

## **Shifting Radioactivity Risks: A Case Study of Waste Management at the Fernald Nuclear Weapons Site**

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Since the late 1990s, the U.S. Department of Energy has produced several versions of “accelerated” cleanup schemes of its nuclear weapons sites. This has led to more rapid decommissioning of two large weapons plants – notably the Rocky Flats Plant in Colorado, where plutonium pits for nuclear weapons were mass produced, and the Fernald Plant near Cincinnati, Ohio, where uranium metal was produced, mainly for plutonium production reactors. These sites are considered flagship sites in the federal government’s effort to “clean up” and “close” some of the most contaminated sites in the country.

“Accelerated” has not necessarily meant better or lower-risk. To examine the effects of hasty cleanup, where timetables were tied to bonuses without reference to radiation doses to future generations, we did a case study of some radioactive waste at the Fernald plant.

The specific wastes we studied derived from the extraction of high-grade uranium ores. Some of these ores were processed during the World War II Manhattan Project and in the immediate post-war years at the Mallinckrodt Chemical Works in St. Louis. Others were processed at Fernald. Besides uranium itself, uranium ore contains thorium-230 and radium-226, which are decay products of uranium-238, the main isotope of natural uranium. (See uranium decay chain below.) Since the ores in question were high-grade, they were also concentrated in radium-226 and thorium-230, which are long-lived, bone-seeking radionuclides. The highest grade ores, up to two-thirds uranium oxide content, were known as “pitchblende” and came from the “Belgian Congo,” so called because the region was then a Belgian colony.

<b>URANIUM DECAY CHAIN – Principal Branch Only</b>		
Read from left to right. Arrows indicate decay.		
Uranium-238 ==> (half-life: 4.46 billion years) alpha decay	Thorium-234 ==> (half-life: 24.1 days) beta decay	Protactinium-234m ==> (half-life: 1.17 minutes) beta decay
Uranium-234 ==> (half-life: 245,000 years) alpha decay	Thorium-230 ==> (half-life: 75,400 years) alpha decay	Radium-226 ==> (half-life: 1,600 years) alpha decay
Radon-222 ==> (half-life: 3.82 days) alpha decay	Polonium-218 ==> (half-life: 3.11 minutes) alpha decay	Lead-214 ==> (half-life: 26.8 minutes) beta decay
Bismuth-214 ==> (half-life: 19.9 minutes) beta decay	Polonium-214 ==> (half-life: 163 microseconds) alpha decay	Lead-210 ==> (half-life: 22.3 years) beta decay
Bismuth-210 ==> (half-life: 5.01 days) beta decay	Polonium-210 ==> (half-life: 138 days) alpha decay	Lead-206 (stable)

<sup>1</sup> Based on Annie Makhijani and Arjun Makhijani, *Shifting Radioactivity Risks: A Case Study of the K-65 Silos and Silo 3 Remediation and Waste Management at the Fernald Nuclear Weapons Site* (IEER: Takoma Park, MD, August 2006). Detailed references are to be found in the full report, which is on the Web at [www.ieer.org/reports/fernalld/](http://www.ieer.org/reports/fernalld/).

The wastes from the processing of uranium ores and uranium concentrates (yellow cake) were stored in three large concrete structures called silos. Silos 1 and 2, which were emptied and demolished last year, stored radium-containing wastes from the processing of the “Belgian Congo” pitchblende. Silo 1 contained only waste produced at Mallinckrodt. Silo 2 contained waste produced at Mallinckrodt and Fernald. Silos 1 and 2 were also known as the “K-65” silos after the name of the process used to extract the uranium from the ore.

Silo 3, which also has been emptied and demolished, contained radioactive waste from the processing of uranium concentrates. Silo 3 wastes are less radioactive than the K-65 silo waste and have far more thorium-230 than radium-226.

This article examines the silo cleanup decisions made by the U.S. Department of Energy (DOE), how they changed over time, how they were implemented, and what their long-term radiological implications are likely to be. It summarizes our August 2006 report, *Shifting Radioactivity Risks: A Case Study of the K-65 Silos and Silo 3 Remediation and Waste Management at the Fernald Nuclear Weapons Site*. The full report, including references for this article, can be found online at [www.ieer.org/reports/fernalld/](http://www.ieer.org/reports/fernalld/).

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 Fernald site**

The Feed Materials Production Center (FMPC), now called the Fernald Closure Project Site, covered 1,050 acres and operated from 1952 to 1989. During these years it produced about 1.3 billion pounds of uranium metal to support the U.S. nuclear weapons program. Its main function was to provide reactor fuel and target rods for plutonium production at the Hanford Plant in Washington state and the Savannah River Plant in South Carolina. Fernald operations resulted in the contamination onsite and offsite of air, soil and water.

The radium and thorium waste that was stored in the three silos posed the most immediate risk to the workers and the offsite residents in two ways: (1) radon emissions, created by the decay of radium-226 into radon-222, and (2) the potential for the roofs of Silos 1 and 2 to collapse and release radioactive waste into the environment. Emptying the silos and putting the waste into a form that would not be prone to dispersal in the short term and that would be stable in the long term was recognized to be a challenging and critical task in the decommissioning of Fernald.

### **The silo waste**

Table 1 shows the concentrations of the various radionuclides in Fernald silo waste. Table 2 shows the silos’ radioactivity content from some radionuclides. The contents of Silos 1 and 2 were similar because they were generated from high-grade ores. It is important to note that while the concentration of radium-226 is far higher than that of thorium-230, the latter has a much longer half-life – 1,600 years, and about 75,000 years, respectively.

Moreover, thorium-230 decays into radium-226, so over a period of a few thousand years their concentrations become approximately equal. They are approximately in equilibrium at times far

longer than the half-life of radium-226 but far shorter than that of thorium-230. Hence the half-life of thorium-230 controls the rate of decay of the waste over the very long term. Moreover, when inhaled, the radiation doses to most organs are considerably larger per unit of radioactivity for thorium-230 than for radium-226.

The main radionuclide of concern for Silo 3 waste is thorium-230. However, radium-226 will build up over the millennia to approximately equal the concentration of thorium-230 for a time. Silo 3 also contains arsenic, cadmium, chromium, and selenium. It is common for ore processing wastes to contain significant heavy metal contamination. Lead-210 and polonium-210 are decay products of radon-222, which is a decay product of radium-226.

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

Radionuclide	Mean Concentration, picocuries per gram		
	Silo 1 (V=3,240 m <sup>3</sup> )	Silo 2 (V=2,845 m <sup>3</sup> )	Silo 3 (V=3,890 m <sup>3</sup> )
Actinium-227	5,960	5,100	618
Lead-210	165,000	145,000	2,620
Polonium-210	242,000	139,000	Not given
Protactinium-231	Not given	2,350	487
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

SOURCE: Adapted from the 1997 IEER report, *Containing the Cold War Mess*, on the Web at [www.ieer.org/reports/cleanup/](http://www.ieer.org/reports/cleanup/), 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.

NOTES: Volumes (V) for Silos 1 and 2 do not include 357 and 314 cubic meters (m<sup>3</sup>), respectively, of bentonite clay added in the 1990s to reduce radon emissions. Bentonite clay was not added to Silo 3. There is a slight discrepancy between the volumes cited in Paine for Silos 1 and 2 (3,240 + 2,845 = 6,085 cubic meters) and the total volume listed in the Record of Decision (6,120 cubic meters).

**Table 2: Radioactivity in Silos 1, 2, and 3 Waste**

Radionuclide	Silos 1 and 2 combined	Silo 3
Lead-210	1,800 curies	4 curies
Radium-226	3,700 curies	26 curies
Thorium-230	600 curies	450 curies
Uranium	28 metric tons (See note)	about 20 curies

SOURCE: 1994 Record of Decision for OU4, and *Safety of the High-Level Uranium Ore Residues at the Niagara Falls Storage Site*, Lewiston, New York (Washington, DC: National Academy Press, 1995).

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

### Silo waste classification and disposal

The waste in all three silos is classified under the Atomic Energy Act as byproduct material resulting from the processing of uranium or thorium ores. Generally this means the tailings or waste produced by the extraction of uranium or thorium from their ores. Byproduct waste is exempt from RCRA (Resource Conservation and Recovery Act) regulation even though all three silos contain toxic metals at concentrations exceeding the RCRA limits. However, the fact that the tailings are exempt from RCRA does not mean that these toxic metals are not going to

adversely affect the health of future generations. On the contrary they are more likely to do so since the exemption makes lax waste disposal more likely.

Mill tailings from U.S. ores generally contain relatively low concentrations of radioactivity compared to other radioactive wastes, but represent the largest volume of such wastes (with the possible exception of uranium mining wastes). That is because U.S. uranium ores have typically been of rather low uranium content – less than one percent. By contrast, the high-grade ores – including pitchblende, from which the Silos 1 and 2 waste came – have up to about 65 percent uranium oxide content resulting in relatively small volumes of waste with high concentrations of thorium-230, radium-226 and the solid decay products of radium-226. Table 3 compares the concentration of radioactivity in tailings from 0.2% ore to the waste in the silos.

**Table 3: Radioactivity of silo waste compared to typical U.S. uranium mill tailings**

<b>Material</b>	<b>Concentration in nanocuries per gram</b>	<b>Ratio of silo waste/tailings</b>
Mill tailings arising from 0.2% uranium ore	2 to 3.4	--
Silo 1 waste	452	133
Silo 2 waste	245	72
Silo 3 waste	54	16

Notes: Mill tailings arising from 0.2% uranium ore are typical in the United States. Values for silo waste include only long-lived alpha-emitting radionuclides – U-238, U-234, Th-230, Ra-226, and Pa-231. For Silo 1, no Pa-231 value was available so the value for Silo 2 was used. U-235 was omitted because it does not play a significant radiological role in this context.

Mill tailings have the most lax procedures for disposal of any radioactive wastes largely because they are typically very voluminous and have low specific activity (radioactivity per unit weight). They are required to be put in lined tailings ponds that have a cover of water to reduce radon air emissions.

The management of typical mill tailings is not protective of public health in the long term due to the very long half-life of thorium-230. However, it is broadly comparable to the category of radioactive waste called Class A low-level waste so long as the *combined* concentration of uranium, thorium-230, and radium-226 (the long-lived, alpha-emitting materials in tailings) remains below 10 nanocuries per gram.

As can be seen from Table 3, the concentration of typical U.S. mill tailings is comparable to that of Class A waste, which restricts plutonium and other transuranic radionuclides to under 10 nanocuries per gram. That is not the case for the waste in the three Fernald silos. The waste in Silos 1 and 2 even exceeds 100 nanocuries per gram of alpha-emitting long-lived radionuclides, though they are not transuranic radionuclides. Rather, they are decay products of uranium-238 and uranium-235. One hundred nanocuries per gram is the upper bound for the content of long-lived, alpha-emitting transuranic radionuclides in Class C low-level waste. Waste with concentrations of long-lived, alpha-emitting transuranic radionuclides greater than 100 nanocuries per gram is called “Greater-than-Class-C” waste, which cannot be disposed via shallow land burial as a general matter. Rather, it must be put in a deep geologic repository, unless a special exemption from such disposal is granted by the Nuclear Regulatory

Commission. (Further information about radioactive waste classifications is provided in the box below.)

#### Some Classifications of Radioactive Waste

**Transuranic waste**, also known as TRU waste, contains elements with atomic numbers greater than 92, the atomic number of uranium. TRU waste contains alpha-emitting transuranic radionuclides with half-lives greater than 20 years and total concentration greater than 100 nanocuries per gram. This is the U.S. Environmental Protection Agency definition. The U.S. Nuclear Regulatory Commission definition is slightly different and is part of a broader category called Greater-Than-Class-C waste.

**Low-level radioactive waste (LLW)** is defined by what it is not. According to U.S. Nuclear Regulatory Commission (NRC) regulations, low-level waste is “radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product material [i.e., uranium or thorium mill tailings]...”

The “low-level” radioactive waste category thus includes everything from slightly radioactive trash (such as mops, gloves, and booties) to highly radioactive activated metals from inside nuclear reactors. It includes both short-lived and long-lived radionuclides.

NRC regulations sub-divide commercial low-level waste into four classes which are determined by the types of radionuclides and their concentrations which make up the waste. These classes are labeled Class A, Class B, Class C, and Greater-Than-Class-C.

**Class A** waste is the least radioactive on average, and is contaminated primarily by what the NRC terms “short-lived” radionuclides.

**Classes B and C** wastes are more radioactive: Class B may be contaminated with greater amounts of “short lived” radionuclides than Class A, and Class C with greater amounts of long-lived and short-lived radionuclides than Class A or B.

**Greater-Than-Class-C** waste is typically much more radioactive than the other classes, and generally is considered unacceptable for near-surface disposal, which is how Classes A, B, and C are generally disposed of in the U.S. Shallow-land disposal used to be simple dumps mainly, but the concept now also includes more elaborate structures.

Sources: Makhijani and Saleska, *High-Level Dollars, Low-Level Sense*, IEER (New York: Apex Press, 1992), and *Classifications of Radioactive Waste*, IEER On-Line Classroom, last updated April 29, 1996, [www.ieer.org/clsroom/r-waste.html](http://www.ieer.org/clsroom/r-waste.html).

The National Academy of Sciences is in general accord with our analysis. Referring to Silos 1 and 2 waste, 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.<sup>2</sup>

According to U.S. regulations, transuranic wastes with a specific activity above 100 nanocuries per gram and half lives of more than 20 years must be disposed in a deep geologic repository.<sup>3</sup> The concentrations of radium-226 in Silos 1 and 2 waste are well above this. Moreover, the radiological properties of radium-226 (and also thorium-230) are similar to those of transuranic

<sup>2</sup> Page 64 of National Research Council, *Risk and Decisions About Disposition of Transuranic and High-Level Radioactive Waste*, Committee on Risk-Based Approaches for Disposition of Transuranic and High-Level Radioactive Waste, Board on Radioactive Waste Management, Division on Earth and Life Studies, National Research Council of the National Academies. Washington, DC: National Academies Press, 2005. On the Web at [www.nap.edu/books/0309095492/html](http://www.nap.edu/books/0309095492/html).

<sup>3</sup> 40 CFR 191.02(i).

elements. Disposal in shallow land burial is therefore not in accord with the spirit of the regulations as they exist, even though there is no explicit classification for Silos 1 and 2 waste that would require deep geologic disposal.

Silo 3 waste has a concentration of thorium-230 that is far larger than the 10 nanocuries per gram limit for Class A low-level waste and therefore should not be disposed of without the precautions for Class B low-level waste or in a facility that is not licensed for Class B waste.

The management of the silo wastes at Fernald has been an abject failure when these considerations are taken into account. This conclusion is borne out by the detailed radiological assessment that we carried out, described below (see “Estimated doses to future generations”). First we will outline a brief history and current status of the silo cleanup program.

### **The silo remediation program: promises and reality**

In 1994, DOE issued a Record of Decision (ROD) stating that the best option for treating the silo wastes was to put them into a melter similar to a glass melter, heat them, and vitrify them (convert them into a glassy material). The glassy blocks of silo waste would be disposed of at the Nevada Test Site. Another option considered but rejected was to mix the silo wastes with cement.

In the ROD, the comparison of the vitrification and cementation options for Silos 1 and 2 waste was discussed separately from that for Silo 3 waste because of differences in chemical composition. Vitrification of the waste from all three silos was selected as the best option because laboratory tests indicated that this would be the best way to prevent the migration of radionuclides into the environment. Other benefits cited in the ROD were waste reduction and the fact that cementation (mixing the waste with cement) did not reduce radon gas emissions as efficiently as vitrification.

At that time the cost for cementation for Silos 1 and 2 waste was assessed to be \$73.1 million versus \$43.7 million for vitrification. For Silo 3 it was \$36.8 million versus \$28 million. The lower cost for vitrification derived in large measure from the estimated savings in transportation cost due to the volume reduction produced by vitrification of the waste.

But this scheme was not implemented due to a series of management and operations failures and bad decisions. The actual program that was implemented was substantially inferior to vitrification.

Whereas the vitrification of fission products from the reprocessing of spent fuel is performed on a routine basis, the vitrification of the type of waste in the silos was a more challenging problem because it had never been done before on a large scale. Fluor Fernald, the DOE contractor, decided to do laboratory experiments and then build a pilot plant to test the concept prior to large scale construction. However, poor design of the pilot plant and the failure to take into account the specific characteristics of Silo 3 waste, despite prior indications of possible problems, led to the failure of the melter before any radioactive waste was put into it.<sup>4</sup>

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<sup>4</sup> For a detailed review of the failure of the melter, see Chapter 4 of IEER’s report, *Containing the Cold War Mess*, on the Web at [www.ieer.org/reports/cleanup/ccwm.pdf](http://www.ieer.org/reports/cleanup/ccwm.pdf).

After the failure of the pilot plant, Fluor Fernald proceeded with the vitrification plan but decided, as it should have from the start, that the waste from Silos 1 and 2 should be vitrified separately from the waste from Silo 3. Thereafter, however, there was a steady deterioration in the silo remediation program.

The deterioration was intimately linked to DOE's "Accelerated Cleanup" program in the late 1990s, followed by its Top-to-Bottom Review in 2002, which moved the closure date of the Fernald site up to 2006 from its previous, less ambitious deadline of between 2006 and 2010. DOE's reasons for speeding things up were the need to address cost escalation and to remove the contamination in a timely manner for protecting human health and the environment. An additional reason proffered was that it would save money.

However, at the same time the schedule was accelerating, the site's long-term cleanup performance goals were essentially being abandoned. The bonus promised to Fluor was geared solely to the deadline for finishing the job. There were penalties for being late, but there was no bonus for better environmental protection nor any penalty for inferior long-term disposal performance.

The result was predictable. In stages, the vitrification program was abandoned for all three silos. Silos 1 and 2 wastes were cemented. The cementation program for the Silo 3 waste was abandoned and that waste was packaged – with minimal treatment for reducing dispersal potential – in large plastic bags (see photograph).

The State of Nevada differed with DOE on whether the Silo 3 waste could be safely disposed at the Nevada Test Site and threatened to sue DOE if the waste was shipped there. Left without other disposal options, DOE shipped the Silo 3 waste to the Envirocare facility in Utah,<sup>5</sup> a low-level radioactive waste facility that is licensed to accept Class A low-level radioactive waste and byproduct material. Envirocare is allowed to accept byproduct material if the average concentration of the waste in the incoming trucks is below 4,000 picocuries per gram for radium-226, and below 60,000 picocuries per gram for thorium-230.

Silo 3 waste meets Envirocare disposal criteria today for these two radionuclides. However, the license does not take into account that thorium-230 decays into radium-226. The waste will exceed the limit of 4,000 picocuries per gram of radium-226 in about 50 years.<sup>6</sup> If it were shipped to the site at that time, the waste would no longer meet the disposal criteria.

Moreover, for most organs in the human body, the dose delivered per picocurie of thorium-230 ingested or inhaled is far greater than that of radium-226. For instance, the inhalation dose per picocurie to the bone surface or to the liver is about 300 times bigger for thorium-230 than for radium-226.

The Division of Radiation Control (DRC) in Utah, which granted Envirocare's license, has not carefully done its homework in creating a regulatory framework for Class A low-level waste that

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<sup>5</sup> The company is now called "EnergySolutions."

<sup>6</sup> It will reach about 50,000 picocuries per gram in about 8,000 years.

protects the health of future generations. The DRC has tried to make such problems go away by simply assuming that no one will ever go to the site, even thousands of years from now.

### **Estimated doses to future generations**

We have done RESRAD calculations to verify whether shallow land burial of the silo waste would meet criteria set forth in federal rules that limit exposure to 25 millirem per year per person in the general population.<sup>7</sup> RESRAD is a government-approved computer program that allows the estimation of long-term health impacts of radiologically contaminated soil.

#### *Silos 1 and 2*

There is, to date, no final disposal solution for the waste from Silos 1 and 2. Because the waste far exceeds the 4,000 picocuries per gram limit for radium-226 for the Envirocare site, it could not be shipped to Utah. The cemented (grouted) wastes have been shipped for temporary storage to a facility in Texas owned and operated by Waste Control Specialists, which does not as yet have a license to dispose of radioactive waste.

In fact, Waste Control Specialists' ability to handle waste is in question because of egregious errors in its license application.<sup>8</sup> For instance, Waste Control Specialists (WCS), using DOE data, claims that Oak Ridge will ship it over 12,000 metric tons of uranium-235 as waste for disposal. This amount is more than the entire inventory of U-235 that has ever been mined worldwide. If WCS cannot detect obvious errors in waste data (and this was not the only absurd value in its license application), how can it be expected to, say, prevent illegal disposal of prohibited radioactive materials during operations?

We performed an assessment of radiation doses far into the future should the WCS site be inadvertently occupied or even used occasionally for such purposes as grazing or hunting. These are uses to which the site has been put in the past. Table 4 shows the estimated peak doses and when they will occur based on the erosion rate of the waste cover. This is for a "rancher scenario," which assumes a future person will spend a limited amount of time on the site and will not build or grow food on the site.

**Table 4: Peak doses from grouted K-65 waste disposal – rancher scenario**

<b>Erosion rate (cm per year)</b>	<b>Peak external dose (rem per year)</b>	<b>Peak inhalation dose (rem per year)</b>	<b>Years until peak dose</b>
0.1	20.1	0.078	9,150
0.01	8.7	0.037	91,500

Depending on the erosion rate, the projected external dose to the maximally exposed person in the future is 346 to 800 times higher than the present regulatory limit of 25 millirem per year. Note that these peak doses are from the radium-226 originating from the decay of thorium-230. The original radium-226 in the waste will be almost completely gone after about 9,150 years and totally gone after about 91,500 years.

<sup>7</sup> 10 CFR 61 subpart C.

<sup>8</sup> These errors are documented in the IEER 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, online at [www.ieer.org/reports/du/LESrptfeb05.pdf](http://www.ieer.org/reports/du/LESrptfeb05.pdf).

### Silo 3

Silo 3 waste is slated to be disposed of at the Envirocare site in Utah. Table 5 shows the doses estimated by RESRAD modeling of that waste. Kd is called the partition coefficient and refers to how tightly the contaminant is bound to the soil. As described in the [article by Brice Smith](#), the value for Kd can vary dramatically among sites and even within a site.

**Table 5: Peak doses for Silo 3 waste disposal –rancher scenario**

<b>Kd</b>	<b>Peak external dose (rem per year)</b>	<b>Peak inhalation dose (rem per year)</b>	<b>Years until peak dose</b>
Low Kd, HIR, HC	245	0.698	6,800
High Kd, LIR, LC	273	0.756	9,000

NOTES: 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 results were the same for both high and low erosion rates.

The more rapid approach of peak doses for Silo 3 waste is due to a less thick cover over the waste than at the WCS site. The external dose from radium-226 dominates in this case as well.

The estimated external doses from the Silo 3 waste, in the 250 rem range, are 10,000 times bigger than the dose limit of 25 millirem. Hence, if a hunter or recreational vehicle user or other visitor in the far future spends just one hour at the site, he or she will have exceeded the allowable dose limit.

These two sets of dose estimates illustrate why the Fernald silo wastes should be disposed of in a deep geologic repository. While there would still be some risks with a deep geologic repository, the risks of exceedingly high doses from shallow land burial would not occur.

### **IEER's proposal for Silos 1 and 2 waste**

Our RESRAD calculations indicate that WCS is a poor site for burial of the wastes from Silos 1 and 2. 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 mainly from the water pathway, while dry sites deliver high doses mainly due to the uncovering of waste by erosion. In the latter case, the principal component is external dose from radium-226.

The question of the disposal of the K-65 silos waste bears a lot of similarities to the question of the disposal of depleted uranium that IEER has extensively addressed.<sup>9</sup> 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.

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

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<sup>9</sup> *ibid.*, section II.A.

The volume of the DU would be several hundred thousand cubic meters. This is much larger than the present grouted volume of waste from Silos 1 and 2. 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.

### **Other challenges at Fernald**

The last two issues we will discuss are important because parts of the Fernald site will remain contaminated for ten of thousands of years to come. The issues are (a) residual radioactivity at the On-Site Disposal Facility and (b) permanent monitoring and community education.

The On-Site Disposal Facility (OSDF), or “waste cell,” is a lined, landfill-like structure located permanently on the Fernald site. (See photograph.) It contains about 2.5 million cubic yards of soil and demolition debris contaminated with low-level radioactive waste. The main problem is that, in estimating allowable residual radioactivity in the waste cell, DOE used a computer program that appears to have a serious systematic error. Specifically, we found that DOE estimated that *four grams* of neptunium could be left as residual radioactivity *per gram* of soil (total weight). This is of course physically impossible. These calculations must be checked and redone after the computer program has been debugged. The publication of an absurd residual radioactivity value indicates a lack of quality control that raises questions about the rest of the effort.

Further, the DOE went back on its promise to provide obligatory funding for an education program that would keep the public informed about the waste cell and residual radioactivity far into the future. The State of Ohio is a natural resources trustee of the site under the law. Funding to the site for damage assessment is required under the Superfund law under such circumstances, but the DOE is not providing it. The Ohio Attorney general has protested and the matter was under negotiation at the time this issue went to print.

**O**ur main findings and recommendations for Fernald silo waste management, waste cell problems, and monitoring and education funding can be found below.

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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 U.S. Department of Energy (DOE) decided to change the waste forms, thereby significantly degrading the expected long-term performance.
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.
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.

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.
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.
6. The DOE altered and loosened the remediation goal for uranium contamination of groundwater at Fernald after remediation commenced because the U.S. Environmental Protection Agency promulgated a more lax standard in the year 2000 than the remediation goal that had been set earlier.
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.
8. The Waste Acceptance Criteria for the On-Site Disposal Facility at Fernald were not subjected to adequate quality assurance.

## **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 U.S. Department of Energy (DOE) from degrading performance or cleanup goals once a Record of Decision (ROD) is issued.
3. Shallow land burial of Fernald's 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 (DU) waste resulting from historical uranium enrichment operations, which also need repository disposal. (This DU waste, currently 740,000 tons in unstable hexafluoride form, are stockpiled at three DOE sites in Kentucky, Ohio and Tennessee awaiting a disposal plan. See SDA vol. 13 no. 2, June 2005, for details.) Because the volume of the Silos 1 and 2 waste is far smaller than the depleted uranium waste inventory and because the specific activities of each waste type 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 large enough for the interest to be sufficient to cover annual costs for the 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 fund.
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. These programs include those used to estimate the total burden and the maximum residual radionuclide concentrations of radionuclides that can be put in waste cells. Specifically, the computer program and the input parameters 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 its rules for waste acceptance so that the total amount of radium disposed of in shallow land at any time remains less than 4,000 picocuries per gram after its in-growth from thorium-230 has been taken into account.