(2) waste.⁵³ As stated above, these latter are mostly left next to the uranium mills where they were extracted, with some level of remediation to control air quality by limiting radon emissions and prevent contamination of groundwater.

Below, we present a brief chronology of the events that led to the decision to send the waste to WCS. Environmental and health concerns tied to the hazardous nature of the waste were the reasons the states of Nevada and Utah opposed receiving the waste.

⁴⁵ 10 CFR 40 2006, Appendix A, Criteria 1 and 5

⁴⁶ 40 CFR 261.4 (a) (4) 2005

⁴⁷ According to the EPA “The Toxicity Characteristic Leaching Procedure (TCLP) is designed to simulate the leaching a waste will undergo if disposed of in a sanitary landfill. ...If the TCLP extract contains any one of the TC [Toxicity Characteristic] constituents in an amount equal to or exceeding the concentrations specified in 40 CFR 261.24, the waste possesses the characteristic of toxicity and is a hazardous waste.” (EPA SW-846 Ch.7)

⁴⁸ ROD OU4 1994, Section 5.2.1 (page 25 of pdf)

⁴⁹ NAS/NRC 2005, page 64, erroneously refers to this as radon-226 at one point.

⁵⁰ NAS/NRC 2005, page 64

⁵¹ WCS License L04971 Amendment 38

⁵² WCS License Application Byproduct

⁵³ See footnote 44 for definition.

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- The Nevada Test Site (NTS) was originally chosen to receive the silos' waste. It is a DOE facility for testing nuclear weapons that also functions as a disposal facility for low level military waste generated off site in the nuclear weapons complex.⁵⁴
- In 2003, in order to accelerate the offsite shipment of the K-65 waste, the DOE envisioned, in addition to sending it to NTS, to send it also to Envirocare in Utah, an NRC-regulated radioactive waste disposal facility licensed to accept 11e.(2) byproducts because

[t]his action reduces the risk of an unplanned shutdown of the silos shipping program and permits the bulk rail shipping and direct truck shipping of the silos wastes. The addition of rail transport reduces cost and schedule risk associated with activities on the critical path.⁵⁵

- However, Envirocare's 11e.(2) license has a waste acceptance criterion with an upper limit of 4,000 picocuries per gram⁵⁶ for receiving radium-226 contaminated waste, while the mean activity in Silo 1 was almost 100 times more and almost 50 times in Silo 2 (See Table 3). In order to abide by Envirocare's waste acceptance criteria the volume of the waste would have had to be increased about 75 times. On March 27, 2003, in order to qualify to receive the K-65 wastes, Envirocare submitted to the NRC, a request for an amendment to raise the limit to 100,000 picocuries per gram.⁵⁷ This request was subsequently withdrawn on November 19, 2003.⁵⁸
- Once it was clear that Envirocare would not be receiving any of the K-65 waste, the State of Nevada vigorously opposed the shipping to and disposal of the waste from Silos 1, 2, and 3 at the Nevada Test Site, based on the environmental hazards posed by the K-65 waste, as well as the DOE's lack of authority to regulate 11e.(2) wastes. In a letter dated April 13, 2004, to Jessie H. Roberson, then DOE's Assistant Secretary for Environmental Management, Brian Sandoval, the Nevada State Attorney General, threatened to sue the DOE if the waste from Silos 1, 2, and 3 were shipped to the Nevada Test Site (NTS) on the grounds that

[it] is a flagrant violation of applicable federal and state laws and, indeed, of DOE's own rules. Even worse, the consequence of this unlawful action will be to create an extraordinary public health and environmental hazard in our state....

... [The] hazardous constituents in this waste exceed standards established by the Resource Conservation and Recovery Act ("RCRA") for lead and probably other hazardous substances (such as selenium), and thus the waste would normally constitute "mixed waste" under Nevada's federally approved RCRA program.

⁵⁴ NTS 2006

⁵⁵ Fernald 2003, page 10. Envirocare has a rail link.

⁵⁶ Envirocare 2005, page 13

⁵⁷ NRC 2003

⁵⁸ Utah 2004

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...Moreover, this material is evidently of such a high radioactivity concentration that it cannot be sent for disposal to Envirocare's commercial radioactive waste disposal facility in Utah....

...If DOE chooses to classify the waste as 11(e)(2) pursuant to the AEA [i.e., exempt from RCRA], then the DOE must also comply with the waste management requirements established through the AEA in conjunction with the 11(e)(2) waste designation and dispose of the wastes at a facility appropriately licensed by the NRC or an Agreement State for 11(e)(2) waste disposal. The NTS disposal facility is clearly not such a facility.

The last paragraph indicates that the NTS site no longer qualifies since, as the letter further states

[a]ny conceivable doubt about DOE's lack of authority to dump the Fernald 11(e)(2) wastes at NTS was put to rest by Congress in the Energy and Water Development Appropriations Act of 2004 (Public Law 108-137, December 1, 2003), which in Section 312 specifically referred to the Fernald silo wastes at issue and required that "[t]he Nuclear Regulatory Commission or an Agreement State, as appropriate, shall regulate the material as '11e.(2) by-product material' for the purpose of disposition of the material in an NRC-regulated or Agreement State-regulated facility." (Emphasis added.) NTS, of course, is not such a facility.⁵⁹

- The refusal of the State of Nevada to accept the waste from the Fernald silos led to a search for alternative sites. Envirocare's waste acceptance criteria have a 4,000 picocuries per gram limit for radium-226 and therefore Silos 1 and 2 waste could not be sent there. The temporary expedient of sending Silos 1 and 2 waste to the WCS site in Texas was chosen even though WCS does not have a disposal license. Silo 3 waste was to be sent to Envirocare. In February 2005, Fluor Fernald awarded a contract to Envirocare to begin receiving Silo 3 waste for disposal at that facility.⁶⁰

Sending the Silos 1 and 2 wastes to WCS is a stopgap measure created to remove the last major hurdle for Fluor Fernald to close the site. As we will show below, this measure just transfers the risk off site and does not address the long-term problem of management of this waste in keeping with its characteristics. Those characteristics show that the Silos 1 and 2 wastes should be disposed of in a deep geologic repository.

⁵⁹ Nevada AG 2004/04/13, pages 1, 2, 4, and 5. This letter outlines the statutory and regulatory case against accepting this waste at the Nevada Test Site.

⁶⁰ Fluor Fernald 2005

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4.2. Radioactivity comparison between the K-65 waste and uranium mill tailings from 0.2% uranium ore

While the classification for the K-65 waste as byproduct residues is justified since it is generated as a result of the processing of uranium ore, its burial in a shallow land site, based on its specific activity⁶¹ is not. According to the DOE

Most 11e(2) volumes result from the initial milling and refining of uranium ore. The residual waste (mill tailings) generated from the ore processes are composed of homogeneous sand- or clay-like particles. After the recoverable uranium is collected, the tailings typically will contain between 50 and 86 percent of the original radioactivity from the ores depending on the proportion of radon lost during the mining operation.⁶²

Uranium ore with a 0.2% uranium oxide content, typical of U.S. ore, has a specific activity of 4 nanocuries per gram; therefore, the specific activity of the tailings, produced from the uranium extraction, is between 2 and 3.4 nanocuries per gram.

The uranium ore processed at Mallinckrodt and Fernald contained between 40 and 50% uranium oxide and sometimes as much as 70%. Table 6 shows the radioactivity per gram of the extracted byproduct material (i.e., the radioactivity of the daughter products of uranium decay of which radium-226 is a contributor) in Silos 1, 2, and 3. The radioactivity in Silo 1 is 133 times higher than the highest value of 3.4 nanocuries per gram for uranium mill tailings. For Silos 2 and 3 it is 72 and 16 times higher respectively.

Table 6: Comparison of Silos 1, 2, and 3 radioactivity with typical U.S uranium mill tailings radioactivity

Material	Specific activity— nanocuries per gram or ratio
Mill tailings arising from 0.2% uranium ore	2 to 3.4 nCi/g
Silo 1 waste	452 nCi/g
Silo 2 waste	245 nCi/g
Silo 3 waste	54 nCi/g
Ratio Silo 1/typical mill tailings	133
Ratio Silo 2/typical mill tailings	72
Ratio Silo 3/typical mill tailings	16

Note: The values for Silos 1, 2, and 3 are the sum of the mean concentrations of the decay products of uranium-238 down to radium-226. For a reasonable comparison with uranium mill tailings we have not included lead-210 and polonium-210, since these two radionuclides are decay products of radon-222. The mill tailings disposal regulations assume that radon-222 would diffuse out of the waste.⁶³

⁶¹ The specific activity of the waste refers to its radioactivity per gram.

⁶² DOE 2001, page 9-2

⁶³ 10 CFR 40 2006, Appendix A, Criterion 6

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Silos 1 and 2 have high concentrations of alpha emitting radionuclides, mainly radium-226 and thorium-230. Similar wastes, if they contain transuranic radionuclides – that is radionuclides with atomic numbers greater than uranium – at levels greater than 100 nanocuries per gram, with half-lives greater than twenty years, are defined as “transuranic waste” (TRU waste) and must be disposed of in a deep geologic repository. The repository for DOE’s TRU waste is called the Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico, near Carlsbad. The EPA requires that WIPP conform to an annual committed dose to any member of the public for a period of 10,000 years that does not exceed 15 millirems.⁶⁴ As we will show below, in a RESRAD calculation, the current plan for the disposal of Silos 1 and 2 wastes, which is shallow land burial, will not be able to satisfy this limit nor will it satisfy the limit of 25 millirem per year to the whole body to any member of the public for such disposal.⁶⁵ The main reason is that both Silos 1 and 2 have specific activities of radium-226 and thorium-230 (both long-lived, alpha-emitting radionuclides) that are high – far higher than the 100 nanocuries per gram limit for TRU radionuclides. The main difference between Silos 1 and 2 wastes and TRU waste is not due to the risk posed, but due to nomenclature of the radionuclides comprising them. Indeed, Silo 1 and 2 wastes are arguably more risky, due to the presence of radium-226, since, unlike plutonium-239, radium-226 emits strong gamma radiation (in addition to alpha radiation).

4.3. The scientific reasons for disposing the K-65 waste in a deep repository

The analysis in this section shows that the K-65 waste should be classified as equivalent to transuranic waste for the purpose of waste management and disposal. This means that it should be put in a deep geologic repository.

According to 40 CFR 191.02(i), transuranic radioactive waste “means waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than twenty years, per gram of waste...”⁶⁶

What matters for reasons of health and the environment is the specific activity of the waste, its mode of decay (alpha or beta decay and whether it is accompanied by gamma radiation), the energy of the decay, and the length of the half-life. Its chemical properties are also a factor. The characteristics of radium-226, thorium-230/232, and the uranium isotopes in the K-65 waste are, in these essential aspects, similar to the characteristics of the elements of transuranic waste. However we will consider only radium-226, since it is the only element with a mean concentration above 100 nanocuries per gram.

There is one nominal difference between radium-226 and transuranic waste. Transuranic elements have an atomic weight greater than 92 (the atomic weight of uranium, hence their name), while the atomic weight of radium is 88. However, this is only a matter of nomenclature that has no bearing on the health and environment questions.

⁶⁴ 40 CFR 191.15 2005

⁶⁵ 10 CFR 61.41 2005

⁶⁶ 40 CFR 191.02(i) 2005

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4.3.1 Properties of radium-226

A. Specific activity

The specific activity of pure radium-226 is one curie per gram. The Silo 1 waste mean specific activity is about four times more than that defining transuranic waste and Silo 2 waste is about two times more. These wastes are much less than one curie per gram because they are mixed with materials used in the ore refining process.

B. Mode of decay, energy of decay, and half-life compared with transuranic elements

The main radionuclide of concern among the transuranic elements is plutonium-239. The other radionuclides present in significant quantities are plutonium-238, plutonium-240, neptunium-237, and americium-241. The predominant form of decay for all of them is alpha decay, that is, the emission of an alpha particle. The form of decay for radium-226 is also emission of an alpha particle. The energies of the emitted alpha particles for all these isotopes range between 4 and 6 MeV. This means that the energy deposited in the tissues, hence the level of damage in the body per disintegration, is the about the same for radium-226 and the transuranic elements.

Table 7: Properties of Radium-226 and Selected Transuranic Elements

Isotope	Main decay mode	Alpha particle energy, MeV (Mega electron Volt)	Half-life, years	Comments
radium-226	Alpha	4.9	1,600	strong gamma emitter, decays into radon-222
thorium-230	Alpha	4.8	75,400	
neptunium-237	Alpha	4.8	2.14 million	
plutonium-238	Alpha	5.5	87.7	
plutonium-239	Alpha	5.1	24,110	
plutonium-240	Alpha	5.1	6,537	
americium-241	Alpha	5.5	432	strong gamma emitter

C. Biochemical characteristics and health risks of K-65 waste and TRU waste

Radium is dangerous when ingested or inhaled. Its chemical properties are similar to the chemical properties of calcium and it accumulates in the bones where it can cause bone cancer and leukemia. The radium-226 dose conversion factors for inhalation for various organs are given below in Table 8. Table 9 shows that the dose per unit of radioactivity delivered by radium-226 to the bone surface, liver, and bone marrow, compared to plutonium-239, is 200, 131, and 41 times smaller, respectively. However, the dose per unit of radioactivity to the lung is approximately the same for radium-226 and plutonium-239, while the dose to the whole body is about 60% of that for plutonium-239. The external dose rate for radium-226 is considerably higher for radium than for plutonium-239.

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The other main radionuclide of concern is thorium-230. The trace contaminants, protactinium-231 and actinium-227 are also important contributors to health risks due to the high dose they deliver per unit of radioactivity. Table 8 shows dose conversion factors for radium-226, thorium-230, protactinium-231, and actinium-227 for some organs compared to plutonium-239 (lung, bone surface, bone marrow, liver).

Table 8: Organ dose and Effective Dose Equivalent dose conversion factors (50-years) for inhalation for some of the silos radionuclides to various organs and plutonium-239, in Sieverts per Becquerel

Radionuclide	Bone surface	Liver	Lung	Bone marrow	Whole body
Plutonium-239	1.84E-04	3.91E-05	8.74E-05	9.13E-06	1.60E-05
Thorium-230	2.79E-04	3.68E-06	7.66E-05	1.00E-05	1.40E-05
Radium-226	9.53E-07	9.53E-07	7.90E-05	6.98E-08	9.51E-06
Protactinium-231	6.03E-04	1.67E-05	1.45E-04	2.38E-05	2.89E-05
Actinium-227	1.93E-04	4.25E-05	4.06E-04	1.03E-05	5.53E-05

Source: EPA 2002

Table 9 compares the dose per unit of disintegration of the radionuclides of concern with plutonium-239. For thorium-230, except for the liver, the dose delivered to the other organs is comparable with plutonium-239. For protactinium-231, again except for the liver, the dose delivered is higher than for plutonium-239. For actinium-227, the dose is similar for the bone surface, the bone marrow and the liver, but 3 to 4 times higher for the whole body and the lung.

Table 9: Ratios of the dose conversion factors for some of the silos radionuclides to plutonium-239

Ratio	Bone surface	Liver	Lung	Bone marrow	Whole body
Th-230/Pu-239	1.52E+00	9.41E-02	8.76E-01	1.10E+00	8.75E-01
Ra-226/Pu-239	5.18E-03	2.44E-02	9.04E-01	7.65E-03	5.94E-01
Pa-231/Pu-239	3.28E+00	4.27E-01	1.66E+00	2.61E+00	1.81E+00
Ac-227/Pu-239	1.05E+00	1.09E+00	4.65E+00	1.13E+00	3.46E+00

Overall, the cancer risk from inhalation of a unit weight of Silo 1 or Silo 2 waste would be considerably greater than that of inhaling the same weight of TRU waste containing 100 nanocuries per gram of plutonium.

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D. Radon

Radium-228 decays into radon-222 gas, which gives rise to additional health risks, notably in the form of lung cancer. Radon gas has a 3.82-day half-life. It decays into a series of very short-lived, highly radioactive elements that, if inhaled, can cause lung cancer.

4.3.2 Conclusion

The K-65 waste should be treated on a par with transuranic waste based on the fact that the radiological characteristics of radium-226, thorium-230, and other radionuclides in Silos 1 and 2 wastes are similar to those of transuranic waste and that the dose from inhalation of a unit weight of K-65 waste would be greater than that caused by inhaling the same weight of TRU waste containing 100 nanocuries per gram of plutonium-239. It should be disposed of in a deep geologic repository. As mentioned above, in section 4.1, although the National Research Council does not address the issue of disposal directly, it suggests that the K-65 silos wastes should be classified as equivalent to transuranic waste.

4.4. Risks posed by the waste and pre-ROD remedial efforts

Unless otherwise stated, the information given in this section is taken from IEER's report, *Containing the Cold War Mess*.⁶⁷ The risks posed by the waste stored in the silos arose mainly from the high specific activity of alpha-emitting radionuclides (including radium-226 and thorium-230) in Silos 1 and 2 and the powder-like content of the radioactive waste in Silo 3, which makes it easily dispersible. The main reasons for concern were:

- the radon-222 emissions from the decay of radium-226 are high -- 50,000 picocuries per square meter per second.⁶⁸ The emissions, especially from Silos 1 and 2, posed a threat to onsite workers as well as offsite residents
- the high gamma ray field from Silos 1 and 2 from the high concentration of radium-226 posed a threat to workers⁶⁹
- the powder-like contents of Silo 3 posed a risk in the event of dispersion and inhalation.

So long as the structures of the silos remained intact, the risk of widespread dispersal of radionuclides other than radon and its decay products was small. However, over time the silos developed structural problems that included:

- Cracks in the walls, resulting in seepage of waste, observed since the 1950s
- Risk of collapse of the concrete dome.⁷⁰

⁶⁷ Fioravanti and Makhijani 1997, page 216-219

⁶⁸ Merrill and Whittington 1994, page 2

⁶⁹ RAC 1998, page 87

⁷⁰ Fernald Feasibility Study 2000, page F-2-8

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To address the most urgent problems of structural integrity and radon emissions, the DOE chose to implement the cheapest measures that resulted in short-term gain rather than measures that would have been effective for the long term. We will only cite the addition of a layer of bentonite clay on the top of the Silo K-65 waste to reduce the radon emissions. The other measures are discussed in detail in *Containing the Cold War Mess*.⁷¹ Although other choices existed to reduce radon emissions more effectively, the addition of bentonite was chosen for reasons of cost. For many reasons this was a poor choice for a short-term remedial action. First, it was not “consistent with the anticipated long-term remedial action” and did not “contribute to the efficient performance of the long-term remedy to the extent practicable.” Second, it was not consistent with the long-term goal of volume reduction.⁷² Finally, there was also no analysis as to how the addition of bentonite might affect the retrieval and remediation of the waste.

4.5. DOE’s legally binding commitments: the selected remedies for Operable Unit 4

In the 1994 Record of Decision, Operable Unit 4 was divided into three subunits:

Subunit A: Silos 1 and 2 contents (K-65 residues and the bentonite clay) and the sludge in the decant sump tank^[73]

Subunit B: Silo 3 (cold metal oxides)

Subunit C: Silos 1, 2, 3, and 4 structures; contaminated soils within the Operable Unit 4 boundary including surface and subsurface soils and the earthen berm around Silos 1 and 2; the decant sump tank; the radon treatment system; the concrete pipe trench and the miscellaneous concrete structures within Operable Unit 4, any debris (i.e., concrete, piping, etc.) generated through implementing cleanup for Subunits A and B, and any perched groundwater encountered during remedial activities⁷⁴

The ROD examined several alternatives for each subunit. The selected remedies for each subunit were:

- Subunit A: Vitrification of the waste and offsite disposal at the Nevada Test Site
- Subunit B: Vitrification of the waste and offsite disposal at the Nevada Test Site
- Subunit C: Demolition, removal, and onsite disposal.

These selected remedies were the legally binding commitments the DOE made. It declared them to be the preferred alternative in part because they were the most protective of the environment and human health. Since then the DOE has reneged on its commitments for Subunits A and B.

⁷¹ Fioravanti and Makhijani 1997, pages 216-219

⁷² Bechtel 1990, pages 10 and 85

⁷³ The decant sump tank was located between Silos 1 and 2 at approximately 0.6 meters below the base of the silos. It was used to decant liquids from waste slurried into the silos. (ROD OU4 1994, Section 5.2 (pages 25 and 26 of pdf))

⁷⁴ ROD OU4 1994, page 3 of pdf

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That is, it has abandoned the vitrification option that was declared to be the preferred one in 1994. The waste disposal sites have also changed.

We discuss the history of these changes and the degradation of the performance of the remediation program as it concerns Subunits A and B in this and the next section.

Subunit A – Contents of Silos 1 and 2 and the sludge from Decant Sump Tank

Of the two remedies proposed for Subunit A, the preferred alternative consisted of vitrifying the waste and disposing it of at the Nevada Test Site. The other remedy consisted of stabilizing the waste in cement and disposing it off site at the Nevada Test Site. The implementation time for both alternatives was estimated to be the same. Although the estimated cost was 67% higher for cementation (or grouting)⁷⁵ this did not dictate the choice of vitrification as the preferred alternative. Rather vitrification was chosen because

[t]he selected remedy [vitrification] would provide greater certainty for overall protection than other alternatives because the **Subunit A residues would be vitrified and removed to the NTS to reduce the potential for contaminant migration to human and ecological receptors....**

Overall protection at the NTS would be maintained because the vitrified residues resist leaching and the NTS is located in a climatic, demographic, and hydrogeological setting which favors minimization of contaminant migration to both human and environmental receptors.”⁷⁶

In contrast, studies for the cementation alternative

have also concluded that the **cement stabilization of the wastes does not effectively reduce the radon emission rate from the waste and the tendency of the waste to leach contaminants into groundwater.** The direct radiation associated with the untreated residues would be slightly reduced due to the effects of mixing the additives with the residues.⁷⁷

⁷⁵ A grout is a mixture of cement, sand, and water. We have used the terms grout and cement interchangeably, as is also the case in the documents referred to in this report.

⁷⁶ ROD OU4 1994, Section 7.2 (page 58 of pdf), emphasis added.

⁷⁷ ROD OU4 1994, Section 7.2.2 (page 60 of pdf), emphasis added.

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Table 10: Silos 1 and 2 -- cost, time estimate, and volume comparisons between vitrification and cementation for Silos 1 and 2 and sludge from decant sump tank, as of 1994

	Vitrification	Cementation	Comments
Capital cost (millions)	\$38.3	\$71.8	
O&M cost (millions)	\$11.7	\$11.7	
Present worth, as of 1994	\$43.7	\$73.1	Note: vitrification was considered cheaper at the time of the RI/FS in 1994.
Years to implement	6	6	Completion date was the Year 2000.
Volume before treatment in Silos 1 & 2	6,796 m ³	6,796 m ³	
Volume of sludge from decant sump tank	3,785 L	3,785 L	
Volume after treatment	2,770 m ³	18,166 m ³	Vitrification had smaller volume – a key point in later developments regarding disposal
Disposal	NTS	NTS	

Source: Compiled from ROD OU4 1994, Section 7.2 (pages 58 to 60 of pdf)

Subunit B – Contents of Silo 3

Of the five proposed remedies described in Table 11 the bench-scale studies conducted in the laboratory for the selected remedy, vitrification and offsite disposal of the waste “indicate that vitrification can effectively reduce the tendency of the Silo 3 residues to leach inorganics and radionuclides to groundwater.”⁷⁸ No such claim was made for cementation. Again the preferred alternative was vitrification with offsite disposal at the Nevada Test Site not because of cost⁷⁹ (although the vitrification program was considered cheaper),⁸⁰ but because vitrification would more effectively reduce the potential for radionuclide migration. The option of cementation with onsite disposal and the option of removal (that is without treatment) with onsite disposal would, in accordance with CERCLA Sec. 9621(c), have required a review to be performed every five years to ensure the protection of the environment and human health.⁸¹

⁷⁸ ROD OU4 1994, Section 7.3.1 (page 62 of pdf)

⁷⁹ The DOE does make a reference, in ROD OU4 1994, about the cost effectiveness of the preferred alternative but not in comparison with the cost of cementation. On page 5 of the pdf version it says that “The selected remedy is protective of human health and the environment, complies with Federal and State requirements that are legally applicable or relevant and appropriate to the remedial action, *and is cost effective* [emphasis added].”

⁸⁰ Note, that since disposal costs are not given, it is not possible to make a comparison between the cost of vitrification versus the cost of cementation.

⁸¹ The five year reviews apply to Superfund sites that have been remediated but that still have residual contamination that restricts site use. Their purpose is to insure that the site is still safe and that the cleanup continues to protect people and the environment. (CERCLA, Sec. 9621(c) 2003)

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Table 11: Contents of Silo 3 -- cost, time estimate, and volume comparisons between vitrification, cementation, and removal with onsite or offsite options, as of 1994

	Removal, Vitrification, Onsite disposal	Removal, Cementation, Onsite disposal	Removal, Onsite disposal	Removal, Vitrification, NTS disposal (preferred)	Removal, Cementation, NTS disposal
Capital cost (million)	\$25.2	\$35.9	\$21.8	\$26.8	\$36.8
O&M cost (million)					
During remediation	\$4.9	\$4.9	\$1.1	\$4.9	\$4.1
Post remediation	\$3.2	\$3.2	\$3.2	\$0	\$0
Present worth (1994)	\$28.0	\$37.4	\$22.0	\$28.0	\$36
Years to implement	4	4	2	4	4
Volume before treatment	3,890 m ³	3,890 m ³	3,890 m ³	3,890 m ³	3,890 m ³
Volume after treatment	1,471 m ³	5,999 m ³		1,471 m ³	5,999 m ³

Source: Compiled from ROD OU4 1994, Sections 7.3.1 to 7.3.5 (pages 61 to 65 of pdf).

Subunit C – Silo structures

The chosen remedy for Subunit C consists in the demolition of the silo structures followed by the excavation of the contaminated surface and subsurface soils within the Operable Unit 4 and the earthen berms around Silos 1 and 2 for onsite disposal. The other main actions include the decommissioning and decontamination of structures associated with the past operations of the silos (the decant sump tank for example) and the implementation of the remedial actions (the vitrification facility). The cost estimates for the remediation of Subunit C are given in the table below. Once disposed of in the On-site Disposal Facility (OSDF) the soils and debris of Operable Unit 4 cease to be part of that unit and become part of Operable Unit 5. Consequently, the long-term impacts of Subunit C on the environment and human health will depend on the integrity of the OSDF and its long-term monitoring. We will study these long-term implications in the section of the report on legacy management (Section 6).

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Table 12: Cost comparison for demolition and removal of Silos 1, 2, 3, and 4 structures, soils, and debris, with various disposal options, as of 1994

	Demolition, Removal, Onsite Disposal	Demolition, Removal, Offsite Disposal (NTS)	Demolition, Removal, Offsite Disposal (permitted commercial site)
Capital cost (million)	\$36.3	\$83.6	\$48.6
O&M cost (million)		\$0	\$0
During remediation	\$0		
Post remediation	\$3.6		
Present worth (1994)	\$34.3	\$75.5	\$44.0
Years to implement	2	2	2
Volume	34,956 m ³	34,956 m ³	34,956 m ³

Source: Compiled from ROD OU4 1994, Sections 7.4.1 to 7.4.3 (pages 66 to 68 of pdf)

The remediation of Silos 1, 2, and 3 was near completion as of the end of June 2006:

- Silos 1 and 2 waste had been completely grouted and shipped to WCS in Texas for temporary storage⁸²
- Silo 3 had been packaged and shipped to Envirocare in Utah for shallow land burial⁸³

However, the commitments made in the ROD were not met. Vitrification was abandoned for all three silos. We will examine the radiation dose and health consequences in Section 4.7 of this report.

4.6. Abandonment of initial remediation strategy for OU4

Although disposal in a deep geologic repository was not the chosen method of disposal, the original disposal alternative chosen - vitrification of the waste - may have provided an adequate level of protection from the radiation risks arising from the constituents in the waste if disposed of in such a setting. For example, studies by the French Commissariat à l'énergie atomique (CEA) on the durability of vitrified high level wastes indicate that in a deep repository 99.9% of the glass would still remain intact, even after 10,000 years of contact with water.⁸⁴ According to this calculation it would take 10 million years for the glass to totally disintegrate. After 10,000 years only 1.3% of the original radioactivity of radium-226 remains. However, more radium will be produced by the decay of thorium-230 present in the waste which has a half-life of 75,000 years. Eventually equilibrium will be reached between the decay of thorium-230 and the production of radium-226 until thorium-230 decays significantly. According to these estimates, after 500,000 years 95% of the glass will still be intact while 99% of the thorium-230 will have

⁸² Fernald 2006h

⁸³ Fluor Fernald 2006

⁸⁴ CEA 2002

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decayed away. We recognize that the composition of high level waste from the reprocessing of spent fuel is much different from the composition of the Fernald waste and that the glass characteristics are also different. Further, the rate of leaching of radioactivity from glass depends on the geologic medium, the flow rate of water, and the details of glass composition. Nonetheless, the poor history of grout performance,⁸⁵ the studies of glass performance, and the laboratory studies conducted on the Fernald waste (see below), taken together clearly indicate that vitrification was the best option for the K-65 wastes.

In the 1994 Record of Decision (ROD) it was decided that, among all the alternatives considered, vitrification of the Silos 1, 2, and 3 residues would be the best technology that held the promise to achieve a reduction of the volume of the waste, its toxicity, and mobility.⁸⁶ For Silos 1 and 2, laboratory studies indicated that cement stabilization “does not effectively reduce the radon emission rate from the waste and the tendency of the waste to leach contaminants into groundwater.”⁸⁷ These studies also found that “vitrified material is expected to have greater durability over the long term.”⁸⁸ For Silo 3, laboratory studies also “indicate that vitrification can effectively reduce the tendency of the Silo 3 residues to leach inorganics and radionuclides to groundwater.”⁸⁹

Moreover regarding cost, the remedial investigation found that

Vitrification is more cost effective than cementation because the reduction in volume of vitrified product minimizes the amount of waste requiring handling, resulting in reduced transportation and disposal costs.⁹⁰

The vitrified waste was to be shipped off site to the Nevada Test Site (NTS) owned by the DOE.

In sum, vitrification was chosen because it was deemed to be the best technology for the protection of the environment and human health. The fact that its cost estimate was less than the cost estimate of cementation does not seem to have been an important factor. The ROD 1994 estimated a \$43.7 million cost for vitrification and offsite shipment to NTS for Silos 1 and 2 and \$28 million for Silo 3.⁹¹

The plan for vitrification involved the construction of a pilot plant to study the feasibility of turning the waste residues of the three silos into glass logs. Because of the lack of sound judgment at the start of the project there were a series of problems that eventually led to the destruction of the pilot plant’s melter. *Containing the Cold War Mess* describes in detail the fate of the pilot plant program. One of the main problems was mixing together the contents of Silos 1 and 2, which had similar chemical and radioactive characteristics, with the contents of Silo 3,

⁸⁵ Smith 2004 and Rosenberger et al. 2005 p. 130-135 and 225-228

⁸⁶ The high temperature of the vitrification process destroys the organic contaminants and reduces the volume by evaporating the liquids. The glass matrix reduces the leaching of the contaminants and emission of radon gas and reduces the mobility of metals below the levels required by RCRA.

⁸⁷ ROD OU4 1994, Section 7.2.2 (page 60 of pdf)

⁸⁸ ROD OU4 1994, Section 8.2.1.2 (page 76 of pdf)

⁸⁹ ROD OU4 1994, Section 7.3.1 (page 62 of pdf)

⁹⁰ ROD OU4 1994, Section 10.3 (page 98 of pdf), emphasis added.

⁹¹ ROD OU4 1994, Sections 7.2.1 and 7.3.3 (pages 58 and 63 of pdf)

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which was quite different in some respects, in particular because of its high sulfate content. Another problem was the high lead content of Silos 1 and 2 that was incompatible with the materials used in the melter. Although the ROD did not specifically advise a separate vitrification for Silo 3, it did address vitrification and cementation stabilization alternatives separately from Silos 1 and 2. A common sense approach would have been to, at a minimum, start with the vitrification of the contents of Silos 1 and 2 and then address the contents of Silo 3.

In November 1996, as the pilot vitrification program was experiencing technical difficulties, delays, and cost overruns, Fluor Daniel convened an 11 member Independent Review Team (IRT) to advise it on reassessing the technical approach to vitrification. After the failure of the melter on December 26, 1996, the IRT unanimously recommended that the treatment of Silo 3 waste be done separately from the treatment of Silos 1 and 2 wastes and that vitrification be abandoned for Silo 3 wastes. The IRT recommended vitrification for the contents of Silos 1 and 2 and cementation for Silo 3 contents while meeting Waste Acceptance Criteria of the disposal site (Alternative II, as opposed to Alternative I which called for the vitrification of waste in all three silos).⁹² The abandonment of vitrification for Silo 3 was based on the following reasoning:

Because of the high concentrations of sulfates present in the Silo 3 waste (15 wt%), the entire IRT agrees and recommends that vitrification of Silo 3 waste should not be pursued. Based on the Team's background and experience, materials containing high sulfate concentrations are extremely difficult to control during vitrification and can result in foaming events causing potentially serious operational concerns. In addition, mechanisms used to control the foaming events (e.g., addition of reductants) could reduce waste loading in the glass matrix to an undesirable level. *Again, although a process could be developed to accommodate these conditions, the time and cost to develop two independent melter designs (one for Silos 1 and 2 waste and one for Silo 3 waste) would not be practical nor warranted.* (Emphasis added)⁹³

For Silos 1 and 2, vitrification was still the method recommended but cementation was presented as a contingency alternative (Alternative III) in the event problems "not conducive to vitrification" were encountered or if the stabilization could not be done within time and cost constraints.⁹⁴ The Nevada Test Site remained the offsite disposal destination.

Subsequently, through a series of ROD amendments and Explanations of Significant Differences (ESD), vitrification of the wastes from the three silos was abandoned. Table 13 summarizes these various steps by which the final grouting of Silos 1 and 2 waste was decided, along with the packaging without grouting of Silo 3 waste. None of the wastes are to be disposed of at the Nevada Test Site.

⁹² IRT 1997, page 3

⁹³ IRT 1997, page 5

⁹⁴ IRT 1997, page 6

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Table 13: Summary of post vitrification history for Operable Unit 4 and cost considerations

Source	Method Waste Stabilization	Disposal Site	Official Reasons for Change
1994 ROD (1)	Vitrification for contents of Silos 1, 2, and 3. Meet RCRA TCLP* limits	NTS	
IRT recommendation 1997 (2)	Vitrification for contents of Silos 1 & 2 and cementation for contents of Silo 3. Meet RCRA TCLP limits	NTS	Physical and chemical characteristics of Silo 3 waste different from Silos 1 and 2 Cost and cleanup time containment
1998 ESD Silo 3 (3)	Cementation for contents of Silo 3. Meet RCRA TCLP limits	NTS or a Commercial disposal facility	Cost and cleanup time reductions
2000 ROD amendment Silos 1&2 (4)	Cementation for contents of Silos 1 and 2 Meet RCRA TCLP limits	NTS	Cost containment
2003 ROD amendment Silo 3 (5)	Cementation for contents of Silo 3 abandoned. Abandonment of RCRA TCLP limits. Addition of a liquid solution into the material to reduce dispersability and mobility and packaging in “soft-sided containers”	NTS or a Commercial disposal facility	Revised NTS WAC says RCRA exempt 11e.(2) materials do not “need to meet TCLP –based acceptance criteria, provided the waste is otherwise disposed of in a manner that is protective of human health and the environment” Cost reduction
2003 ESD silos 1&2 (6)	Cementation of contents of Silos 1 & 2 Abandonment of RCRA TCLP	NTS or Commercial disposal facility	Revised NTS WAC says RCRA exempt 11e.(2) materials do not “need to meet TCLP –based acceptance criteria, provided the waste is otherwise disposed of in a manner that is protective of human health and the environment” Cost reduction
2004 ESD UO4 (7)	Cementation of contents of Silos 1, 2. Packaging (not specified) of contents of Silo 3.	Option of temporary offsite storage for a max of two years. Return to Fernald prohibited.	Legal issues raised by the State of Nevada
Feb 2005 Fluor Fernald (News release) (8)	Packaging (not specified) of contents of Silo 3	Envirocare of Utah	
April 2005 Fluor Fernald (News release) (9)	Cementation of contents of Silos 1 and 2	Interim storage in Texas at WCS	
Silo 3 Contingency Packaging Fact Sheet, Dec. 2005 for the remaining waste (10)	Alternate contingency method. Direct loading. No liquid solution to reduce dispersability. Double or single layer polypropylene soft-sided package.	Envirocare of Utah	Different characteristics of the remaining waste to be retrieved and packaged. Timely completion, cost, worker safety. This alternate option was a contingency in case liquid treatment could not be used.

Sources:

(1) ROD OU4 1994, Section 7

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- (2) IRT 1997 pages 1, 5, and 6
- (3) ESD OU4 1998, pages 10 and 11.
- (4) ROD OU4 Amendment 2000, pages DS-2, DS-3 and 1-4.
- (5) ROD OU4 Amendment 2003, pages 1-1, 3-1 to 3-2; 4-3 to 4-4, 4-6;
- (6) ESD OU4 2003, pages 6 to 8.
- (7) ESD OU4 2004 Draft, pages 2 to 3 and 7 to 8.
- (8) Fluor Fernald 2005.
- (9) Fluor Fernald 2005b.
- (10) Fernald 2005p.

As shown in Table 13, cost and time reductions are the two reasons given for the abandonment of the vitrification program for Silos 1 and 2. However, our review (below) of the documents cited in Table 13 for cost estimates shows that, although the costs were estimated to be somewhat higher for vitrification compared to chemical stabilization,⁹⁵ they were still in the same general range. Therefore the loss of protection for health and the environment incurred by the cementation of waste in Silos 1 and 2 is not justifiable on cost considerations. This is especially relevant in view of the fact that the DOE cost estimates for large waste management projects are rarely accurate. These projects often incur large cost overruns.

In fact the drive to reduce costs as well as cleanup time has been based on DOE's overall policy of accelerated cleanup for the entire weapons complex.⁹⁶ This policy gives financial incentives to contractors who accelerate cleanup. For Fernald the target cost of cleanup is \$1.911 billion with a target fee for Fluor Fernald of \$215 million. In case the target cost is exceeded, 70% of the excess cost is shared by the government and 30% by the contractor. On the other hand, if the actual cost is less than the target cost Fluor Fernald would receive 30% of the cost saving, but not to exceed \$288 million. Moreover, this "cost incentive fee shall be reduced by \$8.11 million for each month after December 31, 2006 if the project is not completed" and "increased by \$8.11 million for each month the project is completed earlier than December 31, 2006."⁹⁷ Since there are no serious long-term health and environmental protection performance criteria, the goal of accelerated cleanup has provided every incentive to the contractor to propose methods that compromise that protection if it shortens the completion schedule. The degradation of estimated long-term health and environmental performance for Fernald Silos 1, 2, and 3 is a prime example of this perverse incentive.

The IRT presented various cost estimate differences provided by Fluor Daniel Fernald for the vitrification and cementation alternatives of Silos 1 and 2. (See Table 14).

⁹⁵ "Chemical stabilization" is defined as a non-thermal treatment process that mixes the Silos 1&2 material with chemical additives to accomplish chemical and physical binding of the constituents of concern. These processes provide reduction in contaminant mobility by chemically stabilizing contaminants into a leach-resistant form". (Fernald 2003, page 10). The chemical stabilization treatment finally used for Silos 1 and 2 waste included cementation.

⁹⁶ DOE 1998

⁹⁷ Fernald 2003, page 30

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Table 14: Fluor Daniel Fernald cost estimates for Alternatives II and III, in million dollars.

	Alternative II – Silos 1 and 2 vitrified, Silo 3 cemented ¹			Alternative III- cement all three silos ²		
	Low	Expected	High	Low	Expected	High
Capital costs (retrieval, design & construction)	152	202	241	85	100	124
Operating & Maintenance	50	75	90	25	29	38
Shipping & Disposal	72	80	94	120	198	227
Total Silos 1 & 2	274	357	425	230	327	389
Total Silo 3	22	25	29	22	25	29
Project Management	46	54	57	43	45	50
D & D ³	34	40	52	30	36	45
Total OU4 Silos	376	476	563	325	433	513
Key Milestones						
Start Operations	2006			2003		
Complete D & D	2011			2008		

Adapted from IRT 1997, Table B.8-1 and pages 3 and 7.

¹ Alternative II: vitrification of Silos 1 and 2, cementation of Silo 3

² Alternative III: cementation of all three silos

³ Decontamination and dismantlement

Note: There is no cost estimate for the alternative in which vitrification of Silos 1 and 2 would be conducted separately from the vitrification of Silo 3

Several remarks can be made about the costs in this table

- The difference in the expected cost estimate between cementation and vitrification was only \$30 million (excluding Project Management and Decontamination and Dismantlement costs). Moreover, “[t]he majority of the IRT concludes that because of the high degree of uncertainty in the cost/schedule estimates prepared by FDF, these criteria do not definitively discriminate between the two alternatives.”⁹⁸
- The costs for shipping and disposal of Silos 1 and 2 wastes, whether they were to be vitrified or cemented, are very high compared to the costs cited in more recent documents. For example the 2000 Revised Feasibility Study for Silos 1 and 2 cites disposal costs (costs of containers, transport, NTS burial, and risk) for two vitrification alternatives of \$24.5 million and \$20 million. Similarly, the costs for the two chemical stabilization alternatives are \$57.6 million and \$55.4 million.⁹⁹

⁹⁸ IRT 1997, page 15

⁹⁹ Fernald Feasibility Study 2000, Volume 2, pages C-2-42, C-3-41, C-4-41, and C-5-41

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- The estimated cost for the cementation of Silo 3 was \$22 million to \$29 million; this is less than the \$36 million cited in the 1994 ROD for cementation and offsite disposal. For vitrification and offsite disposal the estimated cost was \$28 million.¹⁰⁰
- The cost estimates for the cementation of Silo 3 waste appear to have been seriously underestimated. Also, a cost estimate for the vitrification of Silo 3 should have been given for comparison.

As a general comment, the costs given in various documents are not well documented, if they are documented at all. Moreover we have found no adequate explanation when they are changed. They vary greatly from one document to the next.

As a result of the changes in the program, the situation, as of the end of June 2006, was as follows:

- The waste in Silos 1 and 2 has now been removed from the silos, treated, mixed with cement, and put in carbon steel containers and shipped by trucks for temporary storage at the WCS (Waste Control Specialists) site in Andrews County, Texas.¹⁰¹
- The waste in Silo 3 has been removed packaged in “soft-side packages.”¹⁰² The offsite shipment by truck to Envirocare’s Tooele County, Utah, site has been completed.¹⁰³

Fluor Fernald claimed that, with the exception of radon emissions, cementation (or grouting) has overall the same level of effectiveness as vitrification in protecting health and the environment.¹⁰⁴ The waste has been put in carbon steel containers that might provide the level of attenuation needed for radon emissions to meet regulations. However, grout is not expected to retain its structural integrity for the period necessary to protect health and the environment from the radionuclides of concern.

IEER has examined questions surrounding the performance of grout in other contexts, which it is useful to recall here. For instance, in a 2004 IEER report on the performance of grout for the high activity sludge in the Savannah River Site high level waste tanks, IEER concluded that DOE’s claim that the use of grout will safely immobilize the radionuclides of concern and consequently be protective of human health and the environment was not based on an adequate scientific analysis:

... and that even within the DOE complex the current lack of information regarding the long-term durability of the grout and its ability to immobilize radionuclides over hundreds to thousands of years is widely recognized.¹⁰⁵

¹⁰⁰ See Table 9 above.

¹⁰¹ Fernald 2005o and Fernald 2006h

¹⁰² Fernald 2005p

¹⁰³ Fluor Fernald 2006

¹⁰⁴ ROD OU4 Amendment 2000, pages 5-5 and 5-14. IRT 1997, page 14, says in regards to Silos 1 and 2 that, “the radon flux from the glass matrix is reduced by 99% when compared to the untreated waste, while the radon flux from the cement matrix is only reduced by 80%.”

¹⁰⁵ Smith 2004, page 1

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Among a number of different examples, the IEER report cites laboratory experiments conducted on the leaching rate of strontium:

Experiments in 1982 at Oak Ridge National Laboratory found a minimum release fraction for strontium in grout of 3.9% and a maximum of more than 50% after just 80 days for various types of grout and lengths of curing times.¹⁰⁶ In 1997 additional experiments at Oak Ridge found a minimum release fraction for strontium of more than 1.25% and a maximum of nearly 2.5% after just one week.¹⁰⁷ While these experiments were conducted with samples that had very large surface to volume ratios compared to the tanks, these results raise serious concerns over the ability of the grout to meet a better than 0.1% annual release rate after 100 years of grout aging and deterioration, and highlights the need for more realistic long-term studies.¹⁰⁸

These experiments on the leach rate of strontium are of relevance in the case of OU4 in light of the chemical similarities of radium and strontium. For example, in their review of radium mobility in soil, the Environmental Protection Agency noted that

...as an alkaline earth element, the adsorption behavior of radium will be similar and somewhat greater to that of strontium for which extensive studies and data exist. For screening calculations of radium migration in soils, the K_d lookup table for strontium in Volume II [of *Understanding Variation in Partition Coefficient, K_d Values* (EPA 2004)] can be used as general guidance for radium.¹⁰⁹

While measurements of the expected leach rate for radium would be needed given its generally greater adsorption, the strontium measurements from Oak Ridge raise concerns over the adequacy of grout as a waste form for the Fernald silo waste.

Furthermore, in their 2005 performance assessment for closing the high level waste Tanks 18 and 19, the operators of the Savannah River Site assumed that the grout would turn to sand between 100 and 5,000 years after closure, with a base case estimate of just 500 years. For all of the tanks combined, the SRS report assumed that the grout would fail and turn to sand after 1,000 years on average, with a standard deviation of 250 years.¹¹⁰ Given the relatively long half-life of radium (1,600 years), a significant amount of the original radioactivity would remain over these timescales. Further, since radium-226 will also be produced as a decay product of thorium-230, which has a half-life of about 75,000 years, both of these radionuclides will pose a waste management problem for extremely long periods.

The addition of a protective layer in the form of a carbon steel container would, for a time, limit degradation of the Fernald waste form. However carbon steel itself has limited corrosion resistance.¹¹¹ A paper presented at a DOE/NRC conference reports that the average estimated life of carbon steel containers is 23 years.¹¹² Moreover it is well known that the corrosion of

¹⁰⁶ Morgan et al. 1982, page 9

¹⁰⁷ Spence and Kauschinger 1997, page 36

¹⁰⁸ Smith 2004, page 3

¹⁰⁹ EPA 2004, page 5.67. See also Smith and Amonette 2006 for a technical review of radium mobility in soil.

¹¹⁰ Rosenberger et al. 2005 pages 130-135 and 225-228

¹¹¹ Key-to-Steel.com 2005 and Yilmaz, Chandra, and Rebak 2005

¹¹² Yim and Simonson 1994, page 121.

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steel in reinforced concrete accelerates the degradation of concrete surrounding the rebar.¹¹³ Thus, the corrosion of the carbon steel containers could pose additional concerns for the long-term durability of the grout.

In light of the estimated degradation of the performance for the final options that were actually implemented for Silos 1, 2, and 3, we will examine the official reasons and record of the changes that were made, first for Silo 3 and then for the other two.

4.6.1 Abandonment of Silo 3 vitrification program and final disposal

In this section, we will examine chronologically, through the Explanations of Significant Differences (ESD), Records of Decision, and other decisions, the degradation of the waste management program for Silo 3.

1998 ESD Silo 3: Abandonment of vitrification for cementation

The 1998 *Final Explanation of Significant Differences for Operable Unit 4 Silo 3 Remedial Action* stated that chemical stabilization (i.e., cementation or grouting) of Silo 3 waste would give a similar level of protection for the public and the environment and would be as cost effective as the vitrification alternative. It stated that cost estimates for vitrification “could be as much as several times higher than the cost to treat the material using an alternate process.”¹¹⁴ The arguments against vitrification were that:

- Because the vitrification of the Silo 3 wastes would have to be carried out separately from the vitrification of Silos 1 and 2 wastes, it would necessitate the development of two melter designs, thereby creating a significant extension of the treatment time required. No cost estimate was given for that option.¹¹⁵
- The dilution of the sulfate rich waste before vitrification would result in an increase in volume of the vitrified waste leading to an increase in costs for the operation and maintenance, packaging, transportation, and disposal.¹¹⁶

2003 ROD Amendment Silo 3: Abandonment of cementation for disposal of untreated material

At the time of the 1994 Record of Decision for Operable Unit 4 the Nevada Test Site required

...that all treated or untreated waste accepted for disposal at the facility -- regardless of its statutory exempt or non-statutory exempt status -- meet TCLP limits for toxicity-characteristic constituents regulated under RCRA.¹¹⁷

¹¹³ Fang et al. 2004, Arya and Ofori-Darko 1996

¹¹⁴ ESD OU4 1998, page 9.

¹¹⁵ ESD OU4 1998, page 8.

¹¹⁶ ESD OU4 1998, pages 8 and 9.

¹¹⁷ ROD OU4 Amendment 2003, page 2-6

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But as explained in the 2003 *Final Record of Decision Amendment for Operable Unit 4 Silo 3 Remedial Actions*, in February 2002, the Nevada Test Site updated its Waste Acceptance Criteria to require that only RCRA regulated waste meet the TCLP limit. This meant that

Statutorily exempt materials, such as 11e(2) materials, no longer need to meet TCLP-based acceptance criteria, provided the waste is otherwise disposed of in a manner that is protective of human health and environment. As part of an eligibility evaluation, a waste profile for each statutorily exempt waste must be reviewed individually to ensure that protective requirements are met for the constituents that would otherwise be regulated under RCRA.

During May 2002, Nevada Test Site regulatory personnel completed a draft waste profile review for the statutorily exempt Silo 3 material, and deemed the material to be acceptable for disposal at the facility without the need for further treatment.¹¹⁸

This new development, along with a newly available option of shipping the waste to a permitted commercial disposal facility that would accept the waste in an untreated form, prompted Fluor Fernald to abandon the cementation option for Silo 3. Instead, the new plan consisted of adding a liquid solution to reduce the dispersability of the waste and package it in plastic bags. Fluor Fernald claimed that the short- and long-term effectiveness of the new process will be protective of the public and the environment. One of the reasons for abandoning cementation seems to have been cost-related, as shown in Table 15, although the ROD states that the difference in cost of \$13 million is within the estimation errors. The other, more likely, reason is that the new plan presented some time-saving advantage over cementation. This is implied in the ROD Amendment discussion:

“Under the revised remedy the waste will be removed from Silo 3 employing both pneumatic and mechanical systems. These waste retrieval systems remain unchanged from the previous remedy.... The previous remedy would require the construction and operation of a chemical stabilization/solidification processing system, which includes the wetting of the material and addition of one or several chemical reagents. ...Under the revised remedy, this chemical processing system will not be constructed; in its place a system will be installed to add a liquid solution to the Silo 3 material as it enters the package, in order to raise the waste’s moisture content and reduce its dispersability and mobility.”¹¹⁹

¹¹⁸ ROD OU4 Amendment 2003, page 3-1

¹¹⁹ ROD OU4 Amendment 2003, pages 4-2 and 4-3

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Table 15: Summary of cost data comparison between cementation and packaging of Silo 3 waste

Summary Cost Data (\$ Million)		
Alternative	Previous Cleanup Plan Cementation	Revised Cleanup Plan Disposal in Plastic Bags
Capital Cost	20.0	14.0
Engineering, Proj. Mgmt., Const. Mgmt. and Startup Cost	15.0	15.0
Operation and Maintenance Cost	7.0	4.0
Transportation ¹ and Disposal Cost	11.0	7.0
D & D Cost	2.0	2.0
Total Cost	55.0	42.0

Adapted from ROD OU4 Amendment 2003, page 5-10.

¹ It is assumed that the waste will be transported by truck to NTS.

Final disposal and packaging

As described in Section 4.1, the Energy and Water Development Appropriations Act of 2004 disqualified NTS as an appropriate site to receive the waste from Silos 1, 2, and 3. The Silo 3 waste was mixed with an additive for reducing dispersability. Shipment of the waste to the Envirocare site in Utah was completed in April 2006.¹²⁰ (IEER's long-term environmental analysis of Silo 3 waste is provided in Section 4.8).

4.6.2 Abandonment of Silos 1 and 2 vitrification program and final disposal

In this section, we will examine, chronologically, through examination of the Explanation of Significant Differences, Records of Decision, and other decisions, the degradation of the waste management program for Silos 1 and 2.

OU4 ROD amendment 2000 for Silos 1 and 2

The 2000 *Final Record of Decision Amendment for Operable Unit 4 Silos 1 and 2 Remedial Actions* stated that the U.S. EPA had determined that an amendment was needed due to cost overruns (about three times the original estimate) in the implementation of the vitrification program.¹²¹ It is unclear why the costs of vitrification tripled during the pilot plant program. Poor overall management, such as lack of coordination in design of the melter and the other parts of the vitrification pilot plant, and the fact that the wastes from the three silos were to be mixed together in one melter, were probably contributory factors.¹²² However, no serious analysis on the cost escalation is available.

¹²⁰ Fluor Fernald 2006

¹²¹ ROD OU4 Amendment 2000, page 3-3

¹²² See Fioravanti and Makhijani 1997, pages 231 to 251

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The estimated cost comparisons between vitrification and chemical stabilization given in Table 16 do not support the abandonment of the vitrification program for Silos 1 and 2, since the cost differential was not large, given the multi-billion dollar cost of the Fernald remediation program, and the fact that Silos 1 and 2 wastes contained wastes with the highest specific activities, by far, for the Fernald site. The cost difference between the most expensive vitrification alternative and the cheapest chemical stabilization (grouting) alternative was about \$50 million per silo or less than 20%.

Table 16: Cost estimates (in million dollars) for vitrification and chemical stabilization alternatives for Silos 1 and 2 waste

Alternative	Vitrification		Chemical Stabilization	
Process Option	VIT 1 ¹	VIT 2 ²	CHEM 1 ³	CHEM 2 ⁴
Capital Cost	69	67	55	56
O&M Cost	134	133	77	83
Waste Disposal Cost	25	20	58	55
D&D Cost	35	38	34	36
Engineering Cost	25	25	24	24
Project Management Cost	22	22	21	21
Cost of Money	46	37	28	28
Summary Cost (un-escalated)	356	342	297	303

Adapted from ROD OU4 Amendment 2000, Table 5.2-2, page 5-23, which used data from the Fernald Feasibility Study 2000, Section 3.

Note: CHEM 1 is a “cement-based stabilization process” and CHEM 2 is a “chemical stabilization process other than a cement-based process.” (Fernald Feasibility Study 2000, v.3, pages D-2-4 and D-2-5)

¹ VIT 1: “Removal, On-site Vitrification – Joule-heated, Off-site Disposal at the NTS” (ROD OU4 Amendment 2000, page d-vi)

² VIT 2: Removal, On-site Vitrification – other, Off-site Disposal at the NTS (ROD OU4 Amendment 2000, page d-vi)

³ CHEM 1: Removal, onsite chemical stabilization – cement based, offsite disposal at the Nevada Test Site (ROD OU4 Amendment 2000, page d-v)

⁴ CHEM 2: Removal, onsite chemical stabilization – other, offsite disposal at the Nevada Test Site (ROD OU4 Amendment 2000, page d-v)

2004 ESD OU4

As described in section 4.1, the Envirocare site in Utah failed to get a license amendment to qualify it to receive the waste from Silos 1 and 2 and subsequently the Energy and Water Development Appropriations Act of 2004 of Congress disqualified NTS as an appropriate site to receive the waste from Silos 1, 2, and 3. In the *Draft Final Explanation of Significant Differences for Operable Unit 4 Remedial Actions*

In order to ensure that there is not a fundamental change to the scope, performance, or cost of the OU4 remedy, the modified remedy will include the following constraints:

- ...
- Storage will be limited to a period of two years....

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- Under no circumstances will it be allowable for the silo material to be returned to the FCP [Fernald Closure Project] after it has been transported to an offsite facility for temporary storage and/or final disposal.¹²³

Temporary status – but final for Fernald

Silos 1 and 2 waste has been grouted. Shipment to the Waste Control Specialists site in Texas was complete in late May 2006. While storage at the Waste Control Specialists site is supposed to be temporary – at most two years, WCS is applying for a license to permanently dispose of the waste. But it is far from certain that it will get it or that it is qualified to handle radioactive materials. See Section 4.7 below for a detailed discussion. The shipment out of Fernald is, however, final, since the final action prohibits return of the waste to Fernald, no matter what the circumstances.

4.7. Radiation dose consequences of changes in silo waste management

The grouted Silos 1 and 2 waste has been sent to Waste Control Specialists (WCS) in Andrews County, Texas, for two-year interim storage.¹²⁴ Currently, WCS does not have a license to dispose of radioactive waste but it has applied for two licenses, one with the Texas Commission on Environmental Quality (TCEQ) that would allow it to dispose of low level radioactive waste¹²⁵ and one with the Texas Department of State Health Services (TDSHS) specifically for 11e.(2) byproduct material waste.¹²⁶ In the event the latter license is granted, WCS will be authorized to not only receive the Fernald waste on an interim basis, but also WCS will be authorized to dispose of it permanently.

In this section we will estimate the long-term radiation dose and compliance consequences of the changes in the strategy that DOE has made in the Records of Decision for the Wastes in Silos 1, 2, and 3. Since the disposal approach adopted is shallow land burial, we have performed RESRAD calculations estimating the dose consequences at the indicated sites.¹²⁷ For Silos 1 and 2, the indicated site is the WCS Site in Texas, because the waste has been transferred there from Fernald. However, as noted, that site does not have a license to permanently dispose of radioactive waste. Recently the Texas Commission on Environmental Quality, in a letter to the President of WCS, has been very critical of the deficiencies in WCS's license application to dispose of low level radioactive waste. The TCEQ wrote that:

...outstanding technical issues are problematic and affect our ability to offer a recommendation to issue a license for the proposed facilities.

¹²³ ESD OU4 2004 Draft, page 8

¹²⁴ Fernald 2006h. WCS is permitted to receive the Silos 1 and 2 waste under its Radioactive Material License L04971. (WCS License L04971 Amendment 38, Section 25)

¹²⁵ WCS License Application LLRW

¹²⁶ WCS License Application Byproduct

¹²⁷ The RESRAD computer code we have used was developed by Argonne National Laboratory to estimate the health risks at sites from residual radioactivity.

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Some significant issues remaining unresolved include the incomplete characterization of the site, performance assessment, waste characterization, and facility design as described below.

- The site characterization does not sufficiently demonstrate depth to the water table. It has not been adequately demonstrated that groundwater will not intrude into the disposal units and contact waste.
- The application does not sufficiently discuss surface geologic processes, such as erosion, to demonstrate that these processes will not affect the ability of the disposal site to meet the performance objectives and to provide defensible modeling and prediction for long-term impacts. The application lacks site-specific data on surface geologic processes to support conclusions made in the application.
- The performance assessment does not appear to use defensible assumptions in the modeling or use adequate waste characterization for the basis of the assessment.
- Waste characterization information in the application appears to be an underestimation in terms of total radioactivity and specific radionuclide concentration. This underestimation impacts performance assessment, worker dose calculations, accident scenario assessments and the overall assessment of the site in meeting required performance objectives.
- The facility design does not comply with TCEQ rules with respect to the proposed disposal of Class A low level radioactive waste containing longer-lived radionuclides.¹²⁸

Although the TCEQ letter refers to the low level waste disposal license application, most of the technical issues that are addressed would also apply to the byproduct license application. In addressing the deficiencies of the WCS license application, the TCEQ demonstrates its current lack of confidence in WCS's ability to understand the challenges of handling radioactive waste. If the byproduct materials disposal license is found to be similarly deficient, the ultimate fate of the Fernald waste will be very uncertain. However, since the waste is at the WCS site, we have performed the RESRAD calculations for parameters corresponding to this site, both as regards disposal cell design and site specific parameters such erosion rates.

Silo 3 waste has already been completely transferred to the Envirocare site in Utah for disposal. Hence we have done calculations for Silo 3 waste corresponding to parameters for this site.

4.7.1 Silos 1 and 2 long term dose estimates and compliance conclusions

IEER's analysis of WCS capabilities in its July 2005 update to the *Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico by LES* revealed that WCS lacks basic scientific competence in the areas of uranium radiochemistry. IEER concluded that WCS was unqualified to manage or dispose of uranium bearing wastes. The IEER report also raised issues with the

¹²⁸ TCEQ 2006

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assessment in the WCS license application to dispose of low level radioactive waste, regarding the potential for erosion at the site.

These issues are described in greater detail below. Reservations regarding the WCS analysis were also expressed by the Texas Commission on Environmental Quality that noted that “[a]dditional information may be required on soil erodability indices and data quality regarding the soil formations.”¹²⁹

Here we examine the performance for cemented waste using the RESRAD model. Performance estimates depend critically on parameters chosen for modeling the site. The parameters we have used to carry out our RESRAD calculations come from several places. We have used the relevant parameters from (i) the WCS license application for low level radioactive waste disposal, mentioned above, that apply to the Federal Waste Facility,¹³⁰ (ii) the WCS byproduct license application, also mentioned above, and (iii) the parameters derived from our calculations and assumptions as explained below. This last case applies in particular to the erosion rate parameter. WCS uses an erosion rate of zero while we do not. We will explain below the reason for choosing a different erosion rate. In Table 17 the parameters that we calculated are in bold, the parameters taken from the WCS byproduct license application are in italic, and the parameters taken from the WCS LLRW license application are in normal font. In Table 18 all the parameters are from the WCS byproduct license application.

The WCS license application for byproduct materials does not give an estimate for the dilution of the waste that would occur in the trench in which the Fernald waste would be buried. However, part of the WCS license application for low level radioactive waste addresses the disposal of low level radioactive waste from DOE sites. That license application gives the total waste volume destined for WCS from all the DOE sites as well as the dimensions of the disposal site in which it would be disposed.¹³¹ From this we calculated the approximate dilution of the federal low level waste and applied it to the Fernald waste. We have used the same methodology to calculate the average waste concentration in the disposal facility as was applied in WCS’s license application for low level radioactive waste and averaged the radium, lead, and thorium activity over the total volume of the waste, including the volume of the canisters and fill materials. We have chosen the scenario of a rancher with a 100% outdoor occupancy and restricted the pathway analysis to the external, inhalation, and radon pathways to reflect an intruder scenario in which there would be no occupancy of a house or consumption of food grown on the site. The choice of 100 % occupancy allows the dose rate to be more easily calculated. This makes the estimation of dose from partial occupancy simpler, as discussed below. Residential occupancy of the site would somewhat decrease the external dose due to shielding, but would significantly increase the inhalation dose due to radon. The consumption of food grown on the site would also significantly increase the dose, as the cover of the disposal facility erodes and the direct uptake of radioactivity from the roots becomes possible.

¹²⁹ Wheatley 2005, Attachment A, page 5

¹³⁰ The WCS License Application LLRW is for two separate disposal units; the Compact Waste Facility and the Federal Waste Facility. The Compact Waste Facility will accept waste from the Texas compact states. The Federal Waste Facility will accept low level radioactive waste from DOE facilities.

¹³¹ WCS License Application LLRW, Appendix 8.0-2, page 6, August 2, 2004 and Appendix 8.0-6, page 32, August 2, 2004

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The total source term for the Silos 1 and 2 waste is 6,100 curies. Of this, 3,700 curies arise from radium-226, 600 curies are due to thorium-230, and 1,800 curies are from lead-210.¹³²

Table 17: RESRAD parameters

Parameter	WCS and IEER
Specific activity of radium-226 nCi/g	11.26
Specific activity of lead-210 nCi/g	5.48
Specific activity of thorium-230 nCi/g	1.83
Waste disposal area (m²)	19,570
<i>Waste thickness (m)</i>	<i>8.23</i>
Waste length parallel to the aquifer (m)	140
<i>Cover thickness (m)</i>	<i>9.14</i>
<i>Cover density (g/cm³)</i>	<i>2.135</i>
<i>Waste density (g/cm³)</i>	<i>2.041</i>
Cover erosion rate (m/year)	0.001 and 0.0001
Waste erosion rate (m/year)	0.001 and 0.0001
<i>Infiltration rate (m/year)</i>	<i>0.002906</i>
<i>Water table drop rate (m/year)</i>	<i>0</i>
Evapotranspiration coefficient	0.91
<i>Saturated zone hydraulic gradient</i>	<i>0.016</i>
Wind speed (m/s)	3.1
Precipitation (m/year)	0.36
Runoff coefficient	0.91
Well pump intake depth (m)	8.53
Water table drop rate (m/year)	0

Adapted from: WCS License Application LLRW, Appendix 8.0-6, Table 8.0-6.9-1, page 8.0-6-32, August 2, 2004, for WCS's Federal facility, and WCS License Application Byproduct, Table 5.3, Sept. 30, 2005.

Note: Activities are expressed in terms of nanocuries of the radionuclide per gram of waste. The rows in bold are based on IEER's calculations; the rows in normal font are from the WCS License Application LLRW and the rows in italics are from the WCS License Application Byproduct.

Table 18: RESRAD parameters for hydraulic properties

	Unsaturated zones 1&2	Unsaturated zone 3	Unsaturated zone 4	Saturated zone
Density (g/cm ³)	2.14	2.04	2.14	2.04
Porosity	0.301	0.140	0.301	0.140
Hydraulic conductivity (m/yr)	0.001	0.110	0.001	0.011
Radium Kd	9,100	500	9,100	500
Thorium Kd	5,800	3,200	5,800	3,200
Lead Kd	550	270	550	270

Adapted from: WCS License Application Byproduct, Table 5.4, Sept. 30, 2005.

¹³² ROD OU4 1994, Section 5.2.2 (page 25 of pdf)

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Erosion rate parameter

We have chosen erosion rate parameters different from the ones used by WCS for reasons related to the nature of the site itself. The analysis here is taken directly from the July 5, 2005, IEER report entitled: *Update to Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico by LES*.¹³³ Since it applies equally to the disposition of the Fernald waste, we will summarize the arguments put forward in that report.

The WCS site is situated in a semi-arid region of Texas. With respect to the potential for surface erosion at the site, the WCS license application claimed that

As is typical of these arid climates, it is generally interpreted that active erosion processes have a minimal impact in the area. Lehman (2000) suggests that the present landscape of the Southern High Plains is in dynamic equilibrium; erosion by overland flow is balanced by deposition through runoff, and wind erosion is balanced by sediment deposition from upwind source areas.¹³⁴

However this claim is not backed by the preliminary conclusion of Stephen D. Etter, a geologist with the Texas Natural Resource Conservation Commission (TNRCC). On the contrary, in an April 1996 draft memo he states that

The WCS site [in Andrews County] is clearly an erosional area and nothing short of a wholesale change in geologic and climatic conditions is likely to alter the situation in the foreseeable future. Even stopgap engineering measures to slow erosion must be considered only temporary fixes in the long-term. Eventually the radioactive wastes will be exposed by erosion and available for migration into the environment.¹³⁵

With respect to rate of erosion, Stephen Etter notes that

Detailed geomorphological studies have not been done for the Andrews County site and long-term erosion rates are not known. The site is located directly on the caprock “escarpment,” which, although at the site appears relatively flat to the eye, is a gently sloping erosional feature. Rough calculations by staff indicate that if the escarpment in the vicinity of the WCS site continues to retreat due to erosion at the same average rate that it has retreated since the integration of the Pecos River system 600,000 to 2 million years ago, then wastes disposed of at the WCS site could be exposed and removed within 5,000 years.¹³⁶

In order to resolve these two opposite conclusions IEER conducted its own investigation by enrolling the help of Dr. James Carr, a Professor of Geological Engineering at the University of Nevada-Reno.¹³⁷ His entire opinion (dated May 16, 2005) is included below:

¹³³ Makhijani and Smith 2005, pages 12-15

¹³⁴ WCS License Application LLRW, Rev.9, Nov 30, 2005, vol.1, page 2-41

¹³⁵ Etter 1996, page 7

¹³⁶ Etter 1996, page 7

¹³⁷ From 1983 to 1986 James Carr was an Assistant Professor of Geological Engineering at the University of Missouri-Rolla and has been a professor of Geological Engineering at the University of Nevada-Reno since then (Assistant Professor – 1986 to 1989, Associate Professor – 1989 to 1994, and Professor – 1994 to present). He has authored numerous peer reviewed technical papers and is the author of two textbooks entitled *Numerical Analysis for the Geological Sciences* (1995) and *Data Visualization in the Geosciences* (2002). The complete curriculum vita

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I have completed my review of the article, “An Assessment of Long-term Erosion Potential at the WCS Facility, Andrews County, Texas,” by Thomas M. Lehman, Department of Geological Sciences, Texas Tech University. I have also reviewed the TNRCC Preliminary Staff Memo that discusses erosion at the WCS Site.

With respect to the Lehman paper, I have the following concerns:

1. Rates of erosion (denudation) are highest for semi-arid environments; the climate at the WCS site is semi-arid, consequently this geographic location should be expected to have a net loss of sediment with time, not a net accumulation.¹³⁸ I agree with the TNRCC Preliminary Staff Memo on this issue that the WCS site is an erosional area.

2. The Lehman paper seems to dismiss climate change as important to the WCS site, although indicating at the bottom of page 3 that the last episode of incision by streams near the WCS site was 20,000 years ago to 12,000 years ago, a period of time that was associated with the most recent ice age; this paper later (page 15) dismisses climate change as a potential problem by noting that increased aridity is predicted to result in the formation of sand dunes consistent with nearby geomorphological features and further stating that increased humidity will result in denser vegetative cover with associated decrease in erosion. In fact, increased aridity may result in increased erosion because vegetation cover is decreased, moreover erosion by water is the most potent erosive agent in deserts; maximum rates of denudation in arid regions are sometimes unknown and may exceed rates observed in semi-arid regions, rates in excess of 100 cm in 1000 years. If precipitation increases at the site, it is uncertain how rapidly vegetation density will increase with increased moisture levels. Erosion rates may be very high initially until vegetation density increases.

3. The most uncertain aspect of long-term erosion rates at the WCS site is the affect that changes in climate will have. Construction of the WCS facility should include a design for erosion mitigation. The maximum rate of erosion observed anywhere is that which occurs in Badlands-type topography, up to 1 meter of erosion per year (100,000 cm over 1000 years; Saunders and Young, 1983, “Rates of surface processes on slopes, slope retreat and denudation,” *Earth Surface Processes and Landforms*, v. 8, pp. 473-501). Rates or denudation in semi-arid regions are 10 to 100 cm over 1000 years (0.01 to 0.1 cm per year) and rates of denudation in arid regions range from as little as 1 cm per 1000 years to a maximum amount that is not known. Given this highly variable rate of erosion, the design of the WCS facility should include erosion control.

4. Rates of erosion for different climates are listed below and are from the Saunders and Young, 1983, article that is referenced in item 3 above:

Climate	Relief	Range of Erosion Rates
Glacial	Normal (ice sheets)	5 – 20 cm / 1000 years
	Valley Glaciers	100 – 500 cm / 1000 years
Polar		1 – 100 cm / 1000 years
Temperate maritime	Normal	1 – 10 cm / 1000 years
Temperate continental	Normal	1 – 10 cm / 1000 years
	Steep	10 – 20+ / 1000 years
Mediterranean	Normal	1 – ? cm / 1000 years
Semi-arid		10 – 100 cm / 1000 years
Arid		1 - ? cm / 1000 years
Subtropical		1? – 100? Cm / 1000 years
Savanna		10 – 50 cm / 1000 years
Rainforest	Normal	1 – 10 cm / 1000 years
	Steep	10 – 100 cm / 1000 years
Any Climate	Badlands	100 – 100,000 cm / 1000 yrs

of Professor Carr accompanies this report. Dr. Carr provided his opinion to IEER pro bono, for which we thank him.

¹³⁸ Professor Carr talks about a net loss of sediment rather than a net accumulation in reference to a sentence that has now been taken out of the WCS license application for low level radioactive waste. The sentence “Lehman (2000) concludes that not only is the area not subject to significant long-term erosion, the area is more likely subject to slow depositional buildup due to addition of wind-blown sand and sediments,” which was in WCS 2004, v.1, page 2-43, but has been taken out of the version cited in this report.

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Please let me know if you have any questions about this letter, or need clarifications of any statements herein.¹³⁹

The 0.01 to 0.1 centimeters per year range of erosion rates cited by Dr. Carr for a semi-arid region are taken from the Saunders and Young, 1983, “Rates of surface processes on slopes, slope retreat and denudation,” *Earth Surface Processes and Landforms*, v. 8, pp. 473-501.

The thickness of the cover on the byproduct disposal facility is to be 9.14 meters (See Table 17). Therefore an erosion rate of 0.1 cm per year would expose the waste after 9,140 years. An erosion rate of 0.01 cm per year would expose the waste after 91,400 years.

The results of our RESRAD calculations using the parameters in Tables 17 and 18 are summarized in Table 19 below.

Table 19: Peak doses from grouted K-65 waste disposal (for a period less than 100,000 years) – Rancher Scenario

Grouted waste			
Erosion rate (cm per year)	Peak external dose (rem per year)	Peak inhalation dose (rem per year)	Year of peak dose
0.1	20.1	0.078	9,150
0.01	8.7	0.037	91,500

In both cases radium-226 accounts for 99.5% of the peak dose. The dose for the higher erosion rate is 800 times higher than the 25 millirem limit per year. This means that a person would have to spend only 11 hours on the site for the 25 millirem limit to be violated. Similarly the lower erosion rate gives a dose that is 346 times higher. In that case, a person would have to spend 25 hours on the site to receive a dose of 25 millirem. However, note that the radium that is present after an elapsed time of more than a few thousand years is essentially all from the alpha-decay of thorium-230 (half-life about 75,000 years) since the originally present radium-226 (half-life 1,600 years) would have decayed away nearly completely.

Since the peak dose is estimated to occur between 9,150 and 91,500 years for the two erosion scenarios, it is reasonable to assume that there will be no institutional memory of waste disposal at the site. It is therefore reasonable to assume that occupancy of the site for agricultural purposes could be one of the many future land uses. We have therefore calculated a dose using the scenario of an autarchic farmer,¹⁴⁰ that is, a farmer (and his family) who uses onsite water and grows all the food the family consumes. Table 20 below summarizes the results of our RESRAD calculations.

¹³⁹ Carr 2005

¹⁴⁰ The autarchic farmer is also called the “subsistence farmer” in radiation protection literature. We use the term “autarchic farmer” since, unlike the term “subsistence farmer,” it does not have a connotation of low income. It simply conveys a literal meaning that the farmer will produce all that he/she locally consumes, using local water resources.

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Table 20: Peak doses from grouted K-65 waste disposal (for a period less than 100,000 years) – Farmer Scenario

Grouted waste			
Erosion rate (cm per year)	Peak non-radon total dose (rem per year)	Radon at year of peak dose (rem per year)	Year of peak dose
0.1	35.6	120	9,150
0.01	15.4	53.6	91,500

When the dose from radon is excluded, radium-226 accounts for 61% of the peak dose and lead-210 accounts for 38% in both cases. The main contribution, 58%, comes from plant ingestion, while external radiation contributes 34% of the dose. The dose from radon contributes 76% of the total dose in both cases. The total dose for the higher erosion rate is 6,000 times higher than the 25 millirem limit per year. This means it would take only 1.5 hours for a person to be on the site for the 25 millirem limit to be exceeded. Similarly the lower erosion rate gives a dose that is 2,600 times higher. In that case, a person would have to spend a little less than 4 hours to receive a dose of 25 millirem. The high dose rate, including the high external dose rate from gamma radiation, means that even a short time intruder, such as a person hunting or grazing animals, would be exposed over the 25 millirem limit in a few hours. Hence, it is not necessary in this case to assume a conservative scenario for the future for the dose limits to be exceeded. It is clear that given the likely uncovering of the site by erosion, the 10 CFR 61 dose limit of 25 millirem per year would be exceeded in a wide variety of circumstances, such as transient hunting, grazing, or recreation, in addition to residence with or without local water use and with or without consumption of locally produced food.

4.7.2 Silo 3 long term dose estimates and compliance conclusions

The waste from Silo 3 contained in soft-sided bags has been sent to Envirocare of Utah for disposal. In this section we have done a dose calculation using the RESRAD program to determine whether the disposal of the waste in this manner will meet the regulations set forth in 10 CFR 61 Subpart C.

Envirocare operates two low-activity radioactive waste cells at its facility in Tooele County, Utah. The designs for the two facilities are “very similar,” and thus we have chosen to focus on the newer Western LARW for our illustrative example.¹⁴¹ The 2000 *Revised Envirocare of Utah Western LARW Cell Infiltration and Transport Modeling*, prepared by Whetstone Associates for Envirocare, contains a description of the cell and an analysis of the hydrologic properties of the engineered cover system. As discussed in the introduction, the purpose of this performance assessment was as follows:

The groundwater discharge permit for the Western LARW cell requires that environmental impacts to groundwater are kept within tolerable risk levels. In order to assess these risks, the flow of water and transport of constituents from the Western LARW disposal cell to a compliance well must be predicted for a period of 200 and 500 years after closure, for hazardous and radioactive constituents, respectively. The purpose

¹⁴¹ Whetstone 2000 page 5

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of this document is to describe the assumptions, input parameters, and results of the infiltration and fate and transport modeling.¹⁴²

The design of the LARW cells includes a variable thickness of waste and a cover that is partially above ground. In order to model this system in RESRAD and explore whether such disposal would be likely to meet regulatory limits we chose to consider a uniform thickness for the waste which was comparable to the average thickness of the waste in the cell. In addition, we used the estimate from the Whetstone analysis for the amount of water infiltration through the cover and assumed that no waste would be exposed until the entire thickness of the engineered cover was eroded. This arrangement also satisfied the additional constraint that none of the Silo 3 waste could be less than 10 feet below the ground surface (taken to be the top of the cover) due to the high thorium content of the waste (see Section 4).

The Western LARW cell at Envirocare has the following design features:

- a two foot compacted clay liner of low permeability below the waste,
- an average waste height of 42.8 feet,
- a seven foot clay cover for limiting the diffusion of radon and limiting water infiltration, and
- a three and half foot thick filter zone and erosion barrier.¹⁴³

Based on these descriptions, we have assumed that:

- the waste is buried 10.5 feet (3.2 meters) below the surface,
- the thickness of the waste is 40 feet (12 meters), and
- the average specific activity of the waste to be buried is the same as the average radioactivity that was in Silo 3.

Table 21 lists the parameters that we have used for our calculations which were different than the RESRAD default values.

¹⁴² Whetstone 2000, page 1

¹⁴³ Whetstone 2000, page 5

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Table 21: RESRAD parameters

Parameter	Envirocare and IEER
Specific activity of thorium-230 nCi/g	51.2
Specific activity of radium-226 nCi/g	2.97
Specific activity of lead-210 nCi/g	2.62
Waste disposal area (m²)	324
Waste thickness (m)	12
Waste length parallel to the aquifer (m)	18
Cover thickness (m)	3.2
Cover erosion rate (m/yr)	0.001 and 0.00055¹
Waste density (g/cm ³)	1.8
Waste erosion rate (m/yr)	0.001 and 0.00055
Precipitation (m/year)	0.2
Infiltration rate (m/year)	0.00265 to 0.00310
Saturated zone effective porosity	0.29
Saturated zone hydraulic conductivity (m/year)	239
Saturated zone hydraulic gradient (m/m)	0.001
Unsaturated zone 1 thickness (m)	0.6
Unsaturated zone 1 hydraulic conductivity (m/year)	0.3
Unsaturated zone 1 density (g/cm ³)	1.8
Unsaturated zone 2 thickness (m)	4.43
Unsaturated zone 2 hydraulic conductivity (m/year)	189 to 429
Unsaturated zone 2 density (g/cm ³)	1.57
Kd for thorium-230 (cm ³ /g) (low value)	10
Kd for radium-226 (cm ³ /g) (low value)	10
Kd for lead-210 (cm ³ /g) (low value)	19
Kd for thorium-230 (cm³/g) (default value)	60,000
Kd for radium-226 (cm³/g) (default value)	70
Kd for lead-210 (cm³/g) (default value)	100

Adapted from Whetstone 2000.

Note: The rows in bold are IEER's parameters.

¹ The high value of 0.001 meter per year for the erosion rate corresponds to the lower end of the range of erosion rates for a semi-arid region such as would apply to the Envirocare site. This value also corresponds to the RESRAD default value. The low value of 0.00055 meter per year is the arithmetic mean of the low and high values for the range of erosion rate of a semi-arid region. See Section 4.7 for the discussion on erosion rates in a semi-arid region.

Note that Table 21 gives a range of values for the infiltration rate and for the hydraulic conductivity of the unsaturated zone 2. We have run RESRAD several times using combinations of the lower and upper values. The peak doses for the rancher scenario and the outdoor radon flux were not significantly affected by this choice. Table 21 shows also the RESRAD default values for the distribution coefficients (Kds) of thorium, radium, and lead. These values are considerably higher than the values used by Whetstone Associates in its performance assessment for Envirocare. Whetstone Associates states that "[t]he most conservative (lowest) Kd values found in the literature ... were applied to all nuclides, except those having site-specific values."¹⁴⁴

¹⁴⁴ Whetstone 2000 p.17

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The use of such low Kds means that the transport of radionuclides from the disposal area into the water pathway is rapid compared to the transport estimates when higher Kd values are used.

The choice of a low Kd value is conservative when the water pathway is the most important, since a finding of compliance with a low value of Kd, would also apply for potential water contamination at higher Kd values over the same length of time. However, the choice of Kd is not the only determining factor for the peak dose to a receptor on site, since erosion and external dose can also play important roles. In fact, when uncovering of the waste by erosion is the main pathway, a high Kd means that more of the waste will remain where it was first buried at the time when the cover is eroded away. This means that external radiation doses as well as internal inhalation doses due to resuspension of radionuclides will tend to be higher for high Kd values in a dry environment.

In order to examine long-term performance of the Envirocare site for Silo 3 waste, we ran a sensitivity analysis using the two values of Kd (the high Kd is associated with the low infiltration and low conductivity rates and the low Kd is associated with the high infiltration and high conductivity rates) and two erosion rates to obtain various dose estimates for a rancher scenario. (The rancher scenario is described in detail in Section 4.7.) We also estimated a flux and a dose for an outdoor radon scenario. The results of the calculations are given in Tables 22 and 23. The RESRAD runs themselves are posted on IEER's website at www.ieer.org/reports/fernald/.

Table 22: Peak doses for Silo 3 waste disposal (for a period less than 10,000 years) – Rancher scenario

Kd	Peak external dose (rem per year)	Peak inhalation dose (rem per year)	Year of peak dose
Low Kd, HIR, HC			
High erosion rate	245	0.698	6800
Low erosion rate	245	0.698	6800
High Kd, LIR, LC			
High erosion rate	273	0.756	9000
Low erosion rate	273	0.756	9000

Note: HIR stands for high infiltration rate, HC for high conductivity, LIR for low infiltration rate, and LC for low conductivity. We have chosen to pair the low Kd with the high infiltration rate and the high conductivity, and the high Kd with the low infiltration rate and the low conductivity in order to obtain the lowest and the highest leaching of radionuclides from the disposal cell.

Table 22 was generated using the parameters in Table 21. Note that the internal dose is mainly due to resuspension after the cover has eroded away, since we assume that at the Envirocare site, the resident rancher will not drink the water or use it for irrigation. The water in the area is reported to be brackish.

With the drinking water and irrigation water pathways turned off, our RESRAD calculations for the rancher scenario indicate the following characteristics of estimated future long-term exposure:

- The peak external doses for the high Kd and the low Kd are independent of the erosion rate. This is to be expected since it would take more than 15,000 years for the cover and

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the waste to be all gone in the case of the high erosion rate and more than 27,000 years in the case of the low erosion rate; for both times, only a fraction of the thorium will have decayed away due to its long half life (about 75,000 years). At several thousand years, the original radium has decayed away and the radium in the waste is essentially all due to the decay of thorium-230. At about 6,400 years or more (four half-lives of radium-226 or more), radium-226 is approximately in equilibrium with Th-230, until the elapsed time begins to be a significant fraction of the half-life of thorium-230 (which is about 75,000 years).

- Due to extremely high peak doses, a person would have to spend only a few minutes at the site after the waste was exposed to get more than the annual 25 millirem limit set by the NRC for maximum exposure from low level waste facilities.
- The peak external dose for the high Kd is only about 11% higher than for the low Kd. This is because the low rainfall and even lower infiltration mean that very little of the waste is mobilized by water moving through the waste. The high Kd case has a high external dose since mobilization by water is even lower in this case.¹⁴⁵ In all cases the peak dose is about 10,000 times, or more, higher than the 25 millirem per year limit in 10 CFR 61, while the inhalation dose is about 30 times higher.

Table 23 shows our results for radon dose.

Table 23: Peak outdoor radon flux and dose for Silo 3 waste disposal (for a period less than 10,000 years)

Kd	Peak radon flux (pCi per m ² per sec)	Peak radon dose (mrem per year)	Year of peak flux and dose
Low Kd, HIR, HC			
High erosion rate	38,998	22.3	6800
Low erosion rate	38,995	22.3	6800
High Kd, LIR, LC			
High erosion rate	43,354	24.7	9000
Low erosion rate	43,368	24.7	9000

Note: HIR stands for high infiltration rate, HC for high conductivity, LIR for low infiltration rate, and LC for low conductivity. We have chosen to pair the low Kd with the high infiltration rate and the high conductivity, and the high Kd with the low infiltration rate and the low conductivity in order to obtain the lowest and the highest leaching of radionuclides from the disposal cell.

The RESRAD dose calculation for the outdoor radon scenario shows that, despite the high radon emanations, the peak dose for both values of Kd is only just under the 25 millirems per year due to the large-scale dilution of radon and radon decay products with fresh air. However, 40 CFR Part 61.192 sets a 20 picocuries per square meter per second limit for radon-222 emissions from Department of Energy sites. While Envirocare is a private disposal facility licensed by the State of Utah under agreement with the NRC, this radon emission limit is still instructive to take as a point of comparison. Specifically, Table 23 shows that this limit would be exceeded by almost 2,000 times for a low Kd case and by more than 2,000 times for the high Kd case. In the case

¹⁴⁵The peak dose is lower in the low Kd case as the rainfall is increased, since more water moves through the waste, but the water pathway is assumed not to deliver any dose. For the low Kd and high erosion rate case, a peak dose of 183 rem per year occurring at 4200 years is obtained if a precipitation of 1 meter per year (the RESRAD default value) is chosen.

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that any type of enclosed structure with a basement would be built on this site, the peak doses would be quite large due to the concentration of radon in the indoor air.

One of the most interesting conclusions that can be drawn from this analysis is to note that, while Silo 3 waste is considered less dangerous than Silos 1 and 2 waste, its disposal at Envirocare is estimated to result in a much higher peak dose than that which could be received from the disposal of Silos 1 and 2 waste at WCS. This is due to the shallower burial at Envirocare and thus the shorter time required for erosion to uncover the waste. However, despite the indicated lower doses at WCS they would still be far out of compliance. Moreover, WCS as a company appears not to possess the necessary qualifications for managing large amounts of radioactive materials. Besides the deficiencies in the WCS license application, IEER research has shown that WCS is not cognizant of even the most elementary radiological properties of uranium.¹⁴⁶

4.8 Conclusions regarding Silos 1, 2, and 3.

The remediation strategies finally used for Silos 1, 2, and 3 were considerably inferior to those in the initial Record of Decision. The original ROD envisioned vitrification of the waste in all three silos. This significant degradation of performance has been allowed to occur despite the marginal overall cost differences between the option implemented for Silos 1 and 2 and vitrification of the waste.

The RESRAD analysis for Silos 1 and 2 indicates that the long term doses from shallow land disposal--even at a dry site--could exceed any regulatory limit for public health by factors of several hundred times or more. This is clearly an unacceptable result. Low level waste disposal rules, specified in 10 CFR 61, Subpart C, set no time limit for public exposure. The company operating the storage site, WCS, has no license to dispose of the waste there. Moreover, based on statements in its license application for low level waste, it does not appear to be qualified to receive radioactive waste, much less to handle it and dispose of it. The high radiation doses and the high specific activity of the radium-226 and thorium-230 in the waste also indicate that deep geologic disposal would be needed to protect public health. Our conclusion in this regard is similar to the one we arrived at for the disposal of large amounts of depleted uranium from enrichment plants. The combination of large total amounts of radioactivity, high specific activity, and high estimated peak doses for shallow land disposal, all point to the need for appropriate waste conditioning and geologic disposal.¹⁴⁷

So far as Silo 3 wastes are concerned, these wastes were put into disposal bags with minimal treatment and sent to the Envirocare, a radioactive waste disposal facility with a byproduct material license in Utah. This facility does not accept shipments of 11e.(2) byproduct material above an average of 60,000 picocuries per gram for thorium-230 and 4,000 picocuries per gram for radium-226. IEER does not have a number for the average concentration that is being shipped to Envirocare. However since the contents of Silo 3 have been being directly packaged into “soft-side” bags and treated only for dispersability the average concentrations shipped is in all likelihood close to average

¹⁴⁶ Makhijani and Smith 2005.

¹⁴⁷ Makhijani and Smith 2004, Section C and Makhijani and Smith 2005, Section 1.6.

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concentrations that were in the silo, that is 51,200 picocuries per gram for thorium-230 and 2,970 picocuries per gram of radium-226. For disposal purposes Envirocare's License states that:

At the end of every calendar year starting with 2001, the licensee shall ensure that the cumulative average activity concentration of waste placed after Jan. 1, 2001, within the upper 3 feet of disposed waste does not exceed 300 pCi/g of Ra-226 or 900 pCi/g of Th-230, and within the next 7 feet does not exceed 500 pCi/g Ra-226 or 1500 pCi/g of Th-230. When both radionuclides are present, the unity rule defined below will apply to ensure that the Ra-226 limit is not exceeded within 1000 years.¹⁴⁸

While Silo 3 waste does not exceed the radium-226 limit for disposal of 4,000 picocuries per gram at present, radium-226 will continue to grow due to decay of thorium-230 into radium-226. This will dominate the radium-226 source term in a few hundred years, since the initial concentration of thorium-230 is far greater than that of radium-226. In fact, the concentration of radium-226 in Silo 3 waste will exceed 4,000 picocuries per gram in less than 100 years.

One of the surprising outcomes of the process of revising and changing the silos' waste management has been that the final cost for a poor choice of final waste form for Silos 1 and 2 is far greater than the initial cost estimate for the vitrification program. However as noted previously, the decision to go ahead with vitrification in the Record of Decision of 1994 was based mainly on the superiority of vitrification versus cementation relative to the protection of public health and the environment. However, after the failure of the vitrification pilot plant, the cost of cementation (excluding transportation) was estimated to be about \$50 million cheaper than vitrification, but no detailed engineering cost analysis was provided for the cost estimates or changes.

According to the various cost revisions, the cost difference, overall, between vitrifying and grouting the waste would have been about \$50 million, or about one-and-a-quarter percent of the four billion dollar cleanup cost of the Fernald site.¹⁴⁹ We note that vitrification of the Fernald waste would have required further process development relative to grouting and may have taken a longer time. However, the increased time was trivial in comparison to the deleterious long-term risks that grouting has created (see below). The one clear incentive for grouting versus vitrification is that the former met the rushed, artificial deadline for completion of site closure by 2006 (with an attendant bonus of up to \$288 million for the contractor.)¹⁵⁰ In other words, the bonus created a perverse incentive to rush the job even if the interests of future generations were compromised.

Despite the expenditure of \$4 billion on cleanup, including hundreds of millions of dollars on silo wastes, the DOE has pursued a path that will not meet even the minimal requirements of long-term stewardship or compliance for these wastes, which represent the majority of the radioactivity in wastes at Fernald.

¹⁴⁸ Envirocare 2005, pages 13 and 14

¹⁴⁹ Fluor Fernald 2005c

¹⁵⁰ Fernald 2003, page 30.

4.9 IEER'S proposal for the waste management of the K-65 silos' waste

Our RESRAD calculations indicates that WCS is a poor site for burial of K-65 wastes. It is highly unlikely that any shallow land burial site would be able to meet the dose limits set by the regulations. Wet sites would deliver high doses from the water pathway, while dry sites deliver high doses due to the uncovering of waste by erosion.

The question of the disposal of the K-65 silos bears a lot of similarities to the question of the disposal of depleted uranium that IEER has extensively addressed.¹⁵¹ It is IEER's scientific conclusion that both should be buried in a deep geologic repository since shallow land burial is highly unlikely to meet compliance dose criteria.

Depleted uranium has, for purposes of disposal, been classified by default as Class A low level radioactive waste according to 10 CFR 61.55(a)(6) which states that "[i]f radioactive waste does not contain any nuclides listed in either Table 1 or 2, it is Class A."¹⁵² Uranium is not listed in either of these tables and therefore it is argued that it belongs to Class A.¹⁵³

However, depleted uranium (which consists mainly of uranium-238), like the K-65 waste, shares many radiological characteristics with greater than Class C transuranic waste, that is, waste that contains more than 100 nanocuries per gram of transuranic elements. Greater than Class C waste generally cannot be disposed of in shallow land burial. All the specific activities of the various chemical forms of depleted uranium are higher than 100 nanocuries per gram. For example, the specific activity of depleted uranium oxide (DU₃O₈) is 340 nanocuries per gram. Like most of the components of transuranic waste, depleted uranium is an alpha emitter, it has a long half life, and its decay energy is in the same order of magnitude. The similarity of depleted uranium with greater than Class C transuranic waste in terms of its radiological characteristics and the difficulty associated with its disposal has been noted by the National Research Council:

If disposal [of depleted uranium oxide] is necessary, it is not likely to be simple. The alpha activity of DU is 200 to 300 nanocuries per gram. Geological disposal is required for transuranic waste with alpha activity above 100 nanocuries per gram. If uranium were a transuranic element, it would require disposal in the Waste Isolation Pilot Plant (WIPP) based on its radioactivity.¹⁵⁴

The Department of Energy is responsible for the management of 560,000 tons of depleted uranium in the form of uranium hexafluoride (UF₆), left over from past enrichment for its weapons program, and its eventual conversion into more stable form, U₃O₈, and disposal, if no use is found for it.¹⁵⁵ This corresponds to almost 130,000 curies. IEER, in the update to its report *Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico by LES*, argues that

¹⁵¹ Makhijani and Smith 2004, Section II.A

¹⁵² 10 CFR 61.55(a)(6) 2005

¹⁵³ 10 CFR 61.55 2005

¹⁵⁴ NAS/NRC 2003, p.64

¹⁵⁵ DOE 1999, page S-2 to S-5

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depleted uranium needs to be disposed of in a repository. Table 24 below shows the volume and number of curies from the depleted uranium that would go into a repository compared to the number of curies and volume of the silos K-65 waste. The ratios of the number of curies and volume between the DOE inventory of depleted uranium and the K-65 are about 25.

Consequently if the depleted uranium were to be put in a deep repository the extra space needed to accommodate the K-65 waste would be minimal. Moreover, since radium-226 is a daughter product of uranium-238, if the disposal of depleted uranium is done in such a manner as to ensure the protection of the public and the environment, not only from uranium-238 but also from the in-growth of its daughter products, then putting the K-65 residues along with the DOE's inventory of depleted uranium will all ensure the protection of the environment and the public.

Table 24: Volumes and curies comparison between U_3O_8 inventory and K-65 wastes

	U_3O_8	K-65	Ratio U_3O_8 / K-65
Curies	~ 130,000	5,100	25
Volume in cubic meters	~ 150,000	6,120	25

Source for U_3O_8 : DOE 1999, pages S-4 and S-5 gives values for UF_6 . For disposal purposes UF_6 needs to be converted to a more stable form. We have chosen U_3O_8 because it is the form DOE intends to convert UF_6 into if no use is found for it by 2010.

Source for K-65: ROD OU4 1994, Section 1.1 (pages 14 and 15 of pdf) for volume and Section 5.2.2 (pages 25 and 26 of pdf) for curies.

1

Table 25: Volume comparison of packaged depleted U_3O_8 and bare K-65 residues in cubic meters

	U_3O_8	K-65	Ratio U_3O_8 /K-65
Bare waste	150,000	6,120	25
Packaged waste	450,000	12,240	37

Source for U_3O_8 , bare waste: DOE 1999, pages S-4 and S-5 gives values for UF_6 . For disposal purposes UF_6 needs to be converted to a more stable form. We have chosen U_3O_8 because it is the form DOE intends to convert UF_6 into if no use is found for it by 2010.

Source for K-65: ROD OU4 1994, Section 1.1 (pages 14 and 15 of pdf) for bare volume

In the interim, until a repository disposal option is developed for DU and the K-65 wastes, the grouted K-65 waste should be put into monitored storage. After that it should be disposed of with depleted uranium, from past U.S. uranium enrichment activities, in a deep geologic repository. There is at present no deep geologic repository for the vast amounts of DU from uranium enrichment plants.

The volume of the packaged DU would be several hundred thousand cubic meters. This is much larger than the present grouted volume of Silos 1 and 2 waste. Even with additional packaging to make the cement blocks compatible with future repository waste acceptance criteria, the Silos 1 and 2 waste would remain small compared to the DU waste. As a result, the marginal cost would not be high, though the average disposal cost will likely be many times the shallow land burial cost.

5. Operable Unit 5¹⁵⁶

We have also looked briefly at Operable Unit 5 which encompasses contaminated soils, sediments, and perched, surface, and ground waters. It includes

the soil under the production area structures and the remaining site acreage, as well as approximately 11 square miles of off-property surface soil.

but excludes the contaminated soils within the boundaries of Operable Units 1, 2, and 4.¹⁵⁷

5.1 DOE's legally binding commitments for OU5

The selected remedy consisted of:¹⁵⁸

- excavating contaminated soil and sediment to assure with reasonable certainty that the contamination left on site is “below final remediation levels” (see below)
- excavating “contaminated soil containing perched water” that poses, through migration, a threat to the Great Miami Aquifer
- placing the contaminated soil and sediments that meet onsite waste acceptance criteria (WAC) in an On-Site Disposal Facility (see below). Soil above the WAC, that is, soil that is too contaminated, is to be shipped off site
- extracting the contaminated water from the aquifer “to provide reasonable certainty that final remediation levels” are met (see below)
- treating the contaminated ground, storm, and waste waters “to attain performance-based concentration discharge limits, mass-based discharge limits, and final remediation levels, in the Great Miami River”
- applying institutional controls to minimize exposure
- implementing “a long-term environmental monitoring and maintenance program.”

The cost of cleaning up the site for unrestricted use by excavating the contaminated soils and shipping them off site would have been prohibitive, according to the DOE, which estimated the cost of this option in the 1996 ROD for Operable Unit 5 of almost \$14 billion.¹⁵⁹ As a result, the DOE opted to leave a certain amount of residual contamination on the site after excavation of the soils for restricted use of the site. The less contaminated excavated soils, amounting to a large part of the waste volume but a small fraction of the total radioactivity, were to be disposed in an onsite facility, while the rest was to be shipped off site. This was in agreement with the recommendations of the Fernald Citizens Advisory Board.¹⁶⁰ The estimated cost cited in the ROD for Operable Unit 5 was \$2.1 billion.¹⁶¹

¹⁵⁶ See ROD OU5 1996

¹⁵⁷ ROD OU5 1996, Section 4.0 (page 20 of pdf)

¹⁵⁸ ROD OU5 1996, Declaration Statement (pages 10 and 11 of pdf)

¹⁵⁹ ROD OU5 1996, Table 7-2 (page 88 of pdf)

¹⁶⁰ FCAB 2002, page 20

¹⁶¹ ROD OU5 1996, Table 9-2 (page 117 of pdf)

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For uranium, the ROD for Operable Unit 5 directed the DOE to remediate the site to levels of:

- 20 ppm (or 20 micrograms per liter or 14 picocuries per liter) of uranium in the Great Miami Aquifer reflecting the proposed EPA maximum level for drinking water, later set at 30 ppm (21 picocuries per liter)¹⁶²
- 530 ppm (371 picocuries per liter) for on-site surface water¹⁶³
- between 20 and 82 ppm (14 and 57 picocuries per gram) of total uranium for onsite soil depending on the retardation coefficient and 50 ppm (35 picocuries per gram) for offsite soil.¹⁶⁴
- 210 ppm (147 picocuries per gram) of total uranium for sediments.¹⁶⁵

The contaminated soils excavated in order to reach the remediation levels listed above were to be placed in an On-Site Disposal Facility (OSDF) as long as their contamination levels were below the OSDF waste acceptance criteria. If too contaminated to meet the OSDF's waste acceptance criteria they were to be shipped off site. The waste acceptance criteria for the OSDF are given in the table below

Table 26: Waste Acceptance Criteria for the On-Site Disposal Facility

Radionuclides	Maximum Concentration, picocuries per gram (pCi/g)
Neptunium-237	3.12×10^9 (Note 1)
Strontium-90	5.67×10^{10}
Technetium-99	2.91×10^1
Total uranium	1.03×10^3 mg/kg (721 pCi/g)
U-238	346 pCi/g

Source: Adapted from ROD OU5 1996, Table 9-7 (page 130 of pdf).

Note 1: The maximum concentration for neptunium-237 does not make physical sense. A calculation based on the specific activity of neptunium shows that 3.12×10^9 picocuries per gram correspond to 4.4 grams of neptunium in one gram of waste.

We note here that the Waste Acceptance Criteria contain a physically absurd value. The maximum allowable concentration of neptunium-237 is so high that it amounts to over 4 grams of neptunium-237 per gram of waste. This is, of course, physically impossible. This indicates a lack of adequate quality assurance in the process of producing a highly sensitive environmental document, which was the basis for deciding how large amounts of taxpayer dollars would be spent. It is unlikely that this particular error in the Waste Acceptance Criteria for OU5 at Fernald would have major environmental consequences, since there were only trace amounts of neptunium-237 at Fernald. The neptunium-237 was present as a trace contaminant in recycled uranium that was processed at the site.¹⁶⁶ However, IEER has not done an audit of the entire ROD or other RODs that were produced at about the same time using similar methods. It is therefore unclear whether there are any serious errors that have compromised the quality of the

¹⁶² ROD OU5 1996, Table 9-4 (page 122 of pdf) and ESD OU5 2001, page 4

¹⁶³ ROD OU5 1996, Table 9-5 (page 124 of pdf)

¹⁶⁴ ROD OU5 1996, Table 9-3 (page 119 of pdf)

¹⁶⁵ ROD OU5 1996, Table 9-6 (page 126 of pdf)

¹⁶⁶ ORAU Team 2004 Sections 2.2.2.2 and 2.2.3.2

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waste cells in OU5 or the understanding of what actually has been put into them. The existence of a literally impossible value also points up the need for external oversight and independent scientific audits of environmental remediation programs.

The ROD cited 20-22 years for soil remediation but also mentions that the DOE, together with the EPA, the Ohio EPA, and local citizens were looking at an accelerated program that would take only 10 years.¹⁶⁷ The remediation of the Great Miami Aquifer to a Maximum Contaminant Level (MCL) of 20 ppb for uranium (the EPA proposed federal drinking water standard at the time) was to take 27 years.¹⁶⁸ In 2000 the EPA changed the MCL for uranium was changed to 30 ppb.¹⁶⁹ This, the DOE determined, would shorten the remediation time by 4 to 5 years.¹⁷⁰

Because hazardous substances will be left on the site above levels protective of health, a review will be conducted no less than every five years after the start of the remedial action. The five year review process is dictated under CERCLA for the sites on which there will be residual contamination after remediation to ensure that the environment and human health continue to be protected.¹⁷¹

5.2 Status of the work

The waste placement in the On-Site Disposal Facility was near completion as of March 2006 and closure is expected to be completed in June 2006.¹⁷² The restoration of the Great Miami Aquifer is expected to go beyond 2020.¹⁷³ The table below gives the current status of the work. By the time of closure the soil remediation and the filling up and capping of the On-Site Disposal Facility are expected to be complete.

Table 27: Status of the remediation for OU5 as of March 2006

Aquifer restoration	
- Contamination	225 acres
- Status	51 % complete
- Uranium removed	7,166 pounds
1996 ROD schedule	27 years (completion in 2023)
Revised schedule	Beyond the year 2020
On-Site Disposal Facility	
Eight cells	Six cells filled and capped Cell 7 filled Cell 8 68% filled. Closure scheduled for June 2006
Soil remediation	75% of the site is certified "clean"
1996 ROD schedule	20-22 years
Revised schedule	2006

¹⁶⁷ ROD OU5 1996, Section 4.0 (page 21 of pdf)

¹⁶⁸ ROD OU5 1996, Section 7.2.2 (page 91 of pdf)

¹⁶⁹ EPA 2000

¹⁷⁰ ESD OU5 2001, page 5.

¹⁷¹ 40 CFR 300.430(f)(4)(ii) 2005

¹⁷² Fernald 2006f

¹⁷³ DOE 2006, page 3-1

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Sources for aquifer restoration: Fernald 2006g, ROD OU5 1996, Section 4.0 (page 20 of pdf), and DOE 2006, page 3-1

Source for OSDF and soil remediation: Fernald 2006f and ROD OU5 1996, Section 4.0 (page 20 of pdf).

The site will not be truly closed in 2006, since remediation of the aquifer will continue beyond that. Monitoring and surveillance will continue into the long term after closure since,

- the aquifer will not be restored to the final remediation level for uranium. The work is estimated to last beyond 2020, when the final remediation level of 30 micrograms of uranium per liter is reached,
- the monitoring of the OSDF will continue,
- institutional controls will be implemented to ensure that the risks to the public from the residual contamination on the site are small,
- the residual contamination levels in the soil are 82 ppm (56 picocuries per gram) for less soluble uranium and 20 ppm (14 picocuries per gram) for more soluble uranium.¹⁷⁴

In the next section we will examine the long-term implications of leaving residual contamination in the soils and contaminated soils and debris in the OSDF.

6. Legacy management

The goal of Fernald's legacy management plan is to protect the general public from the residual soil contamination left on site and from potential future migration into the water of the radionuclides placed in the OSDF.

In order to ensure the protection of the general public, the Fernald site will consist of three areas described in the DOE's *Comprehensive Legacy Management and Institutional Controls Plan*:

- approximately 900 acres of restored area, with restrictions "ensuring no residential or agricultural and only limited recreational" use of the land. For example swimming, camping, and hunting will be prohibited.¹⁷⁵
- approximately 120 acres of the On-Site Disposal Facility and buffer zone. The restricted access will be provided by warning signs, fences, and gates.¹⁷⁶
- 23 acres were reserved for "potential community use." Since no interest was shown, they are now included in the surveillance and maintenance part of the Legacy Management Program.¹⁷⁷

According the *Waste Acceptance Criteria Attainment Plan for the On-site Disposal Facility*, the average soil uranium concentration will be 100 ppm (70 picocuries per gram).¹⁷⁸ IEER

¹⁷⁴ ROD OU5 1996, Table 9-3

¹⁷⁵ DOE 2006b, pages 12 and 19

¹⁷⁶ DOE 2006b, page 12 and DOE 2006c, page 26

¹⁷⁷ DOE 2006b, page 16

¹⁷⁸ Fernald OSDF WAC 1998, page 2-15

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calculated that the total amount of radioactivity in the OSDF would be 154 curies.¹⁷⁹ This corresponds to 231 metric tons of natural uranium.

Since institutional controls are to be maintained, this plan essentially calls for such controls into the indefinite future. Specifically, to protect the public from the residual contamination left in the soil, the site will be declared a recreational park with institutional controls. The controls will consist of restrictions such as prohibition of swimming, restricted paths, and prohibition of camping.

The care and maintenance of the OSDF is specified for the next 30 years. It includes routine inspections and monitoring of leak control system (LCS) and the leak detection system (LDS) and the monitoring of the groundwater in the vicinity of the cell system and as well as CERCLA reviews every five years.¹⁸⁰

Table 28: Cost estimates of Legacy Management for the first six years (April 2006 to September 2012) after closure

Surveillance and Maintenance	\$5,929,015
Aquifer restoration mgt, Environmental monitoring, Environmental compliance, and reporting	\$26,667,654
CAWWT ¹ , groundwater extraction well, field operations, and the OSDF leachate transmission system	\$32,123,896
Overhead and project support	\$19,214,634
Total	\$83,935,199

Adapted from DOE 2006b, Appendix A

¹ Converted Advanced Waste Water Treatment Facility

The funds for legacy management have not been secured for the indefinite future, even though there is no time limit in the plan for institutional controls. Indeed, even the \$83.9 million that is estimated as the cost that will be incurred in the next six years (until September 2012) is not guaranteed. Legacy management costs are subject to annual appropriations by Congress, even though the monitoring costs are an unavoidable part of the approach to creating onsite waste cells. According to the DOE

[f]unding for legacy management will need to be secured by DOE in future budget requests for the years after site closure. Currently, it is anticipated that Office of Legacy Management funds will be available for OSDF monitoring, maintenance and leachate management, aquifer remediation, and for ensuring that applicable laws and regulations are adhered to in restored areas. DOE will keep the public informed of its plans to fund legacy management activities as new information becomes available.

Currently, legacy management activities at the various DOE facilities are funded through the annual appropriations process. Funding for sites in the long-term surveillance and maintenance program is maintained in a separate line item in the Office of Legacy Management budget. For the time being, this process for funding legacy management

¹⁷⁹ For this calculation IEER used also the soil volume of 1.8 million cubic yards given in Fernald OSDF WAC 1998, page 2-14. IEER assumed a soil density of 1.6 grams per cubic centimeter.

¹⁸⁰ DOE 2006b, page 24

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will continue; however the DOE will continue to investigate other funding and management options.¹⁸¹

7. Community and State oversight

The community and the State of Ohio have played a crucial role, first in helping establish the DOE's commitments to remediation laid out in the RODs for the five operable units and subsequently in seeing that a great number of these commitments are being met. Although the vitrification program for the silos was scrapped, and the 20 micrograms per liter of uranium in water was changed to 30 micrograms per liter, they managed to keep other aspects of the remediation program intact.

Protection of the environment and public health from residual radioactivity in the waste cell and in the groundwater from 2006 onwards depends centrally on the supply of adequate funds by the DOE to (i) continue remediation of the Great Miami Aquifer, and (ii) implement and maintain the monitoring, oversight, and public information program. However, there are already clear signs that the long-term arrangements are breaking down, even before the remediation is complete.

Under CERCLA, the “parties responsible for contaminating a particular site ... are liable for” the remediation and damage caused by this contamination.¹⁸² In particular, a State, whose natural resources have been damaged, may file a claim for compensation, if the responsible party does not adequately address the problem in its site remediation plan.¹⁸³ In 1986, the State of Ohio filed a \$206 million Natural Resources Damages (NRD) claim against the DOE (the responsible party) for damages done to its natural resources, but in 1988 agreed to put this claim on hold until the RODs were approved.¹⁸⁴ In 1993, the Fernald site Natural Resource Trustees, composed of the DOE, the State of Ohio, represented by Ohio EPA, and the U.S. Department of the Interior, began discussing the incorporation of the natural resources restoration into the RODs, in order to ensure fair compensation for the public.¹⁸⁵

The “tentative settlement,” reached in April 1998, to resolve the 1986 claim and any future claims provided the following:

- “884 acres dedicated to natural resource restoration;
- 20 acres dedicated to ecological research projects; and
- Implementation of a groundwater education project to provide educational resources to the public.

Of the remaining acreage, DOE has committed 123 acres to the On-Site Disposal Facility, an engineered waste disposal facility, and has set-aside 23 acres for potential development.”¹⁸⁶

¹⁸¹ DOE 2006b, page 29

¹⁸² NRTCSC 1999

¹⁸³ NRTCSC 1999

¹⁸⁴ NRTCSC 1999 and Ohio 1998

¹⁸⁵ Fernald 2005n and Ohio 1998

¹⁸⁶ Fernald 2005n

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A part of the NRD settlement proposal was the implementation of a groundwater education program. This program was designed to educate the public about the damages to the natural resources in the area. It was a part of DOE's July 1998 *Natural Resource Restoration Plan* (NRRP).¹⁸⁷ The DOE continued to reaffirm this until November 2004. Since it was part of the tentative settlement of the Natural Resources Damages claim, DOE was obliged to develop and fund the education program. However, in April 2005, the DOE deleted this commitment from the NRD settlement program, according to the Ohio Attorney General (See Appendix):

Now, despite DOE's admission regarding the necessity of an education component to address the groundwater damages and its commitment to implement the education component with 5 million dollars, DOE has reversed course and deleted all commitments for the education component from the April 2005 Natural Resource Restoration Plan. The State is frustrated by this change in DOE's position and expects that the education component will be reinserted into a revised Natural Resource Restoration Plan and fully funded, as previously agreed to by DOE.

Furthermore, it is not acceptable that DOE's commitment to perform long term monitoring, maintenance, and management of the restored areas will be relegated to a legacy plan that is *not an enforceable part of an NRD Consent Order*. Since such a plan is part of the remediation process, the State will only be able to provide review and comment and will have no direct enforcement authority if the provisions for long term monitoring, maintenance, and management are not sufficient or not implemented as set forth in the plan. Without a DOE commitment to maintain the restored areas that is enforceable by the State, the State cannot be assured that it will be fully compensated for the natural resource damages caused by DOE.¹⁸⁸

IEER's view of long-term stewardship, or legacy management, was developed in some detail as part of its study, *Containing the Cold War Mess*.¹⁸⁹ The main recommendation in regard to monitoring and education was that a fund commensurate with the amount of waste (in terms of radioactivity and toxicity of the non-radioactive wastes) be created so that the revenues from that fund could be used by state and local governments for these purposes. An enforceable Consent Order under CERCLA would serve the same purpose, since it would be more likely to insulate these funds from the pressures of annual Congressional appropriations. One of these two approaches is essential because either one would effectively make monitoring and education an entitlement program. Since the communities have suffered damage on behalf of the entire country and will continue to bear a residual environmental burden for the indefinite future, they are surely entitled to resources that are essential to maintaining the vigilance and education that will be needed to protect public health and the environment.

The abandonment by the DOE of its commitment to an education program as part of a Consent Order fits a pattern of degradation of long-term stewardship commitments and performance that has also affected Operable Unit 4 at the Fernald site, as well as other sites, such as Savannah River Site.

¹⁸⁷ Ohio AG 2005

¹⁸⁸ Ohio AG 2005 (emphasis added)

¹⁸⁹ Fioravanti and Makhijani 1997, pages 5-7

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The tendency of the DOE to diminish, degrade, or abandon its commitments to the community and to the state government requires a much stronger role for both communities and local governments in long-term stewardship. Control of financial and technical resources as well as educational resources that is assured for the long-term is needed to sustain the role that they must play if the health and environment of future generations is to be well-protected.

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Appendix – Ohio Attorney General’s Office letter

Re: State of Ohio v. United States Department of Energy –
Natural Resource Damages Claim.

Letter dated May 31, 2005.

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May 31, 2005

Daniel J. Dertke
Environmental Defense Section
United States Department of Justice
P.O. Box 23986
L'Enfant Plaza Station
Washington, D.C. 20026-3986

Re: State of Ohio v. United States Department of Energy – Natural Resource Damages Claim

Dear Dan:

The State of Ohio has reviewed the Department of Energy's April 29, 2005 settlement proposal regarding the natural resource damages (NRD) claim for the Fernald, Ohio site. The State does appreciate that the Department of Energy (DOE) has made some movement towards a resolution of the issues. However, for the State to settle its NRD claim, all of the provisions in the December 2004 Scoping Document for Fernald Closure Project Natural Resources, agreed to by DOE, the State, and the Fernald Citizen Advisory Board ("Citizen Group"), need to be addressed in a Consent Order enforceable by the State. DOE's proposal that some of the provisions of the agreed Scoping Document will not be part of a Consent Order and will be incorporated later in a legacy plan that DOE will prepare is not acceptable.

For example, DOE states that the educational component of the NRD settlement will be set forth in the legacy plan and it is "neither necessary nor appropriate to include such commitments as part of a NRD settlement." Not only is this approach contrary to the agreement in the Scoping Document regarding the education component, it is contrary to the commitment made in DOE's July 1998 Natural Resource Restoration Plan. On page 1-4 of DOE's July 1998 Restoration Plan, DOE admitted that a groundwater education module was necessary to address the natural resource damages to the groundwater at the Site. That provision states:

1.5 APPROACH FOR GROUNDWATER

The HEA ("Habitat Equivalency Analysis") process is appropriate for estimating restoration acreage when injuries are associated with ecological functions and habitat loss. Service losses to humans, such as contamination of a drinking water supply, cannot easily be equated to habitat restoration. Restoration activities must be conducted to

replace, restore, or acquire the equivalent of the injured natural resource. Therefore it is very difficult to compensate for ground water impacts through ecological restoration.

Because the FEMP NRTs ("Fernald Natural Resource Trustees") agreed to focus on habitat restoration as compensation for all impacts, an attempt was made to calculate restoration acreage due to groundwater impact. Several scenarios for using HEA were proposed, but the NRTs were not satisfied that justification was adequate. As a result, the FEMP NRTs agreed to abandon the use of HEA for groundwater compensation. Instead, the NRTs agreed to ensure that all on-property areas [minus the On-site Disposal Facility (OSDF) and the 23 acres of land under consideration for potential economic development by the Community Reuse Organization (CRO)] are ecologically restored. This would protect a portion of the Paddys Run watershed, which contributes to the recharge of the Great Miami Aquifer. **In addition, DOE agreed to develop a ground water education module, which may be either permanently displayed at the FEMP or made available to area schools. By implementation of these projects, and by completion of remedial activities, the FEMP NRTs agreed that DOE would adequately compensate for injuries to groundwater.** (emphasis added).

In addition, the May 28, 1998 letter from Jack R. Craig, Director, Fernald Area Office, Ohio Field Office, DOE, to Tom Schneider, Ohio EPA (enclosed) sets forth DOE's commitment that an education component would be part of the NRD settlement. Thus, these documents demonstrate that, not only did DOE admit that it has caused natural resource damages to the groundwater at the Site, it also admitted that the education component was necessary to address these damages adequately.

The Natural Resource Restoration Plan, as revised by DOE in October 2001, provided details regarding the education component and committed 5 million dollars for implementation. The October 2001 Natural Resource Restoration Plan, again revised by DOE in January 2002, includes the following statement: "The NRTs expect the \$5 million will be used to support development of an on-site MUEF ("Multi-Use Education Facility") and associated environmental education activities." This commitment of 5 million dollars for implementation of the education component was a part of May 2, 2002 Settlement Terms transmitted from Steve McCracken, DOE Ohio Field Office, to Mark Navarre, Ohio EPA (enclosed), and continued to be documented in the November 2004 Natural Resource Restoration Plan, which was negotiated by DOE and Ohio EPA.

Now, despite DOE's admission regarding the necessity of an education component to address the groundwater damages and its commitment to implement the education component with 5 million dollars, DOE has reversed course and deleted all commitments for the education component from the April 2005 Natural Resource Restoration Plan. The State is frustrated by this change in DOE's position and expects that the education component will be reinserted into a revised Natural Resource Restoration Plan and fully funded, as previously agreed to by DOE.

Furthermore, it is not acceptable that DOE's commitment to perform long term monitoring, maintenance, and management of the restored areas will be relegated to a legacy plan that is not an enforceable part of an NRD Consent Order. Since such a plan is part of the

remediation process, the State will only be able to provide review and comment and will have no direct enforcement authority if the provisions for long term monitoring, maintenance, and management are not sufficient or not implemented as set forth in the plan. Without a DOE commitment to maintain the restored areas that is enforceable by the State, the State cannot be assured that it will be fully compensated for the natural resource damages caused by DOE.

Regarding the April 2005 Natural Resource Restoration Plan, attached to DOE's April 29, 2005 settlement proposal, Ohio believes the November 2004 version of the Natural Resource Restoration Plan should be the basis for further discussion. The November 2004 document was the product of negotiations between Ohio EPA and DOE in the fall of 2004, as requested by DOJ and agreed to by the Ohio Attorney General. The majority of the language removed in the April 2005 version has been a significant component of the Natural Resource Restoration Plan since the 1998 version and includes important bases for the restoration projects. Thus, the State does not accept the deletions made to the Natural Resource Restoration Plan.

Once review is completed and agreement is reached upon a final draft Natural Resource Restoration Plan the document will need to go out for public comment prior to final approval. The State does not believe that such review and approval should be objectionable to DOE because, in the Scoping Document, DOE, the State, and the Citizen Group agreed that the Restoration Plan was subject to final agreement. Furthermore, in the NRD Consent Order, the State will need provisions regarding the review and approval of future documents required to be submitted by the Restoration Plan and a mechanism to resolve any disputes between DOE and the State regarding implementation of the requirements of the Restoration Plan. The State will need these same provisions regarding the long term monitoring and maintenance plan for the restored areas.

As to the environmental easement attached to DOE's settlement proposal, the State has enclosed a draft environmental covenant proposal based on the State's new environmental covenant statute, Ohio Revised Code 5301.80, et seq. This easement will be recognized by officials responsible for the recordation of real property documents in Ohio and will be enforceable by DOE and the State of Ohio. The State believes its proposed easement is substantially consistent with the environmental covenant DOE is negotiating with the State of Colorado for the Rocky Flats site.

Finally, the State cannot and will not agree as part of a settlement of the Fernald NRD claim to covenant not to sue and discharge its natural resource damage claims for the other DOE sites listed in your April 29, 2005 settlement proposal. These sites are separate and distinct from the Fernald Site and are not part of the State's NRD claim in its Complaint.

In summary, your proposal of April 29, 2005 simply fails to address and adequately incorporate vital provisions necessary to the settlement of the State of Ohio's natural resource damage claims as agreed by DOE and Ohio EPA representatives as recently as December 2004. For the State to settle its NRD claims, DOE and the State need to reach agreement on an NRD Consent Order that is enforceable by the State and requires implementation of the provisions in the December 2004 Scoping Document. The State is prepared to submit such a Consent Order

proposal to DOE. However, if DOE will not agree to include the provisions of the Scoping Document in an enforceable NRD Consent Order, the State will not be able to reach settlement.

If you have any questions, please do not hesitate to call.

Very truly yours,

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