

Stabilization of Vitrified Wastes Task 4

Topical Report
October 1994 - September 1995

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September 1995

Work Performed Under Contract No.: DE-FC21-94MC31388

U.S. Department of Energy
Office of Environmental Management
Office of Technology Development
Washington, DC

For

U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
University of North Dakota
Energy and Environmental Research Center
Grand Forks, North Dakota

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TASK 4

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ACKNOWLEDGMENT

This annual report was prepared with the support of the U.S. Department of Energy (DOE) Morgantown Energy Technology Center Cooperative Agreement No. DE-FC21-94MC31388. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the DOE.

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TASK 4 – STABILIZATION OF VITRIFIED WASTES

EXECUTIVE SUMMARY

The goal of this task was to work with private industry to refine existing vitrification processes to produce a more stable vitrified product. The initial objectives were to 1) demonstrate a waste vitrification procedure for enhanced stabilization of waste materials and 2) develop a testing protocol to understand the long-term leaching behavior of the stabilized waste form. The testing protocol was expected to be based on a leaching procedure called the synthetic groundwater leaching procedure (SGLP) developed at the Energy & Environmental Research Center (EERC). This task will contribute to the U.S. Department of Energy's (DOE's) identified technical needs in waste characterization, low-level mixed-waste processing, disposition technology, and improved waste forms.

The proposed work was to proceed over 4 years in the following steps: literature surveys to aid in the selection and characterization of test mixtures for vitrification, characterization of optimized vitrified test wastes using advanced leaching protocols, and refinement and demonstration of vitrification methods leading to commercialization. For this year, literature surveys were completed, and computer modeling was performed to determine the feasibility of removing heavy metals from a waste during vitrification, thereby reducing the hazardous nature of the vitrified material and possibly producing a commercial metal concentrate.

Subtask 1 Survey of Vitrification Technologies

The literature review provides an overview of low- and high-level nuclear waste immobilization. Emphasis is on vitrification technologies based on borosilicate glass, since this glass will be used in the United States and Europe to immobilize radioactive high-level liquid waste (HLLW) for ultimate geological disposal.

Vitrification of aqueous radioactive wastes will achieve volume reductions of 86–97 vol% and will ensure their stabilization. Borosilicate waste glasses are the most studied and probably best understood waste form that has been developed. The application of synrocs, cements, and bentonites for radionuclide immobilization is also discussed.

This survey indicates that crystallization of vitrified waste typically makes toxic elements more easily leached by groundwater. It also indicates a lack of information exists in the following areas:

- Vaporization of heavy or radioactive metals from the melts and whether vaporization behavior could be controlled by modifying the heating environment in order to separate the hazardous materials from the bulk waste.
- Avoiding the formation molten sodium sulfate on the cold cap.
- Catalytic activity of radionuclides at the surface of the glass and glass corrosion in water.

- The effect of the glass cooling rate on the generation of residual stresses below the temperature of glass transformation and its effect on the leachability of nuclear waste glass.
- The effect of foaming of the melt on the homogenization of nuclear waste during vitrification using plasma technology.
- Immobilization of scrubber-condensed volatilized hazardous components such as strontium, cesium, lead, cadmium, and others in inorganic materials with low melting temperatures not related to silicate glasses.

Subtask 2 Survey of Cleanup Sites

The magnitude and variety of contaminants at the numerous DOE Environmental Management program waste sites are difficult to summarize. Overviews of waste types and combinations and site-specific information are available, but complete information required to make good decisions regarding the applicability of an innovative technology is not readily available or cross-referenced in the DOE documents that were reviewed for this report. Based on the review performed, it can be concluded that small businesses and others trying to determine whether or not a specific technology has a role in the DOE Environmental Management program will find the necessary information difficult to obtain. If DOE is to take advantage of small business innovation, the information must be more readily available.

Review of DOE and Environmental Protection Agency (EPA) documents resulted in the development of preliminary selection criteria to focus the EERC's waste site selection. Using these preliminary selection criteria, several waste sites were identified as examples of the type of waste sites that would provide the opportunity to investigate innovative technologies that would be broadly applicable to numerous DOE sites as well as industrial sites and processes. Each of the identified waste sites requires environmental restoration and is scheduled for remediation. Specific technologies that fit most readily include solidification, fixation, and encapsulation (SFE) techniques. SFE would be most applicable to hazardous solid wastes, but may also have extensive application to mixed wastes. Hazardous trace elements, including heavy metals, were identified as the mixed-waste constituents that EERC efforts should focus on for further work, including their removal during vitrification by enhancing their vaporization.

Subtask 3 Selection and Characterization of Test Mixtures for Vitrification and Crystallization

Based on the findings of the two literature surveys, it was decided that inducing crystallization in vitrified wastes would not be the most efficient way to stabilize them. Instead, it was decided to pursue the idea of removing certain heavy metals from the waste during vitrification through enhanced vaporization.

Subtask 4 Selection of Crystallization Methods Based on Thermochemistry Modeling

As a result of the survey of vitrification technologies, it was decided to modify the original scope of work to delete crystallization of vitrified waste as a stabilization technique. Instead, the

idea of removing some toxic elements from a waste during vitrification by enhancing the vaporization of the elements would be investigated.

Common oxides such as silica, alumina, calcium, and boron are durable under the extreme conditions of vitrification in an oxidizing atmosphere, but the stability of other oxides such as mercury, lead, and even plutonium is questionable in silicate melts. Vaporization of the elements may present a way to remove them from the melt and reclaim them, leaving the vitrified product much easier to dispose. The radionuclides commonly found in waste forms are tritium, uranium, strontium, plutonium, and cesium. The nonradioactive trace metals most commonly noted are lead, chromium, arsenic, zinc, copper, mercury, and cadmium. Because of the difficulties associated with performing tests on mixtures containing radioactive elements, the EERC focused primarily on the heavy trace metals for modeling.

Thermochemical equilibrium calculations of the stable phases of the elements over a range of temperatures were performed with a computer code obtained from a Canadian-Swedish team at the École Polytechnique de Montréal in Canada. Tailored for the treatment of about five thousand species, it is known as the Facility for the Analysis of Chemical Thermodynamics (FACT) code. We employed the code to calculate the vaporization temperatures of the heavy elements and their oxides from borosilicate melt/glass in the temperature range of 600° to 2000°C at three different oxygen pressures: 1, 0.001, and 0.000001 atm. The lower pressures simulate reducing atmospheres. For some temperatures and mainly lower oxygen pressures, the FACT code was unable to calculate the vapor concentration since the code was not able to calculate a solution for the equilibrium composition.

Generally, there is a characteristic temperature (T_{cr}) at which the elements and their oxides vaporize, and this depends on the oxygen pressure over the melt/glass. Usually, T_{cr} decreases with oxygen pressure and is very well defined below 1 atm. The following table lists these temperatures for the seven elements and their oxides released from borosilicate melt/glass at 1 atm oxygen pressure.

It is found that lead may vaporize from borosilicate melts above 1530°C; cadmium, zinc, arsenium, chromium, and copper may vaporize at temperatures between 1230° and 1430°C; and mercury may vaporize above 530°C. Also, it is found that, for the range studied, the concentration of the elements in the melt does not significantly affect the vaporization temperatures.

Phase Transformation of Metallics and Their Oxides

Vapor-Phase Component	Solid - Liquid K	Solid - Gas K	Liquid - Gas K
PbO	1159	---	---
Pb	600	---	---
Pb ₂	Gas	Gas	Gas
HgO	---	811.6	---
Hg	---	---	630.5
Hg ₂	Gas	Gas	Gas
As ₄ O ₆	Gas	Gas	---
As	---	2290	---
As ₂	Gas	Gas	---
As ₃	Gas	Gas	---
CrO ₃	470	---	---
CrO ₂	---	---	---
CrO	---	---	3687
Cr	2179	---	---
CuO	---	---	---
Cu	1358	---	---
Cu ₂	Gas	Gas	---
Cd	594	---	---
Zn	692	---	---

FUTURE WORK

The ability to enhance the vaporization of heavy trace metals during vitrification will take significant development, including more detailed computer modeling as well as laboratory- and bench-scale testing before field testing can commence. Therefore, the work does not meet the EERC's brokering criteria of an identified industrial partner and a high probability of near-term commercialization, so it was not proposed for continuation in 1996. In addition to the vaporization work, another area for EERC focus is waste cleanup and site remediation. This area will allow small businesses to benefit the most from EERC staff expertise and facilities. Specific technologies that fit most readily include SFE techniques. SFE would be most applicable to hazardous solid wastes, but may also have extensive application to mixed wastes. The EERC could participate in materials characterization, mix design, and solidified waste form evaluation for both physical integrity and mobility of constituents. Opportunities exist to work with commercial partners in all of these areas, and new tasks will be proposed when defined activities meeting the commercialization criteria are met.

TASK 4 – STABILIZATION OF VITRIFIED WASTES

1.0 INTRODUCTION/OBJECTIVES

Simply vitrifying a material into a glassy slag does not necessarily produce an environmentally stable product. To make a waste material stable for disposal, the chemistry of the materials will need to be assessed and, possibly, modified. An assurance that toxic metals and radionuclides have been incorporated into stabilized phases will also need to be determined.

The ability of a vitrification process to produce an environmentally stable product from a hazardous material is largely dependent upon the chemical composition of the material as well as the conditions of the process. The goal of this task is to work with private industry to refine existing vitrification processes to produce a more stable vitrified product. The initial objectives of this multiyear task were to 1) demonstrate a waste vitrification procedure for enhanced stabilization of waste materials and 2) develop a testing protocol to understand the long-term leaching behavior of the stabilized waste form. The testing protocol was expected to be based on a leaching procedure developed at the Energy & Environmental Research Center (EERC), called the synthetic groundwater leaching procedure (SGLP). This task will contribute to the U.S. Department of Energy's (DOE's) identified technical needs in waste characterization, low-level mixed-waste processing, disposition technology, and improved waste forms.

The proposed work was to proceed over 4 years in the following steps: perform literature surveys to aid in the selection and characterization of test mixtures for vitrification, fabrication and characterization of optimized vitrified test wastes using advanced leaching protocols and refinement and demonstration of vitrification methods leading to commercialization. For this year, literature surveys were completed and computer modeling was performed to determine the feasibility of one method of improving the environmental stability of vitrified waste.

2.0 ACCOMPLISHMENTS/WORK PERFORMED

2.1 Subtask 1 Survey of Vitrification Technologies

2.1.1 Introduction

A literature review has been completed that provides an overview of low- and high-level nuclear waste immobilization. The objective of the survey was to make a concise summary of glass properties with nuclear wastes and/or hazardous elements for their effective immobilization, and to specify directions of further tests to produce durable and highly stable glasses. Emphasis is on technologies based on borosilicate glasses since this glass will be used in the United States and in Europe to immobilize radioactive high-level liquid wastes (HLLW) for ultimate geological disposal.

Radioactive wastes are produced at all stages in nuclear fuel cycles over the world. In the United States, they are stored at three DOE sites: the Hanford reservation in Richland, Washington, the Savannah River Site in South Carolina, and Idaho Chemical Processing Plant in

Idaho Falls. The Hanford site was the world's first to concentrate plutonium used for atomic weapons. It holds from 3×10^7 to 6.5×10^7 gal of HLLW. To store the waste, DOE is considering enhanced waste form options for numerous sites, because the immobilization of radionuclides requires materials with long-term chemical durability, preferably more than 10^4 – 10^6 years (1). Therefore, vitrification of nuclear wastes is considered the best alternative for radionuclide immobilization and has been a subject of interest for almost four decades (2).

Generally, the stability of any material can be characterized by its thermodynamic equilibrium with its surroundings and by the rate of structural and/or chemical changes to reach this equilibrium. As an example, glasses with their disordered structures are less stable than their crystalline forms under normal environmental conditions, so the glasses are somewhat less durable than crystalline forms. However, sufficient knowledge exists today to develop selection criteria for glass compositions based on long-term rather than short-term behavior.

The durability of glass in contact with groundwater and its ability to retain nuclear waste within its structure depends on bulk glass properties, hydrodynamic constraints, the groundwater composition, and the solubility and complexation behavior of nuclear wastes (3–5). The presence of low-level impurities such as iron may enhance the solubility of the glass (6). All these factors may cause the same material fabricated in two different laboratories to have different chemical durabilities. However, two major factors contribute to the suitability of immobilizing high-level nuclear wastes into glass matrices: technical performance—such as chemical durability, the ability to incorporate waste streams having small amounts of flux components, and limited requirements for purchased additives—and ease of fabrication (7, 8).

Research programs on HLLW immobilization using vitrification technologies have been mostly concentrated on either borosilicate glass or Synroc ceramic made from a reactive mixture of Al, Ba, Ca, Ti, and Zr oxides. In borosilicate glasses, hazardous elements can be immobilized by dissolving them in the glass, forming Si–O–M–O chemical bonds, and by encapsulation where bonds are not formed (9).

2.1.2 Characterization of Nuclear Waste Streams

Generally, radioactive wastes are separated into two groups: 1) high-level waste (HLW), which includes transuranic constituents (elements with atomic numbers greater than uranium) generated from reprocessing spent fuel and making plutonium, that have more than 100 nanoCuries (nCi) per gram (g) as well as having half-lives greater than 20 years, and 2) low-level waste (LLW), which include medical materials and protective casings and tools used around radioactive materials that have a total specific activity below 100 nCi/g. Many DOE sites have large-volume waste streams that contain a significant amount of high-level nuclear waste both from military programs and from defense reactors; these are rich in plutonium and uranium along with a large variety of other contaminants, often highly heterogenous. They may contain complex hazardous organic compounds with low, medium, and high heating values and inorganic materials such as heterogenous debris and pieces of metals.

An example of a site where high-level waste is stored is the three silos at the Fernald Environmental Management Project in Fernald, Ohio, which contain residues from the processing of pitchblende ores. Silos 1 and 2, designated collectively as K-65, contain the depleted ore, while

Silo 3 contains calcined residue from processing solutions. Silos 1 and 2 also contain a bentonite clay cap that was added to the silos to reduce random emanation from the waste. The K-65 residue totals 8.6 million kg (9500 tons). It is a siliceous material containing uranium, uranium-derived products, and thorium, with high levels of radium and lead; Silo 3 residue is lower in silica and consists largely of metal oxides and sulfates, phosphates, nitrates, carbonates along with uranium and thorium (10). The gamma radiation from the residue is sufficient to result in an average dose of about 200 mr/hr outside the silo dome. The radon concentration of the silo headspace is around 30 million pCi/L.

At another site, the Savannah River Site (SRS) in Aiken, South Carolina, HLW is stored as a concentrated liquid radioactive waste by-product of plutonium processing, consisting of a strongly caustic solution of nitrate salts. Insoluble and highly radioactive metal oxide sludge is also present in some of the materials. These waste streams are pumped from the separations facilities to the liquid radioactive waste-handling facilities (called the waste tank farms) located in F-Area and H-Area. The tank farm facilities consist of 51 underground waste tanks with a nominal capacity of 1 million gallons each. The sludge of highly radioactive metal oxide undergoes aging and several chemical processes prior to vitrification in borosilicate glass (11).

Examples of other materials in waste streams are as follows:

- Scrap metals, e.g., 22 wt% of the buried wastes at the Idaho National Engineering Laboratory Radioactive Waste Management Complex
- Metal oxides, e.g., the K-25 pond sludge-soil of over 16 million kg at the DOE Oak Ridge site, which contains 25 wt% iron oxide, 20 wt% aluminum oxide, and 20 wt% calcium oxide (8, 12). Other wastes contain chromium and nickel oxides. Because the maximum solubilities of iron, chromium, and nickel oxides in borosilicate glass are 20, 3, and 3 wt%, respectively, a large amount of glass will be necessary to fix these materials (8).

Analytical results have shown that nuclear wastes may also contain organochloride pesticides, ketones, and other volatile and semivolatile components. As this waste is heated, volatiles are released, and organics are either pyrolyzed in an oxygen-poor atmosphere or oxidized in an oxygen-rich atmosphere. Offgas treatment is required to minimize air emissions (13).

Some DOE sites such as the SRS have contaminated soils resulting from spills over the many years of processing radioactive and hazardous materials that also should be disposed.

2.1.3 Borosilicate Glass Use in the Vitrification of High-Level Nuclear Wastes

Borosilicate glass was selected in 1982 as the reference waste matrix for solidifying high-level radioactive wastes stored in tanks at Savannah River and West Valley. The vitrified waste produced by the Defense Waste Processing Facility (DWPF) at the SRS will be in the form of glass logs contained in 2-ft × 10-ft Type 304L stainless steel canisters. This disposal system is designed to provide safe and permanent storage.

Borosilicate glasses have been shown to be a good solid matrix for immobilization of radioactive wastes. Their success stems from the following:

- Amorphous structure and strong interatomic bonding
- Ability to be processed at lower temperatures than other glasses
- Higher durability than that of other most glasses
- Boron remaining in the residual glass phase upon crystallization of other phases (14)

2.1.4 Glass Structure

Oxides that form glasses when melted and cooled are called glass-forming or network-forming oxides. They include SiO_2 , GeO_2 , P_2O_5 and As_2O_5 because of the ability of these oxides to build continuous three-dimensional (amorphous) random networks. On the other hand, modifying oxides such as Na_2O , K_2O , CaO , and MgO are incapable of building a continuous network, and the effect of such oxides is usually to weaken the glass network. The addition of the modifiers to the network-forming oxides invariably lowers the viscosity of the glass melt.

The nature of the bonding between the cations and oxygen plays a critical role in the immobilization of nuclear waste. This bonding behavior is described by the model validity constraints. Generally, those oxides with highly covalent bonds to oxygen are more likely to assume the role of network formers than oxides in which the bonding is predominantly ionic. One measure of the power of a cation to attract electrons and, therefore, a description of the covalent or ionic nature of the bonds it will form, is the ionic field strength, given by (15)

$$F = Z/r^2 \quad [\text{Eq. 1}]$$

where Z is the valency and r the ionic radius. Table 1 lists the ionic radius and the ionic field strength for some cations. The data show that some ions such as U^{4+} and Pu^{4+} may occupy either network-forming positions (because of their high charge) or network-modifying positions (because of their low F values).

Generally, the maximum concentration of either network formers or modifiers in a glass depends on structural limits. In Table 2, the approximate measured solubilities of elements in silicate waste glass are listed.

Since some oxides have limited solubility in glass, it is important to obtain information on the solubility properties from *The Handbook of Glass Manufacture* prior to vitrification (16). An example of target composition determined for the DWPF is shown in Table 3 (17).

The composition of nuclear wastes are often unknown, which makes it difficult to predict glass properties such as liquidus and softening temperatures and even the probable level of radioactivity of the waste. For example, only 1–3 wt% plutonium in a vitrified waste is enough to create a chain reaction which will dramatically increase the radioactivity of the material. The presence of water, which is an excellent neutron moderator, around the glass can substantially

TABLE 1

Ionic Field Strength of Cations Present in Silicate Glasses			
Ion	Ionic Radius, Å	Field Strength, Z/r^2	Structural Role in Glass
B ³⁺	0.23	56.7	Network-forming ions
Si ⁴⁺	0.42	22.6	
As ⁵⁺	0.46	23.6	
Al ³⁺	0.51	11.5	Intermediate ions
Ti ⁴⁺	0.68	8.7	
Mg ²⁺	0.66	4.6	Network-modifying ions
Ca ²⁺	0.99	2.04	
Na ⁺	0.97	1.06	
K ⁺	1.33	0.57	
U ⁴⁺	0.97	4.2	
Pu ⁴⁺	0.93	4.6	
Cs ⁺	1.67	0.35	
Sr ²⁺	1.12	0.79	

TABLE 2

Approximate Solubilities of Elements in Silicate Glasses ¹	
Less than 0.1 wt%	Ag, Au, Br, H, Hg, I, Pd, Pt, Rh, and Ru
Between 1 and 3 wt%	As, C, Cl, Cr, S, Sb, Se, Sn, Tc, and Te
Between 3 and 5 wt%	Bi, Co, Cu, Mn, Mo, Ni, and Ti
Between 5 and 15 wt%	Ca, F, Gd, La, Nd, Pr, Th, B, and Ge
Between 15 and 25 wt%	Al, B, Ba, Ca, Cs, Fe, Fr, K, Li, Mg, Na, Ra, Rb, Sr, U, and Zn
Greater than 25 wt%	P, Pb, and Si

¹ Taken from Reference 13.

TABLE 3

Target Composition Range for DWPF Waste Glass

Component	Minimum Range, wt%	Maximum Range, wt%
SiO ₂	44.6	54.4
Al ₂ O ₃	2.9	7.1
B ₂ O ₃	6.9	10.2
CaO	0.8	1.2
MgO	1.3	1.5
Na ₂ O	8.2	12.1
K ₂ O	2.1	4.6
Li ₂ O	3.1	4.6
Fe ₂ O ₃	7.4	12.7
MnO	1.6	3.1
TiO ₂	0.6	1.0
U ₃ O ₈	0.5	3.2
ThO ₂	0.01	0.8
Group A ¹	0.08	0.2
Group B ²	0.08	0.9

¹ Isotopes: Tc, Se, Te, Rb, and Mo.

² Isotopes: Ag, Cd, Cr, Pd, Ti, La, Ce, Pr, Pm, Nd, Sm, Tb, Sn, Co, Zr, Nb, Eu, Am, and Cm.

increase the probability of a chain reaction (18). In addition, technology constraints related to viscosity of the molten glass can be difficult to predict (19, 20).

2.1.5 Glass Processing

The most important technological property for glass processing is its viscosity. The viscosity determines the working, annealing, and fining (removal of bubbles from the melt) temperatures, upper temperatures of use, and devitrification rate. These properties are often defined in terms of viscosity (η) as follows (21):

- Glass melting temperature: $\log \eta = 2.0$ poise
- Working temperature: $\log \eta = 4.0$ poise
- Flow point: $\log \eta = 5.0$ poise
- Softening point: $\log \eta = 7.6$ poise
- Annealing point (upper annealing temperature): $\log \eta = 13.0$ poise
- Transition temperature (T_g): $\log \eta = 13.3$ poise
- Strain point (lower annealing temperature): $\log \eta = 14.6$ poise

Typical acceptable viscosity values for melt processing should range between 2 and 10 Pa · s (20–100 poise) (22), because these lower viscosities ease homogenization of the constituents. The addition of 14% waste to the melt can lower the viscosity by a factor of two. Depending on the vitrification process, glass-forming constituents should be added as a premelted ground glass frit to the precalcined radioactive waste.

In addition to viscosity, the temperature of glass transition, T_g , is a very important glass property. Below it, glass loses its ductility and becomes brittle, and its volume significantly decreases. If a quenched glass is reheated above the T_g , it speeds devitrification. It is desirable, therefore, that a glass containing radioactive material is not subjected to temperatures higher than the T_g so that the radioactive material does not segregate into crystals where the radioactive elements are highly concentrated. Atmosphere also plays an important role in glass processing since reduced glasses tend to be less durable than oxidized glasses (23). However, to avoid precipitation of metals and metal sulfides such as NiS and CaS from the glass-forming solution, processing should occur under reducing conditions in which the $Fe^{2+}:Fe^{3+}$ ratio is higher than 0.5.

In addition to glass properties, several properties of the feed materials will also limit the effectiveness of vitrification, including the following (13):

- Feed moisture content (lower than 20 wt% for many processes)
- Feed material composition
- Feed compatibility (ability of the process to handle all sizes and types of materials)
- Presence of combustible material (organics)
- Presence of process-limiting materials (halogens, reducing agents, and metals)
- Potential volatilization of contaminants and metals with low partial pressures (e.g., Hg, Pb, and Cd)
- Potential shorting of electrodes in Joule heating caused by metals

2.1.6 Devitrification

Devitrification implies the growth of crystalline material in the glass. It can occur as a result of the selection of an unsuitable glass composition or prolonged contact and reaction with the furnace refractories in stagnant regions of the melting furnace. The addition of nucleating agents to the glass may promote devitrification. Usually, the nucleating agents are soluble in the molten glass.

Devitrification of borosilicate glass occurs to a certain extent between 900° and 500°C (24). Usually, the crystalline phase will be a maximum of 3.6 vol% of the canisters filled with glass (25). The size and number of crystalline phases depend on the rate of cooling. Thus, to avoid generation of internal stresses (mainly tensile stresses around the temperature of glass transformation that lead to cracking and void formation), the cooling rate should be carefully

controlled. Stresses in glass can be relieved above the glass transition temperature, 430°–450°C, so cracking usually occurs as the temperature drops below 450°C (26). At room temperature, the rate of crystallization of borosilicate glass is very slow and is not expected to occur for 10⁶–10¹³ years (27).

Borosilicate glasses are also susceptible to phase separation into two or more noncrystalline phases. If the phase separation takes place in the melt at a temperature above the liquidus temperature, it is described as stable immiscibility, whereas phase separation occurring below the liquidus is described as metastable immiscibility (28). The presence of stable immiscibility is important in glass manufacturing. Two mixed glassy phases often have quite different properties from those of a single phase of the same average composition. Devitrification rates and leachability are higher in phase-separated glasses. Phase separation occurs only if the waste compositions are modified to contain much higher levels of B₂O₃ (29). Generally, there is no evidence of phase separation in properly formulated borosilicate glasses (30–32).

Decay of radionuclides in nuclear waste glasses, self-irradiation, and internal and external stresses generate heat, and the temperature of the material may rise to the glass transition temperature, which can lead to devitrification. The temperature can subsequently increase exponentially with the cumulative irradiation dose (33).

Devitrification of glass may have a number of deleterious effects on the integrity of the glass waste form (14). They include the following:

- Depletion of silica leaves the residual glass phase with a lowered chemical durability.
- Problems with draining of the melt occurs if it crystallizes at the bottom of the drain tube.
- Crystalline materials are more susceptible to radiation damage than glasses, and chemical durability may decrease even more than it does for a glass.

2.1.7 Durability of Nuclear Waste Glass

Long-term glass stability is related to the maintenance of silica saturation in the surrounding environment. Generally, glass dissolution in an aqueous solution is controlled by orthosilicic acid activity in solution (34). Glasses with more alkali than the sum of boron and aluminum tend to yield alkaline leach solutions in which the increase of pH is faster than the accumulation of silica. The exchange of hydronium ions in solution for the alkalis in the glasses is the main rate-determining step, and the rate of the glass reaction depends on the concentration of the hydronium ions (35). The main glass reaction process can be presented as



where R⁺ represents an alkali metal.

It has been shown that waste glass durability also depends on 1) the amount of water contacting the glass waste, 2) temperature, 3) the ratio of glass surface area to solution volume, 4) radionuclide decay effects, 5) glass composition, and 6) alteration phases resulting from glass

hydration (36). The chemical behavior of individual radionuclides in glass depends on the glass homogeneity of the glass and the reaction conditions, such as pH, temperature, water flow rate, and pressure. Also, glass dissolution is enhanced by the presence of clay (37).

Usually, radiation influences glass stability through the formation of corrosive daughter products and by physically altering the glass structure through atomic displacements. Radioactivity can also make the surrounding aqueous solution more reactive through the ionization of water molecules, mostly from gamma and alpha radiation, which creates highly reactive radicals. Also, nitrogen and carbon dioxide dissolved in the water undergo radiolytic decomposition to form nitric and carboxylic acids, respectively (38, 39). These processes can change the leachate pH and glass dissolution rates. Under batch test conditions, glass corrosion has been shown to increase up to three- to fivefold in irradiated tests relative to nonirradiated tests (40).

Many studies have shown that the Al_2O_3 (alumina) reduces borosilicate glass leachability because of the stronger interconnection of alkali and alkaline-earth elements within the network structure of glass containing alumina (41). There is, however, an anomalous increase of the dissolution rate at 150°C (42).

Some controversial techniques are used in measuring the chemical durability of the glasses, such as the Savannah River product consistency test (PCT) procedure (43). The test uses washed, crushed glass powder (100–200 mesh) and a glass surface-area-to-solution-volume ratio of 2000 m^{-1} . It is performed with deionized water (100 mL) at 90°C . This test provides only information on the maximum solubility of glasses and wastes in deionized water and no real solubility of vitrified nuclear wastes. Also, it was acknowledged in some studies that dissolution is affected by the surface area and the volume of leachate (SA/V) (25, 31). The lack of a standardized test to determine leachability makes the results difficult to compare.

2.1.8 Application of Glass Ceramics for Radionuclide Immobilization

The study of glass ceramics for immobilizing nuclear wastes stems from pioneering work at the Hahn-Meitner Institut in Berlin on the crystallization of borosilicate-based waste glasses to improve the thermal stabilities and mechanical properties of the products. The compositions investigated included those that produced celsian ($\text{BaAl}_2\text{Si}_2\text{O}_8$), perovskite (CaTiO_3), diopside ($\text{CaMgSi}_2\text{O}_6$), or eucryptite ($\text{LiAlSi}_2\text{O}_6$) and residual glass (44).

Practically any inorganic glass can crystallize above the softening temperature. The crystals may deplete the residual glass of ions, such as Al^{+3} , Zn^{2+} , etc., that confer durability on the glass, such that the vitreous matrix becomes more susceptible to aqueous dissolution than the original glass. However, these glasses have considerably higher mechanical and impact strengths and are more resistant to cracking than their parent glass. Therefore, they may be used for radioactive waste immobilization in a low flow rate environment if crystalline phases are thermodynamically stable (45).

Also, sphene-based glass ceramics have been considered as an alternative for HLLW immobilization in Canada. These materials consist of discrete crystals of the major crystalline phase, sphene (CaTiSiO_5), within a matrix of aluminosilicate glass, and the waste ions are either incorporated in the sphene structure as solid solution replacements for Ca and Ti or dissolved in

the glass matrix. The aluminosilicate glass matrix that remains after sphene crystallization is a highly durable material for immobilizing those waste ions that do not partition into the sphene phase. Generally, sphene is a common accessory mineral in many types of rocks and is resistant to chemical alteration.

The glass ceramics usually have compositions in the following ranges: Na₂O (5.1–9.0 wt%), Al₂O₃ (5.9–11.5 wt%), CaO (9.2–17.1 wt%), TiO₂ (10.7–26.7 wt%), and SiO₂ (40.1–59.2 wt%) and can include waste oxides of Ce, La, U, Sr, Cs, and U (0–25 wt%). The melting temperature is between 1250° and 1450°C. Crystallization is accomplished by controlled reheating of the glass between 900° and 1050°C and holding for 1–3 hours before cooling to room temperature. Typically, crystalline phases that occur in the glass consist of sphene, pyrochlore, fluorite, wollastonite, anorthite, and other minor phases.

2.1.9 Natural Glasses in High-Level Nuclear Waste Immobilization

The common observation of natural glasses persisting in nature for long periods of time provides evidence that natural glasses can be kinetically stable in a variety of environments. Natural glasses are classified according to their silica content from silica-rich rhyolitic glasses and tektites to silica-poor basalt glasses (Table 4) (46). Tektites are glasses of excellent durability with approximately 74 wt% SiO₂. They resist water diffusion similarly to nuclear glasses, which have diffusion coefficients of approximately 2×10^{-24} m²/s at 25°C (47). The results of a series of experiments with tektite glass in water between 150° and 225°C for up to 400 days show a reaction resulting in the formation of a birefringent hydration layer that increased in thickness up to 4.8 μm as a function of the square root of time.

A series of basalt-based glass ceramics for immobilization of nuclear wastes was developed at Battelle Pacific Northwest Laboratory (44). The suggested composition was given as 52 wt% SiO₂, 1.6 wt% TiO₂, 2.7 wt% Na₂O, 10 wt% CaO, 6.8 wt% MgO, 11.9 wt% Fe₂O₃, 14.1 wt% Al₂O₃, and 0.2 wt% MnO₂. This particular basaltic melt is able to incorporate up to 20 wt% defense and commercial wastes. The melting temperature is 1300°–1400°C with nucleation and crystallization of 670°–700°C for 0.5 hour. The final products are 35–45 vol% crystalline material with major phases of augite (a Ca,Mg,Fe pyroxene), powellite ([Ca,Sr]MoO₄), and a NiFe₂O₃ spinel.

Iron-enriched basalt glasses were developed at the Idaho National Engineering Laboratory, with melting temperatures of 1400°–1500°C. Devitrification takes place during controlled cooling with an optional holding period of 16–24 hours at 1000°–1100°C. This particular glass may incorporate transuranic defense waste. Leaching resistance, mechanical properties, and degrees of crystallinity depend on the quantity of radionuclides.

Beginning in the late 1950s, an alternative to high-temperature vitrification of soda–alumina–silicate glasses, a sol-gel process producing phosphate glasses, was suggested. The basic building block in phosphate glasses and crystals is the phosphorus–oxygen tetrahedron. However, in contrast to the tetravalent glass formers (such as Si⁴⁺ in silicates), the pentavalent phosphorus is double-bonded to one of its surrounding oxygen atoms. Apparently this bonding increases the solubility of the phosphate-related glasses, so they cannot be recommended for use in immobilizing HLLW material.

TABLE 4

Typical Compositions (wt%) of Natural Glasses and Representative Waste Glass SRL 165¹

Oxide	Basalt Glass	Rhyolitic Glass	Roman Bottle Glass	Tiffany Window Glass	SRL 165 Glass
SiO ₂	50.7	74.9	68.48	43.3	52.86
Al ₂ O ₃	11.7	14.2	2.61	2.0	4.08
B ₂ O ₃	--	--	--	11.5	6.76
Na ₂ O	4.5	4.68	19.73	0.2	10.85
K ₂ O	0.7	4.59	0.77	2.7	0.19
CaO	10.6	0.53	6.74	0.35	1.62
MgO	6.7	0.02	0.68	0.03	0.72
FeO	--	0.49	0.29	0.09	--
Fe ₂ O ₃	13.1	0.29	--	--	11.74
TiO ₂	1.9	0.04	--	0.1	0.14
MnO	0.4	0.03	0.65	--	2.79
P ₂ O ₅	--	--	--	0.26	0.02
Li ₂ O	--	--	--	--	4.18
NiO	--	--	--	--	0.85
ZrO ₂	--	--	--	--	0.66
PbO	--	--	--	38.93	--
CuO	--	--	0.06	0.06	--
H ₂ O	0.1	0.3	--	--	0.1

¹ Compositions are taken from Reference 46.

2.1.10 Application of Synrocs for Radionuclide Immobilization

Synrocs consist of an assemblage of four main titanate minerals: zirconolite (CaZrTi₂O₇), hollandite (Ba₁₂[(Al,Ti)₈O₁₆]), perovskite (CaTiO₃), and titanium oxide (Ti_nO_{2n-1}) (48). Synrocs are capable of dissolving the transuranic waste ions such as U⁺⁴, Np^{+3,+4}, Pu^{+3,+4}, Am^{+3,+4}, and Cm⁺³ by substituting waste ions for host ions. The creation of synrocs requires temperatures of 1250°–1400°C, and a relatively high pressure of at least 20 MPa. Since HLW contains a wide range of components, some of which are readily reduced to the elemental state and others which are readily oxidized to higher valence states, it is important to provide careful control of the atmosphere.

Zirconolite is considered the most durable of the synrocs and can immobilize waste actinides at levels up to 30 wt% (49). Excess uranium would react with TiO₂ to form very stable CaUTi₂O₇ crystalline phase. Cesium would react with trivalent titanium plus additional TiO₂ to form a

cesium hollandite component, $\text{CsTi}_x^{3+}\text{Ti}_{8-x}^{4+}\text{O}_{16}$. The primary concern with synroc minerals is their excess porosity. To date, samples have been made by solid-state sintering for extended periods (about 100 hours) at 1450°C, and/or at 1250°C and 20 MPa pressure for 2 hours, and the density of the sintered materials was only about 90% (50, 51). This porosity can increase the leachability of the material.

The leachability rate of synrocs sharply decreases with time. The decrease is attributed to the depletion of monovalent and divalent cations in the surface layer, leaving it enriched in TiO_2 and, to lesser extent, ZrO_2 (Figure 1) (52, 53). The chemical durability of synrocs is higher than that of borosilicate glasses. Also, crystalline phases formed in synrocs such as $\text{Ca}_2\text{Nd}_8(\text{SiO}_4)_6\text{O}_2$, $\text{Gd}_2\text{Ti}_2\text{O}_7$, and $\text{CaZrTi}_2\text{O}_7$, are less leachable than that of borosilicates after irradiating at doses as high as 10^{25} α -decay events/ m^3 .

2.1.11 Cements and Bentonites

Two other groups of materials capable of immobilizing radioactive wastes include cements and bentonite. Bentonites are weathering products of volcanic ash. Their essential component is the clay mineral montmorillonite, present in proportions of 65%–99%. However, their durability is less than that of borosilicate glasses and synrocs ceramics.

Cement can be used for immobilization of low- and intermediate-level radioactive wastes (48). For use in encapsulation of radioactive wastes, cement blends have to meet a number of requirements: they should make a stable monolith; heat generation must be avoided since temperatures exceeding 100°C will result in steam generation and creation of cracks; and water should not be segregated since this complicates the encapsulation process.

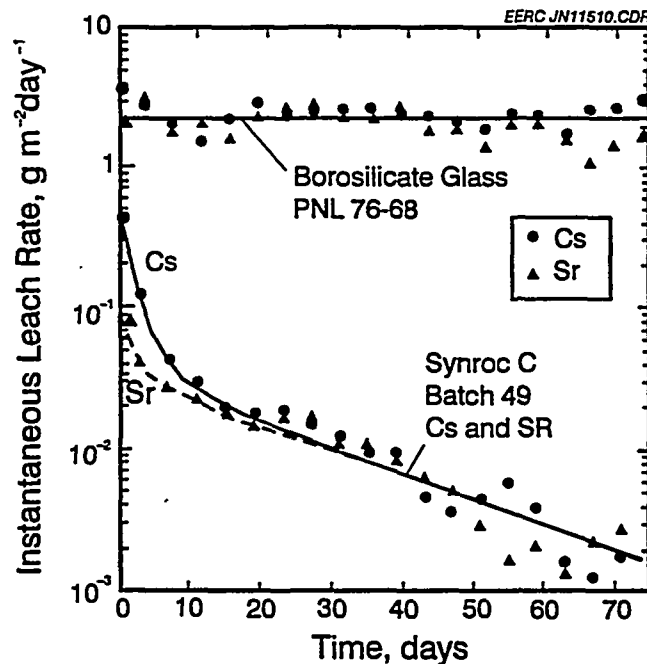


Figure 1. Leach results for cesium and strontium from Synroc-C (10 wt% simulated HLLW) and waste glass (PNL 76–68) at 100°C; leachant: deionized water, replaced daily.

Cements are chemically reactive, and after hydration, they have a mineralogy capable of incorporating a range of radionuclides. They are also slightly water-soluble and give rise to waters with high pHs. Cement is also susceptible to failure as a result of the action of stress, its environment, and naturally occurring microorganisms (54). However, a great deal of information exists on working with cements in natural environments. A thermodynamic model of major crystalline phases, such as hydrogarnet ($\text{Ca}_3\text{Al}_2\text{O}_6 \cdot 6\text{H}_2\text{O}$), ettringite ($\text{Ca}_6\text{Al}_2\text{Si}_3\text{O}_{21}[\text{OH}]_{12}$), hydrotalcite ($4\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 10\text{H}_2\text{O}$), and gehlenite hydrate ($\text{Ca}_2\text{Al}_2\text{SiO}_7 \cdot 8\text{H}_2\text{O}$), has been developed to predict the composition of solid and aqueous phases in blended cements as a function of the bulk composition (55). Departures from the predicted model occur in cements with alkali-bearing components.

Use of bentonites for immobilization of radioactive waste is frequently identified as a worst-case scenario. However, in Switzerland, montmorillonite is used as a natural safety barrier to seal construction-caused joints and rock fractures around containers holding vitrified waste because the clay swells in the presence of water. The solidified waste is a borosilicate glass matrix that will be encapsulated in a 25-cm-thick steel canister with a minimum life expectancy of 1000 years. The canisters will be placed in horizontal tunnels 3.7 m in diameter at a depth of around 1000 m (56).

2.1.12 Vitrification Technologies

Two major, well-recognized types of vitrification technologies are differentiated by their heating methods, either electrical heating or heating by firing a fossil fuel. Usually, electric heating is subdivided into Joule heating, plasma heating, and microwave heating. These types of heating are potentially applicable in vitrification of nuclear wastes (13).

Electric heating, also called *ex situ* Joule heating, is an efficient method of transferring energy to a waste, since no combustion air needs to be heated with the waste as is necessary when a fossil fuel is fired. The method is readily applied to glasses since glass resistivity decreases by a factor of 10^{13} – 10^{14} as temperature increases from ambient to 1300° – 1400°C . Since the conductivity of molten glass is a result of its ionic character, an alternating current must be used to avoid the risk of electrolysis, anodization of the electrode, and the depletion of charge carriers. Electrodes must withstand corrosion from the molten glass bath, offer adequate mechanical strength at high temperatures, and possess low resistivity. These limitations imply that the maximum temperatures of the melt should range between 1000° and 1600°C (57). The commercial glass industry uses graphite and molybdenum for electrodes. Figure 2 illustrates the typical glass melter used in the glass industry.

For a Joule-heated ceramic melter, the variation in resistivity of a glass with temperature is a very important parameter, and it is highly correlated with liquidus temperature and glass viscosity. The glass liquidus temperature constraint for the Hanford melters (Hanford Waste Vitrification Plant, Westinghouse Hanford Company, WA) has been $T_L < T_M - 100^\circ\text{C}$, where T_L and T_M are the liquidus and melter temperatures, respectively (58). In this type of melting, the ability to predict the electrical resistivity of a glass from its composition has the same importance as prediction of viscosity from composition (59). The electrical conductivity requirement at T_M , 10–100 S/m, is usually satisfied for any glasses with viscosity within 2–10 Pa · s (20–100 poise) at T_M (60).

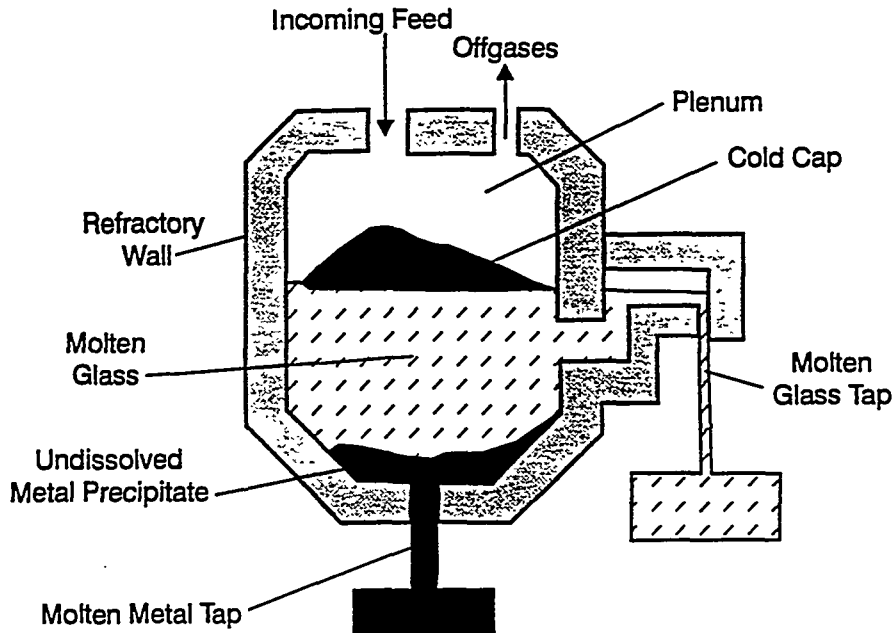


Figure 2. Schematic of a Joule-heated ceramic melter (JHCM).

Electric furnaces may encounter several of the following processing problems:

- Foaming leading to unstable operations and pressure surges
- Cold-cap bridging occurring when liquid flows under the cold cap
- High electrical conductivity in the melt causing the current to exceed the recommended maximum
- Low electrical conductivity in the melt resulting in a high voltage potential causing conduction within the refractory material
- High viscosity slowing the processing rate
- Low viscosity (< 100 poise) increasing refractory corrosion

At the Savannah River Site (SRS) in Aiken, South Carolina, the vitrification of HLLW is accomplished in a Joule-heated melter. The nominal glass temperature beneath the cold cap is 1150°C, the nominal glass weight is 6500 kg, and the average residence time in the melter is about 65 hours (61). It has been suggested that the HLLW will be mixed with glass frit and vitrified to form a durable, solid borosilicate glass. A small amount of sodium titanate would be added to adsorb the traces of soluble strontium and plutonium in sludge (62).

Another Joule heating process is induction heating, developed in France and known as the AVM process (Atelier de Vitrification Marcoule). This process is accomplished by inducing currents in the material using a solenoid, which creates a variable magnetic field inside the coil and around it.

Plasma heating relies on the conversion of surrounding gas into a plasma (an ionized gas) by an electric arc. The technique offers high operating temperatures and high power densities. An argon plasma may theoretically offer temperatures as high as 19,000°C, but in the partially ionized plasmas that occur in industrial applications, the temperature varies between 2000° and 5000°C. Usually, the plasma torch operates in the transferred arc mode. The transferred arc mode uses a flow of gas (Ar, N₂, air) to stabilize an electric discharge (arc) between a high-voltage electrode (inside the torch) and a molten pool of waste maintained at ground potential. The longer the arc, the more of the arc energy is diverted to the walls of the melter by radiation. Retech, Inc., of Ukiah, California, has developed a plasma-heating furnace called the plasma centrifugal reactor (PCR) that allows the material to exceed a temperature of 10,000°C (Figure 3). The rotating reactor helps to transfer heat evenly throughout the molten phase. Periodically, the melted material is allowed to fall into a slag chamber where it is collected in waste containers. Electro-Pyrolysis Incorporated (EPI) of Wayne, Pennsylvania, employs a similar direct-current plasma arc technology in its vitrification process. The technology was developed in cooperation with the Massachusetts Institute of Technology and Pacific Northwest Laboratories.

In microwave heating, a form of dielectric heating is introduced to the body through the absorption of electromagnetic radiation. A microwave installation consists of a microwave

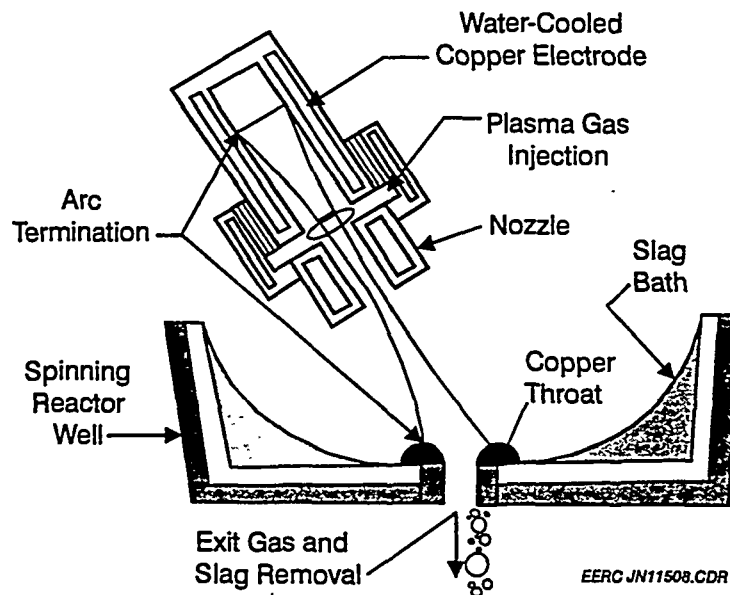


Figure 3. Schematic of the plasma centrifugal reactor (PCR).

generator, a waveguide, an applicator, and ancillary monitoring devices. The main disadvantage is its relatively high energy consumption.

The next group of thermal process heating devices is based on burning of fossil fuels in a rotary kiln incinerator. These methods are inherently less efficient at transferring the energy to the waste material since a large mass of combustion air must also be heated. However, the fuel is cheap and is used directly for heating the waste, unlike electrical heating, where the fuel must first be converted to electricity, a process that is approximately 35% efficient. Inorganic Recycling Inc. (IRI) has developed a vitrification process using only incineration, while Marine Shale Processors has developed a vitrification process in which only a portion of the incineration products is vitrified. Figure 4 shows a schematic of the IRI process. Vortec Corporation has developed a portable system that can fire natural gas or coal. The gas flow within the combustor is forced into a strong cyclonic motion causing the molten waste to separate efficiently from the gas for casting into ingots.

2.1.13 Summary and Recommendations

This literature review provides an overview of low- and high-level nuclear waste immobilization. Emphasis is on vitrification technologies based on borosilicate glass, since this glass will be used in the United States and in Europe to immobilize radioactive HLLW for ultimate geological disposal. Vitrification of aqueous radioactive wastes will achieve large volume reductions (86–97 vol%) and will ensure their stabilization. Borosilicate waste glasses are the most studied and probably best understood waste form that has been developed. The application of synrocs, cements, and bentonites for radionuclide immobilization is also discussed.

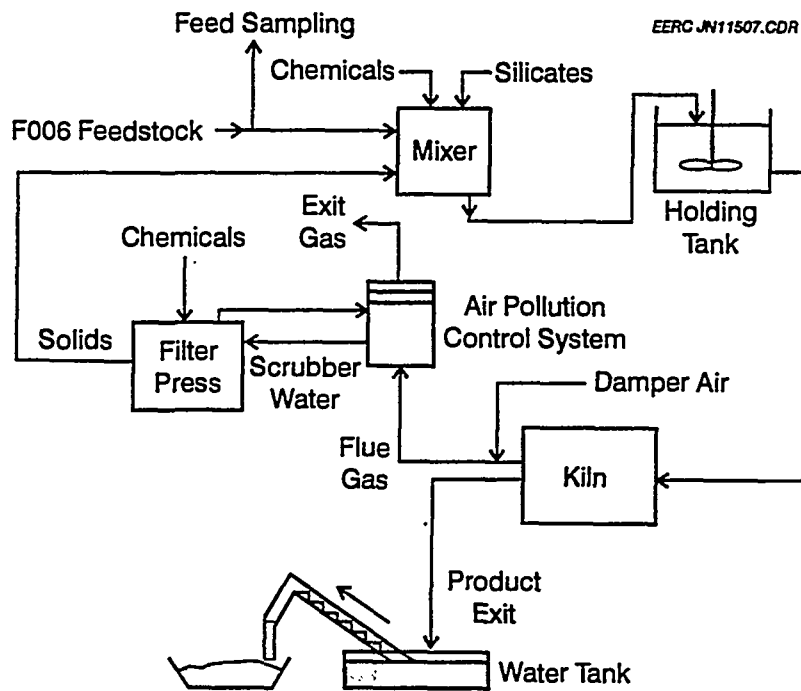


Figure 4. Schematic of IRI process (13).

Generally, radioactive wastes contain volatile hazardous components such as lead, mercury, cadmium, cesium, and strontium compounds, which must be captured in scrubbers and treated as secondary waste. Any immobilization technology must consider alkaline-acidic environmental conditions.

This survey indicates that a lack of information exists in the following areas:

- Vaporization of heavy or radioactive metals from the melts and whether vaporization behavior could be controlled by modifying the heating environment in order to separate the hazardous materials from the bulk waste.
- How to avoid the formation molten sodium sulfate on the cold cap.
- Catalytic activity of radionuclides at the surface of the glass and glass corrosion in water.
- The effect of the glass cooling rate on the generation of residual stresses below the temperature of glass transformation and its effect on the leachability of nuclear waste glass.
- The effect of foaming of the melt on the homogenization of nuclear waste during vitrification using plasma technology.
- Immobilization of scrubber condensed volatized hazardous components such strontium, cesium, lead, cadmium, and others in inorganic materials with low melting temperatures not related to silicate glasses. Survey of these materials has begun.

2.2 Subtask 2 Survey of Cleanup Sites

2.2.1 Introduction

DOE has recognized and documented waste sites and contaminant categories under their jurisdiction in a series of reports (63–67). The U.S. Environmental Protection Agency (EPA) has also documented information regarding DOE waste sites (68). This information is readily available to research organizations and the general public through the respective government agencies. These agencies have made a commitment to both direct remediation and restoration activities and to basic research to improve the understanding of contaminant behavior in subsurface environments. DOE has also made a commitment to bringing new technologies, particularly those involving small businesses, into commercialization to facilitate remediation and restoration efforts at DOE waste sites (69–72). Numerous programs have focused on the basic research and development of technologies. The EERC has specific experience in scientific and engineering research and in working with industry in environmental management (73).

The focus for immediate EERC efforts will be on cleanup of non-high-level wastes, most likely including those wastes designated as low-level waste, hazardous waste, or low-level hazardous waste, also referred to as low-level mixed waste and mixed waste. Mixed waste is the most broadly defined of these waste types and has the potential to benefit from innovations in waste management technologies. Each of these waste types has been explicitly defined in several DOE

documents. For reference, these definitions are in the glossary of terms in Appendix A, which includes all defined DOE waste types and site description terminology.

2.2.2 Summary of DOE Information on Waste Sites

Extensive information has been developed by DOE on the waste sites under its jurisdiction (63, 65, 68, 74). The EERC reviewed much of this information in order to make preliminary selections of waste types and potential sites for coordination with small business for environmental management activities. DOE includes the following in its environmental management activities: 1) waste management, 2) environmental restoration, 3) nuclear material and facility stabilization, and 4) technology development. Several key factors must be summarized in order to focus the EERC's potential participation in this DOE Environmental Management activity.

Eighty-one waste sites are listed in DOE's 1995 Baseline Environmental Management Report (74). These sites are located in 30 states. Cleanup activities are completed at nine of the sites listed. These are all Uranium Mill Tailings Remedial Action projects with long-term Surveillance and Maintenance (UMTRA S&M) activities. Further definition of UMTRA sites is given in Appendix A. In another report (63), it is stated that there are 91 waste sites at the 18 DOE facilities within the weapons complex. There are also 46 FUSRAP (Formerly Utilized Sites Remedial Action Program) sites in 14 states (65,74). Both UMTRA and FUSRAP are DOE programs mandated by Congress (64). Since 1974, more than 400 sites were identified as potential FUSRAP candidates, but 300 have been eliminated. Eighteen of the 46 FUSRAP sites have been completely cleaned up and 11 have undergone partial cleanup. The waste at these facilities is low-level waste, but the volume is estimated to be 2.3 million cubic yards. These sites are not currently in use for any energy- or defense-related activities. Following the original decommissioning of many of these sites, commercial and industrial use of the sites was allowed for a variety of activities including storage, manufacturing, and salvage operations. The EERC's review indicates that these activities have ceased until final cleanup to current environmental standards has been completed. Some of these industrial and commercial activities resulted in distribution of low-level waste into surrounding areas, which now must also be considered in environmental restoration activities.

DOE has identified five sites that are the most complex from the standpoint of waste types and quantities present, as well as the extent of environmental impact. These sites are 1) the Hanford site (Washington), 2) the Savannah River site, South Carolina, 3) the Rocky Flats Environmental Technology site, Colorado, 4) the Oak Ridge Reservation (including the K-25 site, the Y-12 Plant, and the Oak Ridge National Laboratory Tennessee), and 5) the Idaho National Engineering Laboratory, Idaho. These sites are also the major environmental management sites based on estimated life-cycle costs, potentially requiring \$164 billion to clean up, which is 71% of the overall DOE Environmental Management program budget.

The expected time frame for cleanup activities at all DOE sites varies widely. Cleanup has been completed at many sites, as noted earlier; however, more require it. The five major sites are scheduled to complete remediation by approximately 2050. Remediation at other DOE sites is generally expected to be completed sooner, with typical dates ranging from 2000 to 2030.

Site characterization is currently under way at numerous sites, but it is important to note that this task is often difficult because acceptable/common waste management practices used in the past frequently did not provide accurate record keeping of waste generation or disposition. It is also important to note that some sites were originally owned and operated by private companies and some site contamination may not be directly related to U.S. energy and defense activities. The responsibility for cleanup at these sites generally includes the original industrial owner or company that has since assumed liability for that entity's actions. DOE has developed waste management practices for sites still in service that meet current waste management requirements and do not add to current environmental restoration requirements at those sites.

Almost all identified sites have one or more type of radioactive waste, but these wastes vary widely. Generally, radioactive waste is a solid, liquid, or gas that contains radionuclides. DOE manages four categories of radioactive waste: 1) high-level waste (HLW); 2) transuranic (TRU) waste; 3) low-level waste (LLW); and 4) uranium mill tailings. Detailed definitions of these waste types and radionuclides are included in Appendix A. DOE also manages hazardous waste, mixed waste or low-level hazardous waste, spent nuclear fuel, and sanitary waste, also defined in Appendix A. Meeting regulatory requirements and resolving questions related to various regulations is one of DOE's most significant waste management challenges. A large portion of DOE's mixed waste is mixed low-level waste found in soils. It is generally true that contamination from all wastes has been identified in soils, subsurface sediments, and in groundwater, but it is important to note that each site is different, not only because of varying types and concentrations of contaminants but also because the sites are located throughout the U.S. and have a variety of geologic characteristics (63).

The magnitude and variety of contaminants that need to be cleaned up is difficult to summarize; however, DOE provided an overview in the document entitled "Chemical Contaminants on DOE Lands and Selection of Contaminant Mixtures for Subsurface Science Research," published in April 1992. While this report does not include the UMTRA sites, it provides information on the waste types and combinations that are applicable to DOE's overall Environmental Management program. The report delineates contamination by contaminant class and the presence in soil/sediments and groundwater at each of the 18 facilities and 91 waste sites. Appendix B includes several tables and graphics from the DOE report that effectively summarize the complexity of waste types and contaminants requiring action at DOE sites. Table B1 indicates the waste compound classes and representative constituents, providing more detail than the simple broad waste classifications generally used in other DOE reports. Several of these (radionuclides, polychlorinated biphenyls [PCBs], and explosives) have special handling requirements. Figures B1 and B2 indicate the occurrence of the contaminants in soil/sediment and groundwater at the 18 facilities and 91 sites surveyed for the report. This graphical representation provides insight to the most common contaminants found. It does not provide information on the levels of contamination reported. Table B2 provides information on common combinations of compound classes. This information is significant in developing remediation strategies. Again, the number of sites with a common combination of contaminants allows some prioritization of effort. More detailed information on the specifics of each contaminant class is provided in Figures B3 through B7. DOE included only the most common contaminant classes. For this graphical representation, more specifics about the contaminants are provided and the number of sites reporting these contaminants indicated. Concentration ranges of specific constituents reported in groundwater and soil/sediment are reported in Table B3. The most significant general information that can be drawn from this

table is that the reported concentration ranges are extremely broad, and the maximum values reported all drastically exceed the regulatory guidelines (also noted in Table B3). Additional information is presented in DOE's document; however, these tables and figures summarize the primary information used to facilitate waste and site selection for the EERC's participation in the overall DOE Environmental Management program.

More site-specific information is included in the 1995 Baseline Environmental Management Report (65, 74), but it does not include a great deal of detail on contaminant classes. The site-specific information required to make good decisions regarding the applicability of a innovative technology is not readily available or cross-referenced in the DOE documents that were reviewed for this report. Based on the review performed, it can be concluded that small businesses and others trying to determine whether or not a specific technology has a role in the DOE Environmental Management program will find this information difficult to obtain. Since the amount of information is so extensive, assembling it in a user-friendly format is expected to be a difficult task; however, if DOE is to take advantage of small business innovation, the information must be made more readily available. As discussed at a DOE-hosted session at the American Ceramic Society Conference on Emerging Technologies in Hazardous Waste Management VII, the best way to determine site-specific needs is to have direct contact with the appropriate individuals at any given site.

2.2.3 Summary of Potentially Applicable Waste Management Technologies

Much of the information on waste management technology has been developed and reported by EPA (68, 75-79). DOE has numerous projects under its EM Technology Development program (64, 67, 69, 71, 72). In several cases, remediation technologies have been identified for use with the various waste types, and several waste disposal sites have been selected. In the 1995 Baseline Environmental Management Report, DOE gives distinct site remediation and restoration plans. DOE documents estimate that a high volume of the wastes at many sites requires removal and disposal in an appropriate disposal facility (65, 74).

The EPA report entitled "Remediation Technologies Screening Matrix and Reference Guide" (77) summarizes numerous remediation technologies for solids, groundwater, and emissions/offgases. The information presented in that document was used in the following summaries of remediation technologies of high interest to the EERC. The technologies of highest interest to the EERC are those that would be applied to solids (soils, sediments, and sludges) or groundwater. Many of these technologies are used in combinations dependent on the actual waste requiring remediation.

Vitrification

The EERC's evaluation of vitrification technology indicates that vitrification is DOE's best available technology for stabilization and disposal of HLW. The evaluation also indicates that development of vitrification technology has been the focus of both private industry and government agencies. Vitrification processes include in situ and ex situ vitrification. Only one vendor is licensed for in situ vitrification, while five are actively promoting proprietary ex situ vitrification technology processes. EERC participation in commercialization of vitrification technologies is currently only loosely defined and will likely require further baseline investigations.

Solidification/Stabilization

Solidification/stabilization (S/S) technology may also be applied in situ or ex situ, like vitrification. Both in situ and ex situ S/S have been demonstrated to reduce mobility of inorganic constituents up to 95%. S/S is most applicable to inorganic constituents, with only limited effectiveness for many organic constituents, although S/S technologies for organics are under development and testing. S/S technologies have the advantage of being relatively simple using readily available equipment. However, destruction of organics is final, while S/S still presents a potential future problem.

Thermal Treatment

Low- or high-temperature thermal desorption is used to volatilize water and organics, which are transported to a gas treatment system. Vendors are currently promoting both the low- and high-temperature thermal desorption as an ex situ remedy.

Incineration and pyrolysis are also used for hazardous wastes containing halogenated and nonhalogenated organics (both volatile and semivolatile), pesticides, and fuels. These are generally ex situ techniques. Incineration, one of the most mature remediation technologies, is in use at Superfund sites. Pyrolysis is in the early stages of development. Since these techniques offer true destruction, future release is not a consideration.

Biological Treatment or Degradation

In situ biodegradation relies on the naturally occurring microbes whose activity is stimulated to enhance degradation of organic compounds. There are numerous limitations to this technology, but it is targeted at nonhalogenated volatile and semivolatile organics and fuel hydrocarbons. It is less effective for halogenated compounds and pesticides.

Biological treatment is also currently being used to treat both slurries of soil or sludge and controlled solid phases. Again, this approach is most effective in treating nonhalogenated organics and fuel hydrocarbons.

Soil Vapor Extraction

Volatile constituents are extracted from the waste (in situ or ex situ) by application of a vacuum or through direct ventilation. The process may be thermally enhanced, which extends its applicability to include semivolatile constituents and some pesticides. In situ techniques are limited to the vadose zone, and the soil type is extremely significant to the effectiveness of the technology. Treatment of offgases and collected groundwater must also be considered.

Chemical Reduction/Oxidation

Chemical reduction/oxidation is used to convert hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. The target constituents are inorganics, although it can be used less effectively to treat nonhalogenated organics, fuel hydrocarbons, and pesticides. Reducing/oxidizing agents commonly include ozone, hydrogen

peroxide, hypochlorites, ozone, chlorine, and chlorine dioxide. Use of these agents in combination or with the addition of ultraviolet oxidation makes the treatment more effective. This is a well-established technology for water and wastewater treatment.

2.2.4 Waste Sites and Environmental Management Technologies for EERC Focus

The EERC objective is to facilitate commercialization of near-commercial innovative waste/site remediation technology from small businesses. Since most government and large industry efforts are focused on high-level wastes and spent nuclear fuel, the EERC will focus more on low-level wastes, mixed wastes, and hazardous wastes.

The EERC research staff has extensive expertise and experience related to DOE's requirements for environmental management at DOE sites. The EERC also has excellent facilities for participating in DOE's technology development effort related to environmental management. There are, however, technical limitations and University of North Dakota safety requirements that limit some materials handling in laboratories on-site at the EERC. The limitations provide preliminary selection criteria for waste and contaminant types for EERC efforts under this task: 1) high-level wastes, transuranic wastes, or spent nuclear fuel will generally not be considered; 2) PCBs and explosives will generally not be considered; and 3) most frequently occurring toxic metals within low-level mixed and hazardous wastes will be given priority. These three preliminary selection criteria focus the EERC's waste site selection for this task.

Using these three preliminary selection criteria, all of DOE's wastes sites as described in the 1995 Baseline Environmental Management Report (65, 74) were evaluated. All the sites for which information was reviewed are listed in Appendix C. The site summaries do not provide all the information required to make final site selections for EERC participation; however, several waste sites were identified as examples of the type of waste sites that would provide the opportunity to investigate innovative technologies that would be broadly applicable to numerous DOE sites as well as industrial sites and processes. Each of the identified waste sites requires environmental restoration and is scheduled for remediation in the future. Remediation activities are not currently under way at the sites identified. The sites identified as examples for potential EERC participation are listed in Table 5. Site summaries for each identified site developed by DOE and reported in the 1995 Baseline Environmental Management Report are also included in Appendix C.

These sites, which have been characterized (at least preliminarily), have a variety of waste types. Specific waste types that do not match the EERC's preliminary criteria are not currently under consideration for this project. Since the site characterization information varies in detail between sites, more complete information will be needed as the site selection proceeds. In many cases, the waste/site descriptions do not provide adequate information on the disposition of the wastes and whether or not they are intermingled. This information may change which sites are selected. Identification of technologies for commercialization may also change or narrow the site selection.

It is worth noting that any site remediation and environmental restoration will result in production of wastes for disposal, and waste minimization should be considered as a part of the technology evaluation.

TABLE 5

DOE Environmental Management Waste Sites Identified by EERC

Site	Waste Types Identified at Site
Geothermal Test Facility, California	Treated and untreated brine; arsenic-contaminated debris Mineral- and salt-contaminated sediments; asbestos
Oxnard Site, California	PCBs Organic coolants and lubricants
South Valley Superfund Site, New Mexico	Soil and groundwater contaminated with organic solvents (trichloroethylene and dichloroethane)
UMTRA Sites, North Dakota	Soil, gravel, and rubble contaminated with uranium-containing ash
Fernald Environmental Management Project, Ohio	Low-level waste storage; radium-bearing residues Metal oxides Soil and construction debris with low levels of radioactivity Fly ash Lime sludge ponds Solid waste landfill
Pantex Plant, Texas	Organic solvents Explosives Heavy metals

Site characterization is still required for many sites, and the development of "Expedited Site Characterization" (Appendix A) allows innovative field and laboratory characterization techniques to be applied. This would be an ideal area for EERC participation as it requires multidisciplinary teaming to make decisions to perform the most cost-effective site characterization. Long-term surveillance and monitoring of many of the DOE waste sites is scheduled and, in some select cases, may be the only activity at a site where minimal environmental risk is assessed. These activities may have limited opportunity for development and commercialization of innovative technologies, but they should not be ignored or excluded from the EERC program.

2.3 Subtask 3 Selection and Characterization of Test Mixtures for Vitrification and Crystallization

Based on the findings of the literature surveys described in Sections 2.1 and 2.2 of this report, it was decided that inducing crystallization in vitrified wastes would not be the most efficient way to stabilize them. Instead, it was decided to pursue the idea of removing certain heavy metals from the waste during vitrification through enhanced vaporization. Section 2.4 of this report describes the results of that work.

2.4 Subtask 4 Selection of Crystallization Methods Based on Thermochemistry Modeling

2.4.1 Introduction

As a result of the survey of vitrification technologies reported in Section 2.1 of this report, it was decided to modify the original scope of work to delete enhanced crystallization of vitrified waste as a stabilization technique. Instead, the idea of removing some toxic elements from a waste during vitrification by enhancing the vaporization of the elements and collecting the condensed materials separately from the vitrified material would be investigated. The specific elements to be focused on were delineated through a site survey described in Section 2.2 of this report.

The two main types of waste vitrification technology are based on either Joule-heated ceramic melters or plasma torch systems. In the former technology the temperature of a silicate melt may reach 1600°C but in the latter the contact temperature between the surface of the melt and plasma may produce localized temperatures of over 10,000°C. Common oxides such as silica, alumina, calcium, and boron are durable under these extreme conditions in an oxidizing atmosphere but the stability of other oxides such as mercury, lead, and even plutonium are questionable in silicate melts. If they vaporize during vitrification extra care must be taken in treating the offgases. However, vaporization of the elements may also present a way to remove them from the melt and reclaim them, leaving the vitrified product much easier to dispose. Therefore, we have begun to define the vaporization temperatures of toxic trace elements and their oxides from melts using thermochemical equilibrium modeling of borosilicate mixtures. In addition we have begun to determine conditions that will enhance their deposition downstream of the melt.

2.4.2 Modeling of the Vaporization-Condensation Behavior of Trace Elements and Their Oxides

In order to accomplish the modeling effort, it was necessary to identify the trace metals that are commonly associated with nuclear wastes. Radionuclides, heavy metals, and other trace metals are commonly found in combination in high-level waste and mixed wastes at numerous DOE waste sites. It was found from the site survey described in Section 2.2 that the radionuclides commonly found in waste forms were tritium, uranium, strontium, plutonium, and cesium. The trace metals most commonly noted were lead, chromium, arsenic, zinc, copper, mercury, and cadmium. Because of the difficulties associated with performing tests on mixtures containing radioactive elements, we focused primarily on the heavy trace metals for modeling.

To determine the conditions of vaporization of the heavy elements from silicate melts, thermochemical equilibrium calculations of the stable phases of the elements over a range of temperatures were performed. The best-developed commercially available computer code for performing these calculations is the result of work of Canadian-Swedish team at the École Polytechnique de Montréal in Canada. Tailored for the treatment of about five thousand species, it is known as the Facility for the Analysis of Chemical Thermodynamics (FACT) code. We have employed the code to calculate the vaporization temperatures of trace elements and their oxides from borosilicate melt/glass in the temperature range of 600°C to 2000°C. The condensation temperatures for pure metals/oxides were taken from database stored in FACT code. For convenience the composition of the borosilicate glass and trace oxides were expressed by mole

fraction (Table 5). The concentrations of the trace oxides were varied between mole fractions of 10^{-3} and 10^{-6} . The calculations were performed at three different oxygen pressures: 1, 0.001 and 0.000001 Atm. The lower pressures simulate reducing atmospheres. For some temperatures and mainly lower oxygen pressures the FACT code was unable to calculate the vapor concentration since the code was not able to calculate a solution for the equilibrium composition.

Figures 5–8 illustrate the variation of trace elements concentration in vapor phase over borosilicate melt/glass with temperature. Generally, there is a characteristic temperature (T_{cr}) at which the elements and their oxides vaporize, and this depends on the oxygen pressure over the melt/glass. Usually, T_{cr} decreases with oxygen pressure and is very well defined below 1 atm. Table 6 lists these temperatures for the seven elements and their oxides released from borosilicate melt/glass at 1 atm oxygen pressure. Table 6 also provides information on the composition of vapor phase. The mole fraction of associated atoms in a vapor phase such as M_2 is usually below 10^{-6} .

It is found that lead may vaporize from borosilicate melts above 1530°C ; cadmium, zinc, arsenium, chromium, and copper may vaporize at temperatures between 1230° and 1430°C ; and mercury above 530°C . Also, it is found that for the range studied, the concentration of the elements in the melt does not significantly affect the vaporization temperatures.

Usually, their mole fraction in the vapor phase is very low, below 10^{-6} . Figure 6b illustrates an example of log mole fraction variation of all mercury species in the vapor phase with temperature. The temperatures of phase transformations 1) solid – liquid, 2) solid – gas and 3) liquid – gas, for all discussed components are listed in Table 6.

3.0 FUTURE WORK

Thermochemical equilibrium calculations of the behavior of heavy elements during vitrification of waste have shown that it may be possible to vaporize some of the elements, reducing their concentration in the vitrified materials. Because of the lower concentrations, the vitrified material may be much easier to subsequently dispose, and it is also likely possible to reclaim the materials in relatively pure form from the melter by selective condensation. However, this type of work will take significant development, including more detailed computer modeling as well as laboratory- and bench-scale testing before field testing could commence. Therefore, the work does not meet the EERC's brokering criteria of an identified industrial partner and a high probability of near-term commercialization, and it was not proposed for continuation in 1996. Opportunities exist to work with commercial partners in both vitrification and leachability testing, and a new task will be proposed when a defined activity meeting the commercialization criteria are met.

In addition to the vaporization work, another area for EERC focus is waste cleanup and site remediation. This area will allow small business to benefit most from EERC staff expertise and facilities. Specific technologies that fit most readily include solidification, fixation, and encapsulation (SFE) techniques. SFE would be most applicable to hazardous solid wastes, but may also have extensive application to mixed wastes. The EERC could participate in materials characterization, mix design, and solidified waste form evaluation for both physical integrity and mobility of constituents.

TABLE 6

Phase Transformation of Metallics and Their Oxides

Vapor Phase Component	Solid - Liquid	Solid - Gas	Liquid - Gas
	K	K	K
PbO	1159	---	---
Pb	600	---	---
Pb ₂	Gas	Gas	Gas
HgO	---	811.6	---
Hg	---	---	630.5
Hg ₂	Gas	Gas	Gas
As ₄ O ₆	Gas	Gas	---
As	---	2290	---
As ₂	Gas	Gas	---
As ₃	Gas	Gas	---
CrO ₃	470	---	---
CrO ₂	---	---	---
CrO	---	---	3687
Cr	2179	---	---
CuO	---	---	---
Cu	1358	---	---
Cu ₂	Gas	Gas	---
Cd	594	---	---
Zn	692	---	---

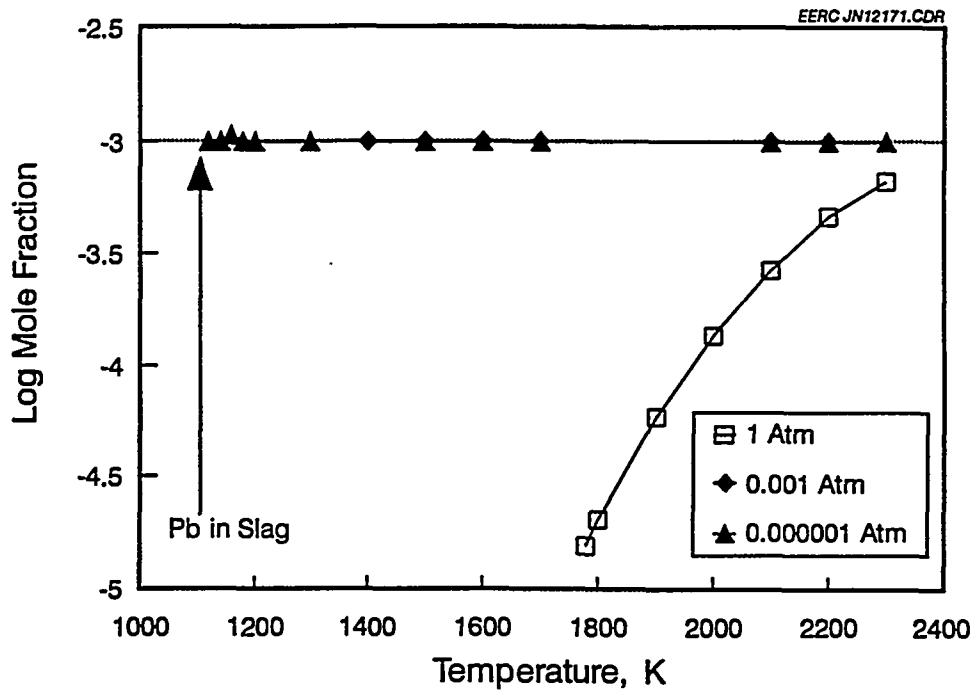


Figure 5. Log mole fraction of lead-derived constituents in vapor phase versus temperature. The arrow represents the temperature at which a significant vaporization can occur.

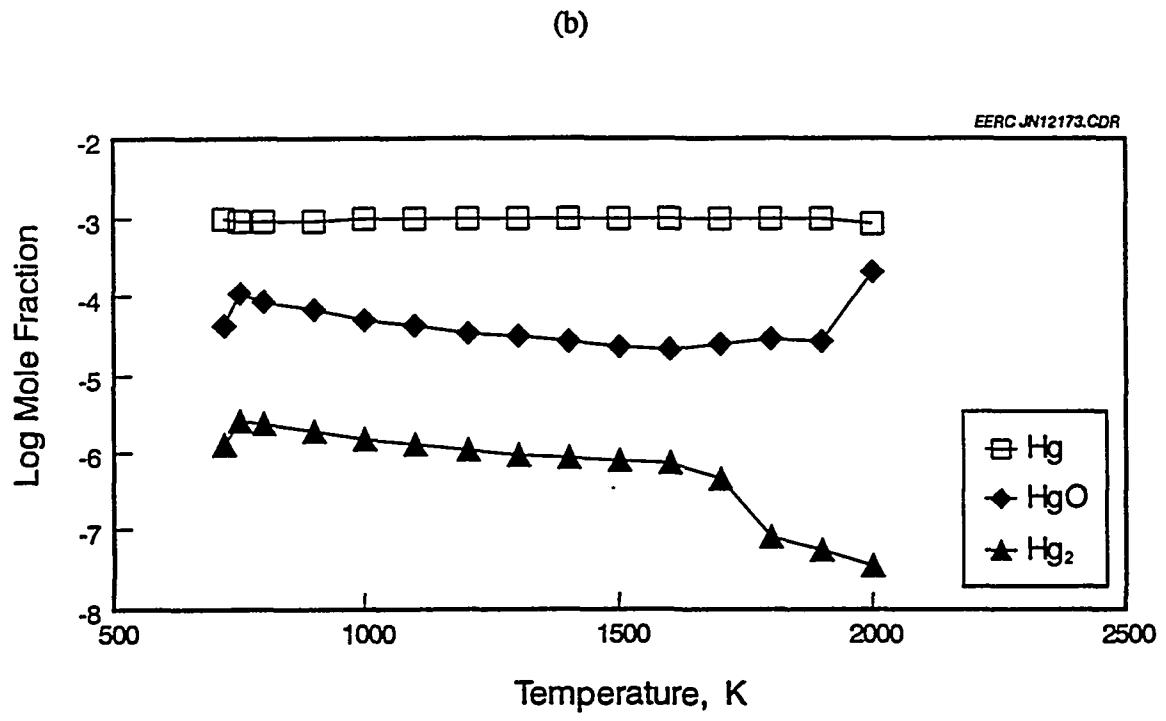
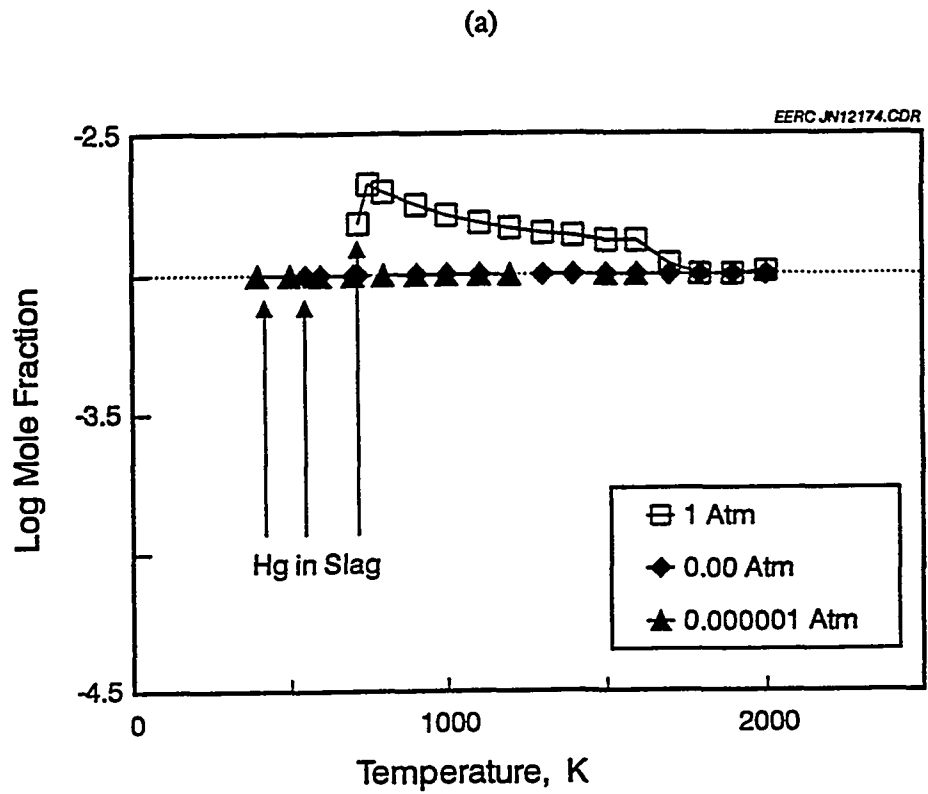


Figure 6. Log mole fraction of all (a) and single (b) mercury-derived constituents in vapor phase versus temperature. The arrows represent temperatures at which a significant vaporization can occur.

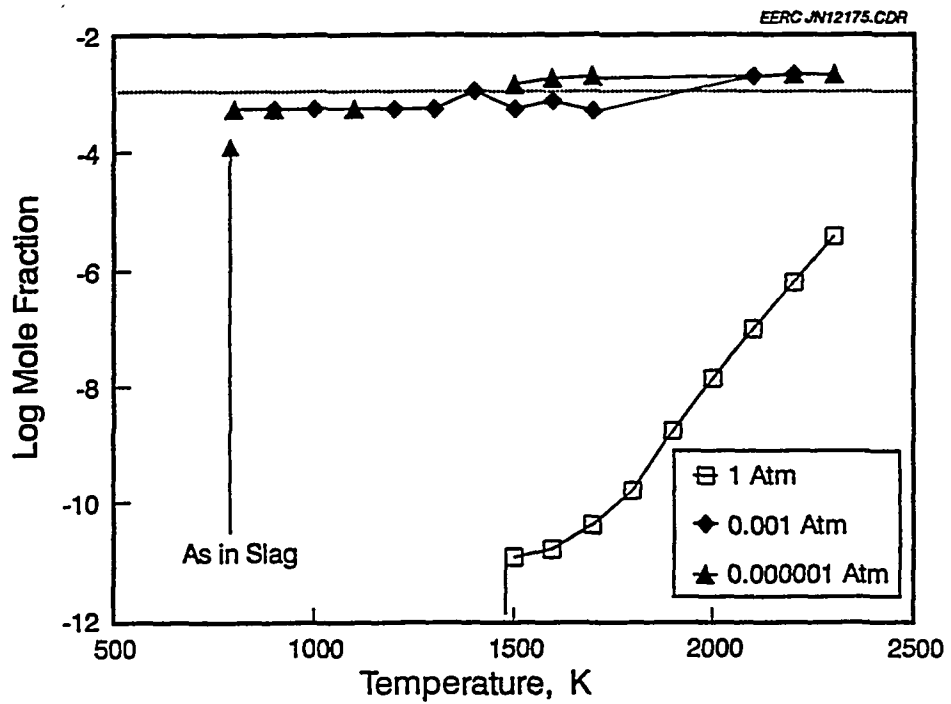


Figure 7. Log mole fraction of arsenic-derived constituents in vapor phase versus temperature. The arrow represents the temperature at which a significant vaporization can occur.

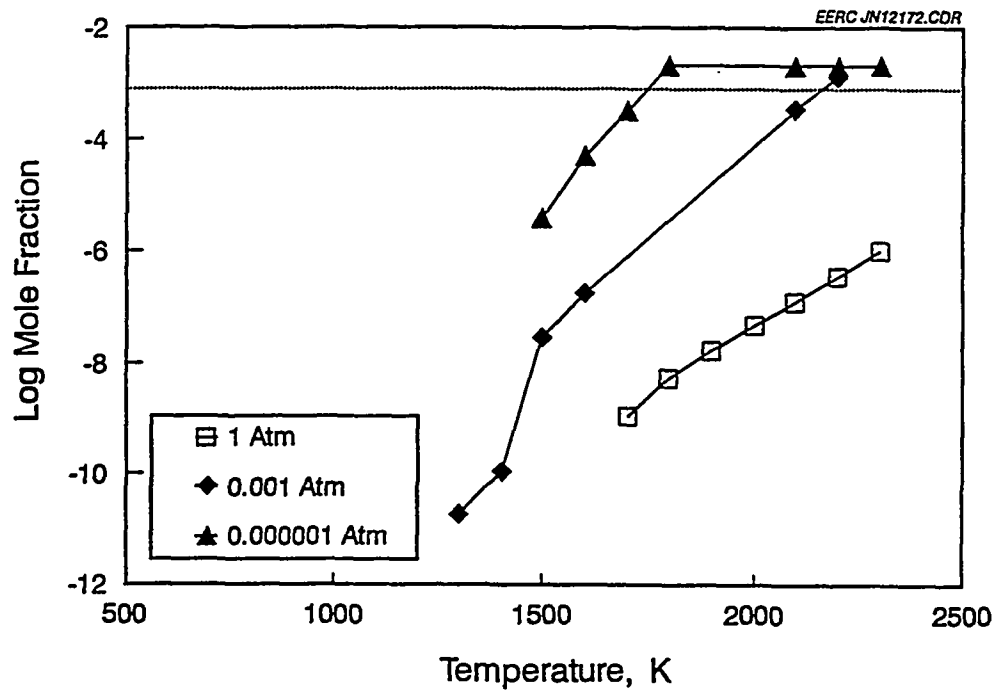


Figure 8. Log mole fraction of chromium-derived constituents in vapor phase versus temperature.

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APPENDIX A
GLOSSARY OF TERMS

DOE "Environmental Management Fact Sheets," August 1994

Radioactive Waste Solid, liquid, or gaseous waste that contains radionuclides.

High-Level Waste (HLW) Highly radioactive material from the reprocessing of spent nuclear fuel. HLW includes spent nuclear fuel, liquid waste, and solid waste derived from the liquid. It contains elements that decay slowly and remain radioactive for hundreds or thousands of years. HLW must be handled by remote control from behind protective shielding to protect workers.

Transuranic (TRU) Waste Contains human-made elements heavier than uranium that emit alpha radiation. TRU waste is produced during reactor fuel assembly, weapons fabrication, and chemical processing operations. It decays slowly and requires long-term isolation. TRU waste can include protective clothing, equipment, and tools.

Low-Level Waste (LLW) Any radioactive waste not classified as a high-level waste, transuranic waste, or uranium mill tailings. LLW often contains small amounts of radioactivity dispersed in large amounts of material. It is generated by uranium enrichment processes, reactor operations, isotope production, medical procedures, and research and development activities. LLW is usually made up of rags, papers, filters, tools, equipment, discarded protective clothing, dirt, and construction rubble contaminated with radionuclides.

Uranium Mill Tailings By-products of uranium mining and milling operations. Tailings are radioactive rock and soil containing small amounts of radium and other radioactive materials. When radium decays, it emits radon, a colorless, odorless radioactive gas. Released into the atmosphere, radon gas disperses harmlessly, but the gas is harmful if a person is exposed to high concentrations for long periods of time under conditions of limited air circulation.

Hazardous Waste Chemicals and nonradioactive materials that are one or more of the following characteristics: toxic, corrosive, reactive, ignitable, or listed. Some environmental laws list specific materials as hazardous waste. For example, hazardous waste can exist in the form of a solid, liquid, or sludge and can include materials such as polychlorinated biphenyls (PCBs), chemicals, explosives, gasoline, diesel fuel, organic solvents, asbestos, acid, metals, and pesticides. Environmental laws also list materials that must be treated and managed as hazardous.

DOE hazardous waste is strictly characterized to ensure it contains no radionuclides. Some hazardous waste is stored at DOE sites in buildings that have been issued a permit through the Resource Conservation and Recovery Act. If hazardous waste has no added radioactivity, it can be shipped off-site to commercially owned and operated disposal facilities. Some hazardous wastes can be reused instead of disposed, saving money and disposal site resources.

Mixed Waste Radioactive waste contaminated with hazardous waste regulated by the Resource Conservation and Recovery Act (RCRA). A large portion of DOE's mixed waste is mixed low-level waste found in soils. No mixed waste can be disposed of without complying with RCRA's requirements for hazardous waste and meeting RCRA's Land Disposal Restrictions, which require waste to be treated before disposal in appropriate landfills. Meeting regulatory requirements and resolving mixed waste questions related to various regulations is one of DOE's most significant waste management challenges.

Spent Nuclear Fuel Nuclear reactors burn uranium fuel, creating a chain reaction that produces energy. Over time, as the uranium fuel is burned, it reaches the point where it no longer contributes efficiently to the chain reaction. Once the fuel reaches that point, it is considered spent. Spent nuclear fuel is high in temperature and highly radioactive.

Sanitary Waste Solid and liquid sanitary wastes are generated from normal housekeeping activities. Solid sanitary waste is typical garbage. Liquid sanitary waste is sewage. DOE owns and operates treatment facilities and sanitary landfills at many of its sites.

**"Committed to Results: DOE's Environmental Management Program, an Introduction,"
DOE/EM-0152P April 1994**

Radionuclide Any naturally occurring or artificially produced radioactive element or isotope.

Waste Management Treats, stores, and disposes of radioactive waste, hazardous waste, mixed waste (radioactive and hazardous waste mixed together), and sanitary waste at DOE sites.

Environmental Restoration Cleans up radioactive, hazardous, and mixed waste contamination at DOE sites. Activities include remedial actions—the assessment and cleanup of inactive waste sites—and decontamination and decommissioning—the cleanup and demolition or reuse of surplus facilities.

Technology Development Develops new and more effective technologies for addressing contamination and managing waste at DOE sites. Technology Development conducts research and development of new technologies and demonstrates, tests, and evaluates technologies developed by DOE and private industry.

Facility Transition and Management Safely transitions contaminated facilities from other offices or programs within DOE to the Environmental Management organization. Responsibilities include developing criteria facilities must meet before transition, safely deactivating the ones designated as surplus, negotiating uses for facilities and land after restoration, and maintaining a database.

From combined sources listed above:

Formerly Utilized Sites Remedial Action Program (FUSRAP) Established in 1974 to evaluate the environmental conditions of sites that had been used by universities and private firms (under government contract) for research projects involving radioactive materials. To date, 45 sites in 14 states have been designated for cleanup, and work has been completed at 15 of these sites.

Uranium Mill Tailings Remedial Action (UMTRA) Project Concentrates on cleaning up uranium tailings (leftover rock and soil containing residual uranium and radium) that were left behind during the uranium ore milling process. Is now cleaning up about 24 million tons of uranium tailings at 24 inactive sites in 10 states and more than 5000 vicinity properties (residences, businesses, and open lands where the tailings were used as fill dirt or put to other uses that contaminated the area).

APPENDIX B

**SUMMARY INFORMATION ON CONTAMINANTS
IDENTIFIED AT DOE WASTE SITES**

TABLE B1

Compound Classes and Selected Representative Constituents

Compound Class	Representative Constituents	Class Number ¹
Metals	Lead, chromium, mercury	1
Anions	Nitrate, fluoride, cyanide	2
Radionuclides	Tritium, plutonium, technetium	3
Chlorinated hydrocarbons	Trichloroethylene	4
Fuel hydrocarbons	Benzene, toluene, xylenes	5
Phthalates	Bis-2-ethylhexylphthalate	6
PCBs	Arochlor 1248, Arochlor 1260 ²	7
Explosives	HMX, RDX, trinitrotoluene	8
Ketones	Acetone, methyl ethyl ketone	9
Pesticides	Chlordane ³ , lindane, 4,4'-DDT ⁴	10
Alkyl phosphates	Tributyl phosphate	11
Complexing agents	EDTA, DTPA ⁵ , NTA ⁶	12
Organic acids	Oxalic acid, citric acid	13

¹ These numbers refer to specific compound classes.

² Arochlor 1248 and 1260 consist of a mixture of different individual PCBs.

³ Mixture of different chlorinated compounds.

⁴ Dichlorodiphenyltrichloroethane.

⁵ Diethylenetriamine pentaacetic acid.

⁶ Nitriloacetic acid.

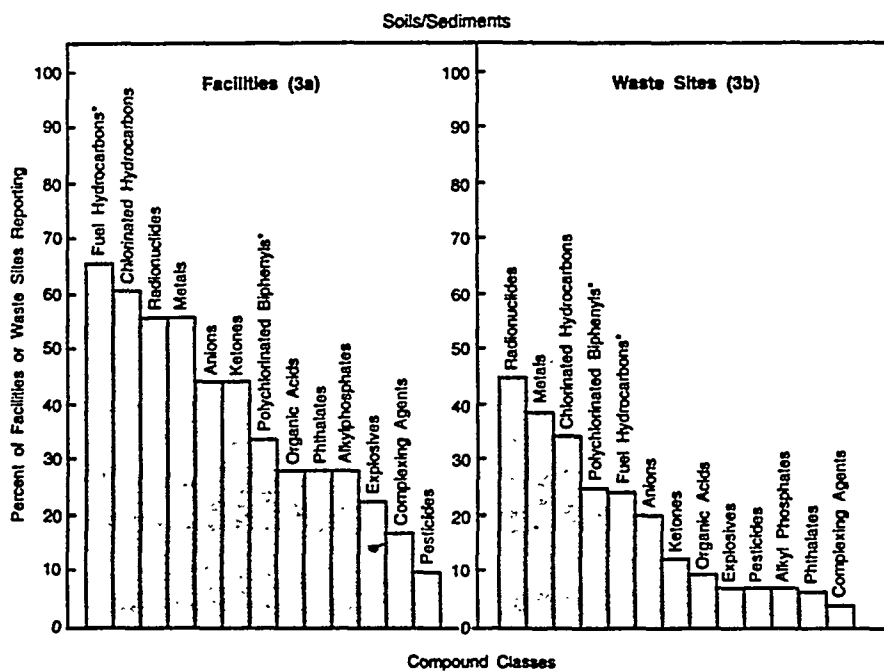


Figure B1. Distribution of compound classes in soils/sediments at 18 DOE facilities and 91 waste sites.

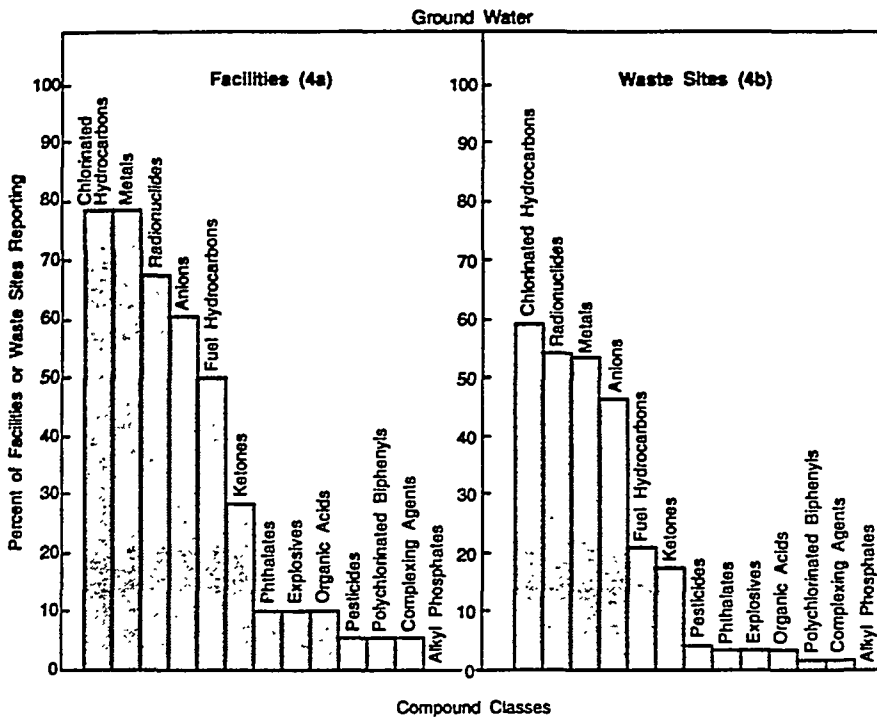


Figure B2. Distribution of compound classes in groundwater at 18 DOE facilities and 91 waste sites.

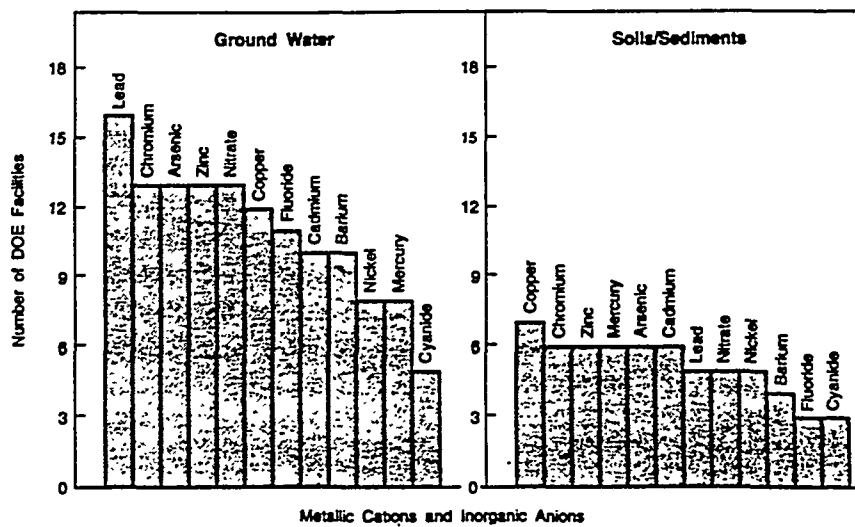


Figure B3. Frequency of occurrence of selected metals and inorganic anions in groundwater and soils/sediments at DOE facilities.

TABLE B2

Combinations of Compound Classes of Contaminants Reported Most Frequently in
Soils/Sediments and Ground Waters at DOE Facilities

Class	Soils/Sediments		Class	Groundwater	
	No. of Sites	No. of Facilities ²		No. of Sites ¹	No. of Facilities ²
Metals, radionuclides	25	7	Metals, chlorinated hydrocarbons	38	12
Metals, PCBs	18	6	Metals, radionuclides	36	11
Metals, chlorinated hydrocarbons	16	9	Metals, anions	33	11
Radionuclides, PCBs	15	4	Anions, radionuclides	33	10
Chlorinated hydrocarbons, fuel hydrocarbons	15	11	Radionuclides, chlorinated hydrocarbons	32	10
Anions, radionuclides	14	8	Anions, chlorinated hydrocarbons	26	9
Radionuclides, chlorinated hydrocarbons	14	6	Chlorinated hydrocarbons, fuel hydrocarbons	17	7
Chlorinated hydrocarbons, PCBs	13	6	Metals, fuel hydrocarbons	16	8
Metals, anions	12	7	Metals, ketones	16	5
Metals, fuel hydrocarbons	11	9	Radionuclides, fuel hydrocarbons	16	6
Anions, chlorinated hydrocarbons	11	6	Chlorinated hydrocarbons, ketones	16	5
Fuel hydrocarbons, PCBs	10	5	Anions, fuel hydrocarbons	12	5
Metals, radionuclides, PCBs	13	4	Metals, anions, radionuclides	29	10
Metals, chlorinated hydrocarbons, fuel hydrocarbons	8	8	Metals, radionuclides, chlorinated hydrocarbons	29	10
Metals, radionuclides, chlorinated hydrocarbons	11	6	Metals, anions, chlorinated hydrocarbons	25	9
Metals, chlorinated hydrocarbons, PCBs	10	6	Anions, radionuclides, chlorinated hydrocarbons	23	9
Metals, anions, radionuclides	9	6	Metals, chlorinated hydrocarbons, ketones	16	5
Metals, anions, chlorinated hydrocarbons	9	6	Radionuclides, chlorinated hydrocarbons, fuel hydrocarbons	15	5
Radionuclides, chlorinated hydrocarbons, PCBs	9	4	Metals, radionuclides, fuel hydrocarbons	13	5
Metals, fuel hydrocarbons, PCBs	7	5	Metals, chlorinated hydrocarbons, fuel hydrocarbons	12	5
Anions, radionuclides, chlorinated hydrocarbons	7	5	Metals, anions, fuel hydrocarbons	12	5
Anions, chlorinated hydrocarbons, fuel hydrocarbons	7	6	Metals, radionuclides, ketones	12	3
Metals, anions, radionuclides, chlorinated hydrocarbons	7	5	Anions, radionuclides, fuel hydrocarbons	11	4
Metals, anions, radionuclides, chlorinated hydrocarbons	7	5	Metals, anions, radionuclides, chlorinated hydrocarbons	23	9
Metals, radionuclides, chlorinated hydrocarbons, PCBs	7	4	Metals, radionuclides, chlorinated hydrocarbons, fuel hydrocarbons	12	4
Metals, anions, radionuclides, alkyl phosphates	5	4	Metals, radionuclides, chlorinated hydrocarbons, ketones	12	3
Metals, anions, chlorinated hydrocarbons, fuel hydrocarbons	5	5	Metals, anions, radionuclides, fuel hydrocarbons	11	4
Metals, anions, chlorinated hydrocarbons, PCBs	5	4	Metals, anions, chlorinated hydrocarbons, ketones	11	3
Metals, radionuclides, chlorinated hydrocarbons, fuel hydrocarbons	5	5	Metals, chlorinated hydrocarbons, fuel hydrocarbons, ketones	11	3

¹ Number of waste sites (out of 91) reporting specific class combination.

² Number of facilities (out of 18) reporting specific class combination.

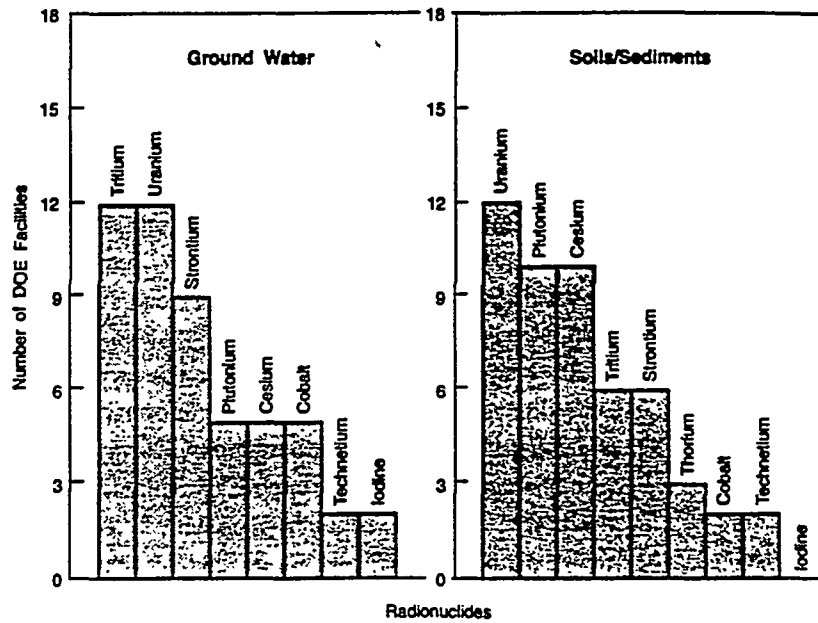


Figure B4. Frequency of occurrence of selected radionuclides in groundwater and soils/sediments at DOE facilities.

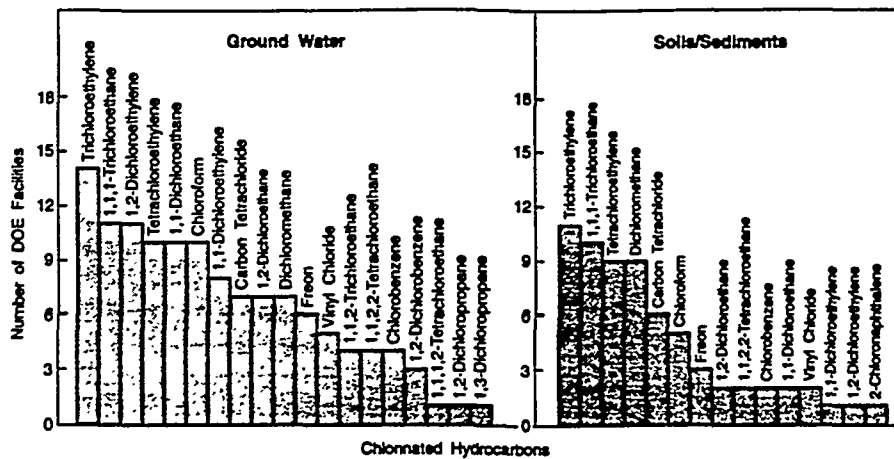


Figure B5. Frequency of occurrence of chlorinated hydrocarbons in groundwater and soils/sediments at DOE facilities.

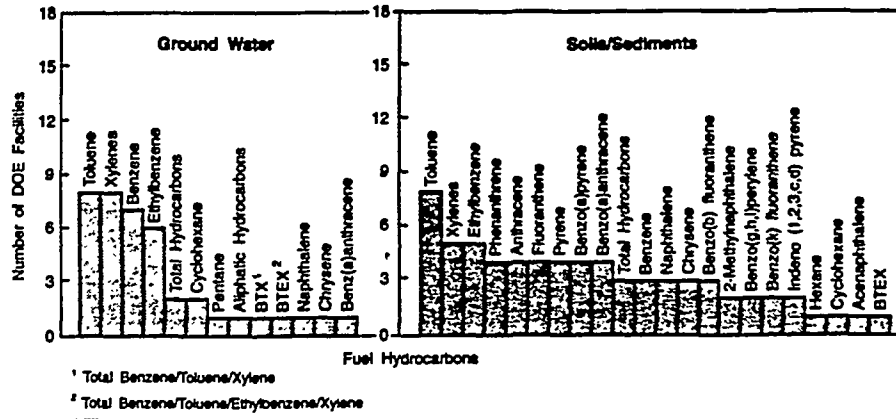


Figure B6. Frequency of occurrence of fuel hydrocarbons in ground water and soils/sediments at DOE facilities.

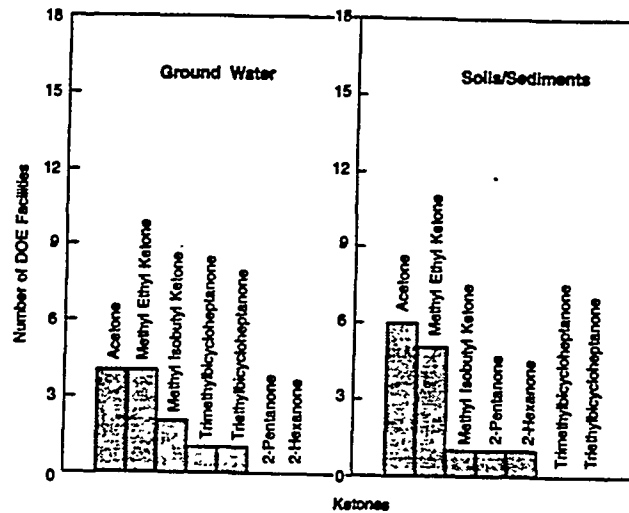


Figure B7. Frequency of occurrence of ketones in groundwater and soils/sediments at DOE facilities.

TABLE B3

Concentration Ranges¹ and Guidelines for Regulation of Most Frequently Reported Constituents in Groundwater and/or Soils and Sediments at DOE Facilities²

Class/Constituent	Groundwater	Soils/Sediments	Guidelines
METALS			
Lead	0.56–120,000	1000–6,900,000	³ 0; ⁴ 50; ⁵ 5
Chromium	0.42–9010	5.1–3,950,000	³ 100; ⁴ 50; ⁵ 100
Arsenic	0.3–32,100	100–102,000	⁴ 5
Zinc	1–697,000	150–5,000,000	⁶ 5000
Copper	1–3300	30–550,000	³ 1300; ⁵ 1300
Mercury	0.08–216,900	0.1–1,800,000	³ 2; ⁴ 2; ⁵ 2
Cadmium	0.005–7600	100–345,000	³ 5; ⁴ 10; ⁵ 5
ANIONS			
Nitrate	2.6–100,000,000	30–1,480,000	^{3,4,5} 10,000
RADIONUCLIDES			
Tritium	³ 3.3–20,900,000,000	⁷ 7.8–124,000,000	⁸ 20,000; ⁹ 2,000,000
Uranium	¹⁰ 0.001–11,700,000 ⁷ 0.02–22,700	¹¹ 0.2–16,000 ¹² 0.06–18,700	⁹ 500–600
Strontium	⁷ 0.05–231,000	¹³ 0.02–540,000	⁸ 8; ⁹ 1000
Plutonium	⁷ 0.0009–12.8	¹³ 0.00011–3,500,000	⁹ 300–400
Cesium	⁷ 0.0027–1830	¹³ 0.02–46,900	⁸ 200; ⁹ 3000
CHLORINATED HYDROCARBONS			
Trichloroethylene	0.2–870,000	0.2–12,000,000	⁴ 5
1,1,1-Trichloroethane	0.2–16,600	1–200,000	⁴ 200
1,2-Dichloroethylene	0.7–50,000	10–1,000,000	^{3,5} 70(cis); ^{3,5} 100(trans)
Tetrachloroethylene	0.18–272,000	1.3–2,045,000	³ 0; ⁵ 5
1,1-Dichloroethane	0.3–7800	27,000–84,000	—
Chloroform	0.3–2070	0.3–1300	—
Dichloromethane	0.29–2,400,000	6–890	³ 0; ⁵ 5
FUEL HYDROCARBONS			
Benzene	0.01–46,000	0.3–310,000	⁴ 5
Toluene	0.19–26,000	0.3–2,000,000	³ 2000; ⁵ 2000
Xylenes	1–14,000	0.3–2,800,000	³ 10,000; ⁵ 10,000
Ethylbenzene	1.5–540	0.7–70,000	³ 700; ⁵ 700
KETONES			
Acetone	3–24,500	13–350,000	—
Methyl ethyl ketone	4–1500	9–470	—
PHTHALATES			
Bis-2-ethylhexylphthalate	2–1050	200–57,000	³ 0; ⁵ 4

¹ Micrograms per liter ($\mu\text{g/L}$) and micrograms per kilograms ($\mu\text{g/kg}$) unless otherwise indicated.

² Concentration data synthesized from references listed in Appendix A.

³ Proposed U.S. EPA Maximum Contaminant Level Goals (MCLG, $\mu\text{g/L}$) in drinking water.

⁴ Existing U.S. EPA Maximum Contaminant Level (MCL, $\mu\text{g/L}$) in drinking water.

⁵ Proposed U.S. EPA MCL ($\mu\text{g/L}$) in drinking water.

⁶ Nonenforceable U.S. EPA secondary level standard ($\mu\text{g/L}$) based on taste, odor, or appearance guidelines.

⁷ Picocuries per liter (pCi/L).

⁸ National Interim Drinking Water Regulations, Table IV-2A (EPA 1976). Derived Guidelines (pCi/L) based on 4 millirem annual dose to target organ.

⁹ DOE-derived concentration guides (pCi/L) based on effective dose limit not to exceed 100 millirem/year. Derived from DOE Order 5480.1A (Jaquish and Bryce 1990).

¹⁰ Micrograms per liter ($\mu\text{g/L}$).

¹¹ Micrograms per gram ($\mu\text{g/g}$).

¹² Picocuries per gram (pCi/g).

¹³ Picocuries per kilogram (pCi/kg).

APPENDIX C
DOE WASTE SITE SUMMARIES

**Volume II:
Site Summaries
March 1995**

Estimating the Cold War Mortgage

The 1995 Baseline
Environmental Management
Report



U.S. Department of Energy
Office of Environmental
Management

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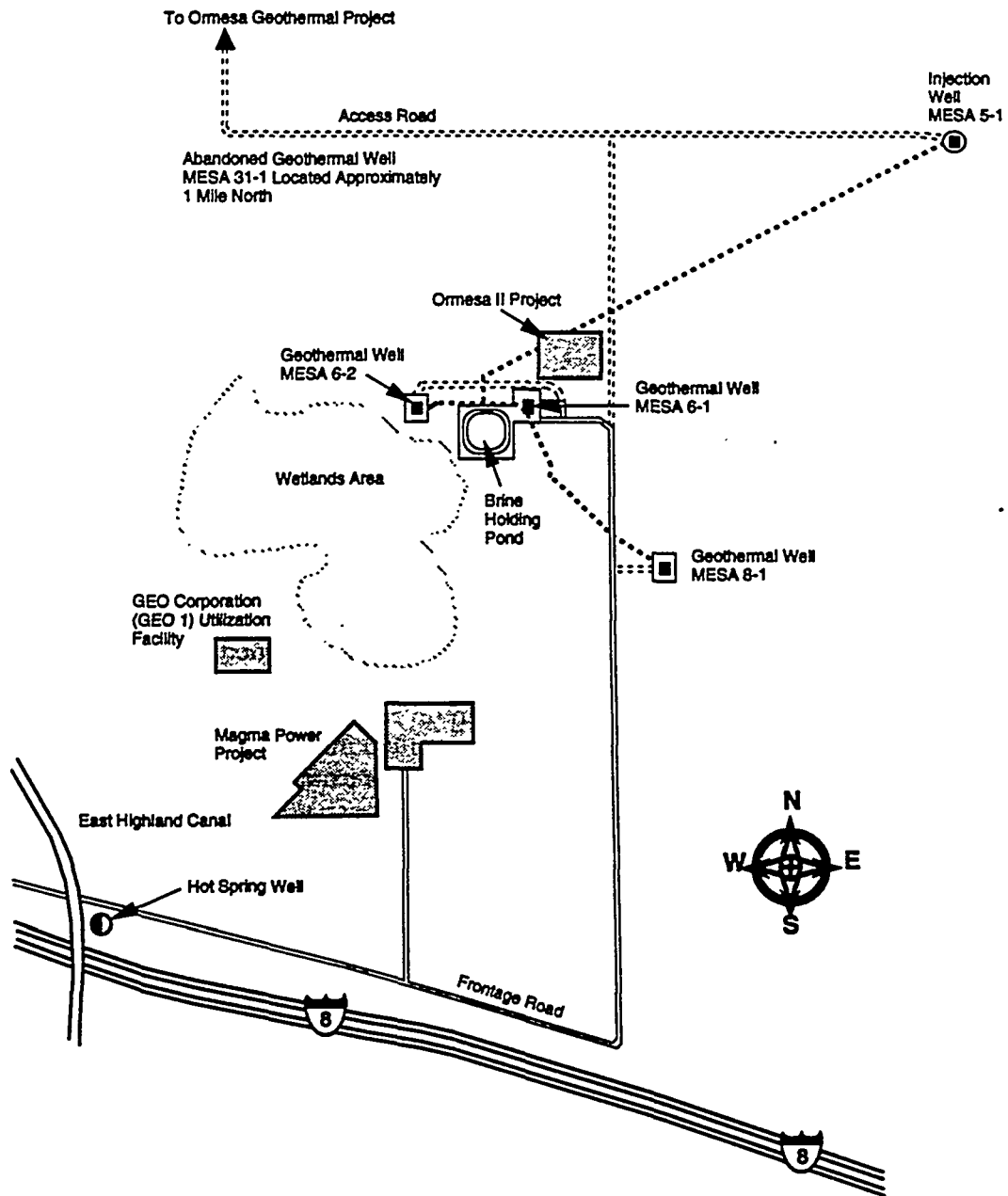
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GEOHERMAL TEST FACILITY

The East Mesa Geothermal Test Facility, an inactive Department of Energy (DOE) geothermal research facility, is in the Imperial Valley, Imperial County, California, about 20 miles east of El Centro and 1.5 miles north of Interstate Highway 8.



Estimated Site Total

*(Thousands of Current 1995 Dollars)**

	FY 1995	1996	1997	1998	1999	2000
Environmental Restoration	0	0	2,000	2,000	1,000	1,500
Program Management**	7,962	7,595	12,879	12,551	12,903	13,150
Total	7,962	7,595	14,879	14,551	13,903	14,650

* Costs for FY 1995 reflect Congressional Appropriation, costs for FY 1996 reflect EM budget submission, costs for FY 1997-2000 reflect Budget Shortfall Scenario, costs for shaded area assume 3% annual inflation.

** Program Management Costs for FY 1996-2000 include DOE Oakland Operations Office Costs.

*Five-Year Averages (Thousands of Constant 1995 Dollars)***

	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	Life Cycle***
Environmental Restoration	983	0	0	0	0	0	0	5,898
Program Management	240	0	0	0	0	0	0	1,438
Total	1223	0	0	0	0	0	0	7,336

** Costs reflect a five-year average in constant 1995 dollars, except in FY 1995 - 2000, which is a six-year average.

*** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

PAST, PRESENT, AND FUTURE MISSIONS

In 1968, the U.S. Bureau of Reclamation constructed the East Mesa Geothermal Test Facility for the investigation and development of geothermal resources in the East Mesa area. DOE became the site operator in 1978 and continued the site's energy research mission.

The 82-acre site includes a 6-acre, PVC-lined holding pond installed in 1972 to temporarily store and evaporate brine blowdown water, as well as untreated brine extracted in the geothermal exploration process. Geothermal research activities at the site were discontinued in 1987 as commercial scale geothermal power developed in the region.

Once restoration activities are complete, the facility will be turned over to the U.S. Bureau of Land Management for unrestricted use. Environmental Management program costs are presented in the Estimated Site Total table for the Geothermal Test Facility.

ENVIRONMENTAL RESTORATION

The Environmental Restoration Projects table provides costs for all environmental restoration activities at the Geothermal Test Facility. These costs are presented by activity in the Environmental Restoration Activity Costs table.

No active processes or experiments involving DOE research are currently operating or planned at Geothermal Test Facility. Sources of contamination are related to past operations at the site; however, hazardous waste may be generated during site restoration and disposed at a permitted Class I or II landfill.

Untreated brine extracted during geothermal exploration and brine blowdown water were stored in a holding pond at the facility. Storage of brine in the holding pond resulted in contamination of sediments due to the concentration of water soluble salts and the precipitation of minerals. The volume of contaminated sediments is estimated at 9,150 cubic meters. On the basis of previous sampling, the quantity of hazardous waste to be generated from restoration activities is expected to be minimal.

A field investigation report on the brine holding pond was prepared in 1992; and a site characterization study of the balance of the site was completed in 1993.

Contamination of the brine pond resulted from salts and minerals concentrated in sediment by evaporation. Decontamination activities will generate two waste streams: nonaqueous soil/debris contaminated with arsenic and nonaqueous, nonhazardous debris contaminated with salts and minerals.

During an asbestos survey conducted in 1992 three types of materials were identified as containing asbestos. These materials included:

- a joint compound used around pipe joints and flanges,
- cooling tower millboard, and
- floor tile and mastic inside the yellow laboratory building.

These asbestos-containing materials will be removed and disposed offsite at an appropriate disposal facility. Several other areas containing potentially airborne asbestos were remediated.

Under the terms of the lease agreement between DOE and U.S. Bureau of Land Management, the site must be restored to its original condition.

Environmental Restoration Activity Costs

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							<i>Life Cycle**</i>
	<i>FY 1995 - 2000</i>	<i>2005</i>	<i>2010</i>	<i>2015</i>	<i>2020</i>	<i>2025</i>	<i>2030</i>	
Environmental Restoration								
Assessment	57	0	0	0	0	0	0	343
Remedial Actions	926	0	0	0	0	0	0	5,534
Total	983	0	0	0	0	0	0	5,898

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

WASTE MANAGEMENT

No treatment of hazardous, radioactive, or mixed wastes occurs now or is anticipated in the future. Generated hazardous waste will be stored in accordance with generator requirements for non-permitted facilities. Any hazardous waste to be generated, by decontamination efforts, will be treated and disposed at appropriate facilities. Waste management at the Geothermal Test Facility is conducted within the scope of environmental restoration.

NUCLEAR MATERIAL AND FACILITY STABILIZATION

There are no current or planned nuclear material and facility stabilization activities at the Geothermal Test Facility.

LANDLORD FUNCTIONS

The Department's Office of Energy Efficiency is currently the landlord at the Geothermal Test Facility and is responsible for associated activities and costs.

PROGRAM MANAGEMENT

Because the Geothermal Test Facility is an inactive site and no restoration activities are underway, there are no current site management tasks other than planning for future potential restoration efforts. Once funding is available for restoration, program management will include typical management tasks such as strategic planning, liaison with DOE and external regulatory agencies, scheduling, document preparation, budget control, and financial forecasting. See the Program Management Cost Estimate table for costs associated with these activities.

Program management costs include overall program management costs for the DOE Oakland Operations Office. These costs include funding for the agreements-in-principle program, grants, program support and waste management.

FUNDING AND COST INFORMATION

The following tables present funding information and major activity milestones for Geothermal Test Facility.

Program Management Cost Estimate

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							<i>Life Cycle**</i>
	<i>FY 1995 - 2000</i>	<i>2005</i>	<i>2010</i>	<i>2015</i>	<i>2020</i>	<i>2025</i>	<i>2030</i>	
Program Management	240	0	0	0	0	0	0	1,438

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

**Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Nondefense Funding Estimate

<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>								
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	Life Cycle**
Environmental Restoration	983	0	0	0	0	0	0	5,698
Program Management	240	0	0	0	0	0	0	1,438
Total	1,223	0	0	0	0	0	0	7,336

*Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

**Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Major Activity Milestones

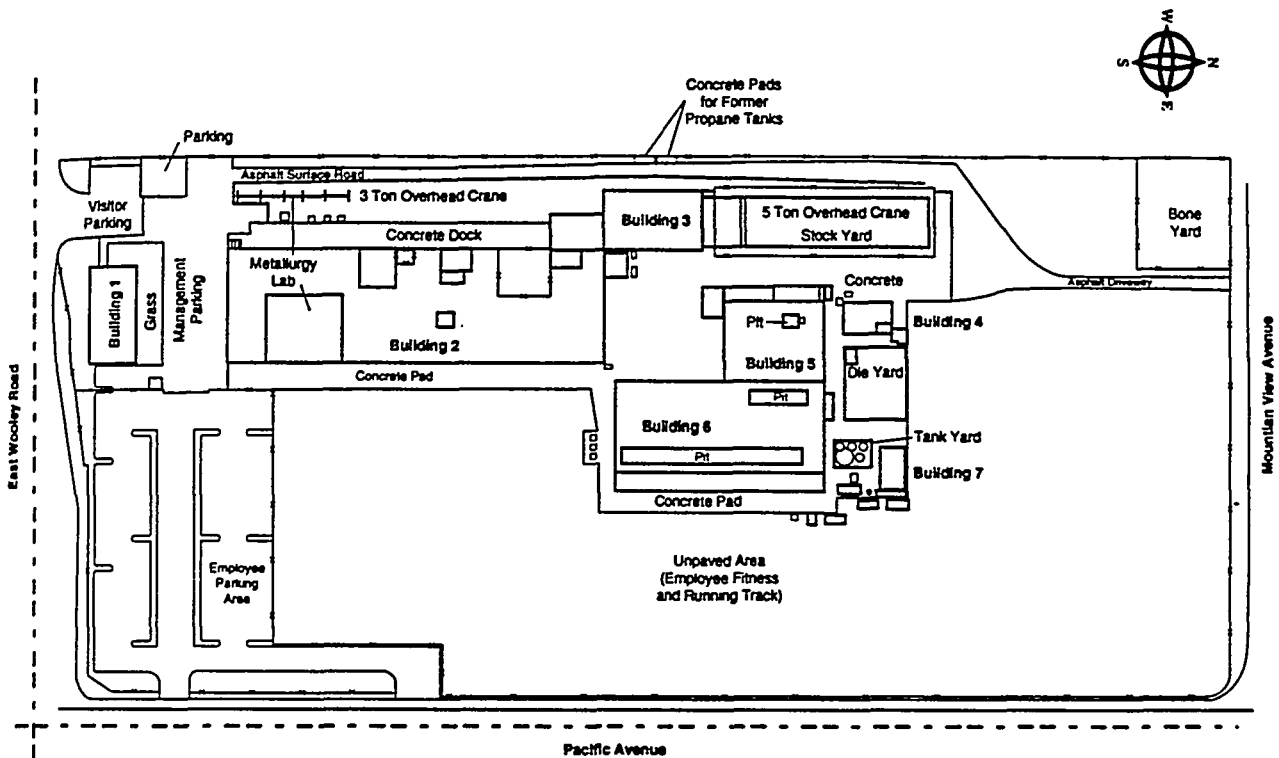
ACTIVITY	TASK	COMPLETION DATE
Environmental Restoration		Fiscal Year
	Complete Site Characterization	1997
	Start Site Remediation Activities	1998
	Complete Decommissioning and Site Remediation Activities	1999

For further information on this site, please contact :

Public Participation Office	(510) 637-1812
Public Affairs Office	(510) 637-1809
Technical Liaison: Rich Fallejo	(510) 637-1639

OXNARD SITE

The Oxnard site is a 14-acre area located in the industrial section of Oxnard, California, approximately 50 miles northwest of Los Angeles.



Estimated Site Total

(Thousands of Current 1995 Dollars)

	FY 1995	1996	1997	1998	1999	2000
Environmental Restoration	3,008	7,210	3,183	1,093	0	0
Program Management	300	515	330	540	0	0
Total	3,308	7,725	3,513	1,633	0	0

*Five-Year Averages (Thousands of Constant 1995 Dollars)**

	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	Life Cycle**
Environmental Restoration	2,414	0	0	0	0	0	0	14,484
Program Management	349	0	0	0	0	0	0	2,092
Total	2,763	0	0	0	0	0	0	16,576

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

PAST, PRESENT, AND FUTURE MISSIONS

Oxnard is a 45-year-old industrial plant originally used from 1949 to 1981 to produce farm equipment. A contractor for the Department of Energy (DOE), Precision Forge, occupied the site from 1981 to 1984. The Department purchased the property in 1984 and will continue to produce forgings for weapon parts through calendar year 1995. The facility will then be returned to private concerns for economic development. DOE-Rocky Flats is the current landlord but landlord responsibilities will likely transfer to Environmental Management (EM) following completion of production. The Grand Junction Projects Office, Grand Junction, Colorado, has recently assumed responsibility for the remediation of the Oxnard site.

ENVIRONMENTAL RESTORATION

The Oxnard facility has been contaminated during its use as a metals-forging plant. Possible hazardous contaminants include polychlorinated biphenyls (PCBs), organic lubricants and coolants, chlorinated solvents, and heavy metals. While several environmental sampling programs have been conducted to determine the type of contamination, an extensive site assessment has not been performed and the extent of contamination has not been defined. Preliminary assessments indicated low concentrations of PCBs (less than 50 parts per million) and the presence of tetrachloroethane and fuel products in soil gases.

The next step is a characterization of the site. This will include collecting and analyzing soil and ground-water samples and assessing hydrogeologic conditions.

Depending on the extent of contamination, corrective measures may include the excavation of contaminated soils, the demolition and replacement of concrete structures, the disposal of contaminated materials, the installation of a water treatment system, and site restoration. Remediation of the Oxnard site is currently planned for completion in FY 1997. Regulatory drivers for this project will be defined when characterization activities are completed.

WASTE MANAGEMENT

There are no current or planned waste management activities conducted at Oxnard.

NUCLEAR MATERIAL AND FACILITY, STABILIZATION

There are no current or planned nuclear material and facility stabilization activities at the Oxnard site.

LANDLORD FUNCTIONS

The landlord functions for Oxnard are managed through the Grand Junction Projects Office. Please see the Colorado site summary for details.

PROGRAM MANAGEMENT

Program management services are tracked and charged to waste management and environmental restoration activity budgets. However, for the purpose of this report program management costs are discretely identified.

FUNDING AND COST INFORMATION

The following tables present funding information and major activity milestones for the Oxnard Site.

Environmental Restoration Activity Costs

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							Life Cycle**
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
Oxnard								
Assessment	638	0	0	0	0	0	0	3,828
Remedial Actions	1,776	0	0	0	0	0	0	10,656
Total	2,414	0	0	0	0	0	0	14,484

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Program Management Cost Estimate

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)**</i>							<i>Life Cycle</i>
	<i>FY 1995 - 2000</i>	<i>2005</i>	<i>2010</i>	<i>2015</i>	<i>2020</i>	<i>2025</i>	<i>2030</i>	
Program Management	349	0	0	0	0	0	0	2,092

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Defense Funding Estimate

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							<i>Life Cycle**</i>
	<i>FY 1995 - 2000</i>	<i>2005</i>	<i>2010</i>	<i>2015</i>	<i>2020</i>	<i>2025</i>	<i>2030</i>	
Environmental Restoration	2,414	0	0	0	0	0	0	14,484

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Nondefense Funding Estimate

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							<i>Life Cycle**</i>
	<i>FY 1995 - 2000</i>	<i>2005</i>	<i>2010</i>	<i>2015</i>	<i>2020</i>	<i>2025</i>	<i>2030</i>	
Program Management	349	0	0	0	0	0	0	2,092

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

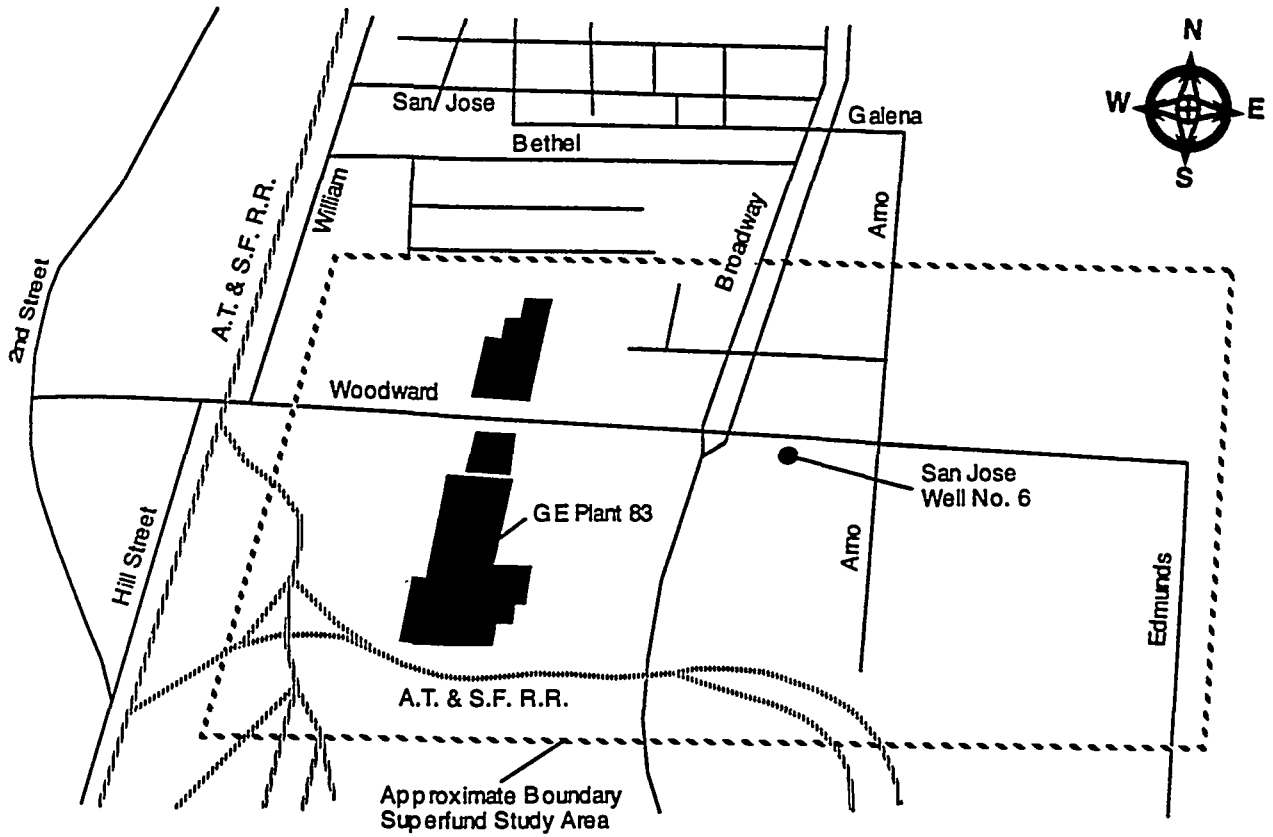
Major Activity Milestones

ACTIVITY	TASK	COMPLETION DATE
Environmental Restoration		Fiscal Year
	ER Characterization Complete	1995
	ER Remediation Complete	1997

For further information on this site, please contact : *Public Participation Office* (505) 845-5951
Public Affairs Office (505) 845-6202
Technical Liaison: Marilyn Bange (505) 845-5160

SOUTH VALLEY SUPERFUND SITE

The South Valley Superfund Site is located in the south valley area of Albuquerque, New Mexico. The site covers an area of 1 square mile. The site houses industrial facilities that require environmental cleanup under the Comprehensive Environmental Response, Compensation and Liability Act.



Estimated Site Total

*(Thousands of Current 1995 Dollars)**

	FY 1995	1996	1997	1998	1999	2000
Environmental Restoration	2136	4580	956	735	735	735

* Costs for FY 1995 reflect Congressional Appropriation, costs for FY 1996 reflect EM budget submission, costs for FY 1997-2000 reflect Budget Shortfall Scenario, costs for shaded area assume 3% annual inflation.

*Five-Year Averages (Thousands of Constant 1995 Dollars)***

	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	Life Cycle***
Environmental Restoration	1,576	871	972	880	0	0	0	23,066

** Costs reflect a five-year average in constant 1995 dollars, except in FY 1995 - 2000, which is a six-year average.

*** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

PAST, PRESENT, AND FUTURE MISSIONS

From 1951 to 1967, the site was owned by the Atomic Energy Commission. The Commission built the South Valley Works there for the manufacturing of nonnuclear components for nuclear weapons. From 1967 to 1983, the plant was owned by the U.S. Air Force and operated by General Electric. At that time, the South Valley Works was renamed Plant 83. In 1983, the plant was bought by General Electric, which remains the current owner.

The U.S. Environmental Protection Agency (EPA) has identified three parties that are potentially responsible for cleaning up the contamination generated by past operations at the site: the Department of Energy (DOE), the U.S. Air Force, and General Electric. All three parties are responsible for meeting the requirements stated in two records of decision.

The three parties reached an agreement outlining the percentage of cleanup costs that each party was responsible for providing. General Electric is currently responsible for operating the facility. The Department's only remaining mission at this site is to successfully complete the requirements of both records of decision and to reimburse General Electric for the percentage of cleanup costs as specified by the settlement agreement. The Department's mission at the site will end when environmental restoration has been completed.

ENVIRONMENTAL RESTORATION

At the South Valley site, ground-water contamination is present in both shallow and deep aquifers, which are separated by an impermeable clay layer. The EPA believes that industrial activities under all three of the site's owners contributed to contamination with

solvents, primarily trichloroethylene and dichloroethane. Soil contamination at several areas resulted from spills and solvents leaking from waste storage areas. The extent of contamination is low enough that no action beyond cleanup with a pilot-scale vacuum extraction system is expected to be necessary.

Planned activities include ground-water remediation in the shallow aquifer with a pump-and-treat system that involves extracting contaminated water, treating it, and then reinjecting the water into the aquifer. Ground water in the deep aquifer will be remediated with a pump-and-treat system that is expected to become operational during FY 1996. The remaining remediation activities will be related to operation, maintenance, and monitoring. These activities are expected to continue into FY 2015.

Under the terms of the settlement agreement, DOE does not manage the cleanup project but is liable for reimbursing General Electric for the cleanup costs. The Department will fund 43.2 percent of the cleanup costs incurred by General Electric in meeting the EPA cleanup standards.

WASTE MANAGEMENT

The Department is not involved in any waste management activities because it neither owns nor operates the facility. It is expected that the ground-water treatment will not create any waste streams.

NUCLEAR MATERIAL AND FACILITY STABILIZATION

Under the terms of the settlement agreement, the Department only funds a portion of the cleanup project. The Department is not responsible for facility stabilization, maintenance, or monitoring.

LANDLORD FUNCTIONS

The Department has no landlord functions at this site.

PROGRAM MANAGEMENT

For this report, the program management responsibilities for South Valley are performed under the Albuquerque Operations Office cost estimate.

Environmental Restoration Activity Costs

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							<i>Life Cycle**</i>
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
Environmental Restoration Remedial Actions	1,576	871	972	880	0	0	0	23,066

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

FUNDING AND COST INFORMATION

The following tables present funding information and major activity milestones for South Valley.

Defense Funding Estimate

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							<i>Life Cycle**</i>
	<i>FY 1995 - 2000</i>	<i>2005</i>	<i>2010</i>	<i>2015</i>	<i>2020</i>	<i>2025</i>	<i>2030</i>	
Environmental Restoration	1,576	871	972	880	0	0	0	23,046

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Major Activity Milestones

ACTIVITY	TASK	COMPLETION DATE
Environmental Restoration:		Fiscal Year
Shallow Ground-Water Remediation	Start Cleanup	1994
	End Cleanup	1997
Deep Ground-Water Remediation	Start Cleanup	1995
	End Cleanup	2015

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

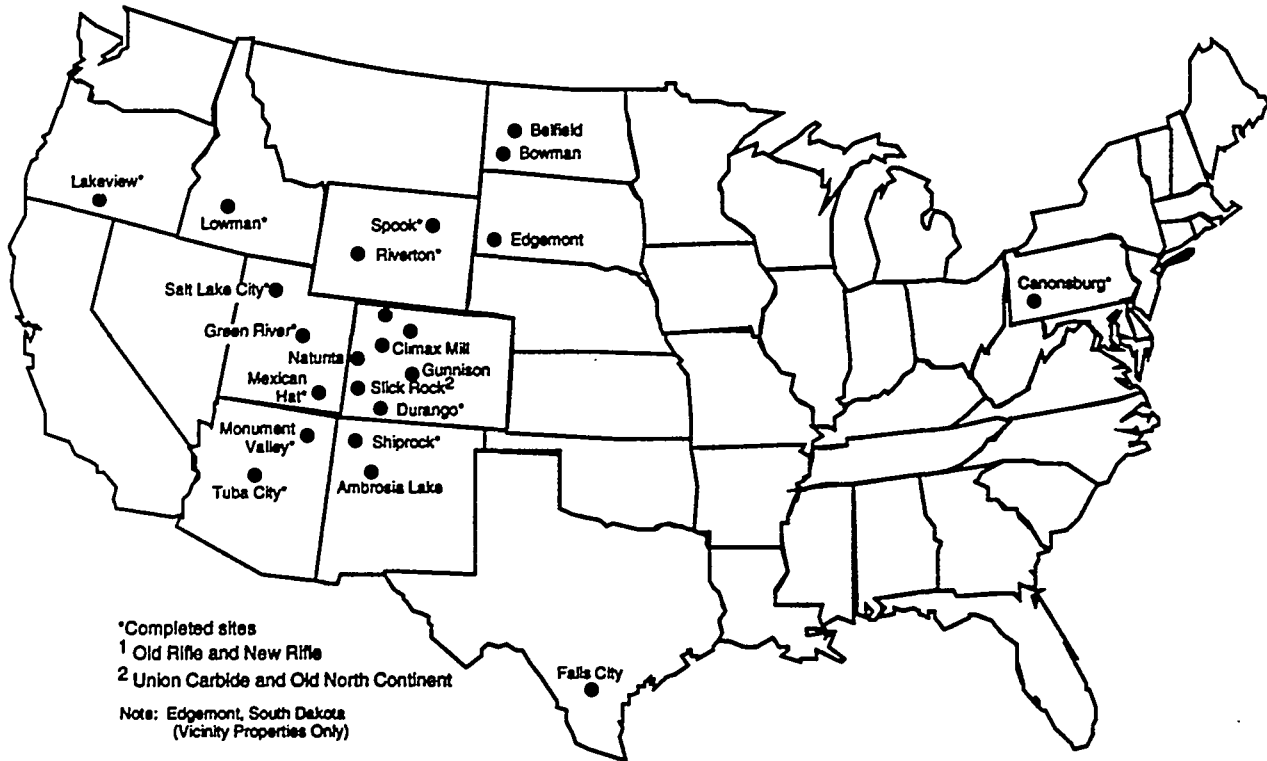
For further information on this site, please contact:

Public Participation Office	(505) 845-5951
Public Affairs Office	(505) 845-6202
Technical Liaison: John Corimer	(505) 845-5956

URANIUM MILL TAILINGS REMEDIAL ACTION PROGRAM OFFICE

24 Surface and Ground-Water Sites in 10 States

There are 24 designated Uranium Mill Tailings Remedial Action (UMTRA) sites located in 10 States. These States include Arizona (2 sites), Colorado (9 sites), Idaho (1 site), New Mexico (2 sites), North Dakota (2 sites), Oregon (1 site), Pennsylvania (1 site), Texas (1 site), Utah (3 sites), and Wyoming (2 sites). The UMTRA Program Office is located in Albuquerque, New Mexico.



PAST, PRESENT, AND FUTURE MISSIONS

The U.S. Congress passed the Uranium Mill Tailings Radiation Control Act in 1978 in response to public concerns regarding potential health hazards from long term exposure to radiation from uranium mill tailings. The Act authorized the Department of Energy (DOE) to stabilize, dispose of, and control uranium mill tailings and other contaminated material at 24 uranium mill processing sites and approximately 5,000 vicinity properties.

Most uranium ore mined in the United States in the 1950's and 1960's was processed by private firms for the Atomic Energy Commission, a predecessor of DOE. The processing plants were shut down, and the tailings piles from mill operations were abandoned. The tailings piles present a potential long term health hazard because they contain low-level radioactive and other hazardous materials that migrated to surrounding soil, ground water, and surface water. Furthermore, the piles often emit radon gas. The tailings, and other contaminated material were also used as fill dirt or incorporated into various construction materials at numerous offsite locations (vicinity properties).

The mission is to remediate 24 designated processing sites as required by the Act. By the end of FY 1995, 15 sites will have been completed and 7 sites will be under active remediation. The final two sites will begin remediation in FY 1996.

Remediated processing sites will not be returned to the public for either limited or unrestricted use until compliance with Environmental Protection Agency (EPA) standards for ground water have been met through the Uranium Mill Tailings Ground-water Compliance Project. Also, approximately 5,000 vicinity properties are

being remediated by the project. Disposal cells containing the contaminated material will be maintained by the Federal Government as defined in the long-term surveillance plan.

ENVIRONMENTAL RESTORATION

Former uranium processing activities at most of the 24 inactive mill sites resulted in contamination of ground water beneath, and in some cases, downgradient of the sites. This contaminated ground water often has elevated levels of contaminants such as uranium or nitrates. After completion of the Uranium Mill Tailings Ground-Water Compliance Project; all of the sites will be returned, at least in part, to the State as identified in the UMTRA Surface Project Plan.

For the 11 sites using the stabilize-in-place or stabilize-onsite disposal option, only the portion of the site not having a disposal cell will be available for restricted use. The portion of the site that contains the disposal cell will be maintained by the Federal Government under the Long-Term Surveillance and Maintenance program. For the 13 remaining sites using the relocation option, the entire site will be available for unlimited use. In most cases, the title to the site will return to the State or to the original owners.

A programmatic environmental impact statement will be used as a decisionmaking framework for determining the project wide ground-water compliance strategy. The programmatic approach proposed, in the UMTRA Ground-Water Programmatic Environmental Impact Statement, is to evaluate specific conditions at each site and select a compliance strategy that will meet the applicable EPA standards. The proposed compliance strategies reflect the variety of

ground-water conditions anticipated at the UMTRA sites. These strategies range from no further action required to engineered remedial actions.

The draft programmatic environmental impact statement is scheduled to be published in the spring of 1995. In conjunction with that activity, the project is proceeding with preparation of site-specific baseline risk assessments. These assessments serve to evaluate risks to human health and the environment by collecting field data and performing calculations and simulations. With one exception, the baseline risk assessments will be complete by FY 1995. The last baseline risk assessment is scheduled for completion in FY 1996. Site observational work plans for applicable sites began in FY 1994 and will continue through 2004 per the project schedule.

The site observational work plans will define the technical scope, objectives, and strategies for the anticipated activities at the site from characterization through engineering design and remediation. Site-specific environmental assessments, borrowing from the programmatic framework defined in the programmatic environmental impact statement, will describe each site's compliance strategy. Because they follow the completion of the site observational work plans, preparation of environmental assessments will be initiated in FY 1996 and continue, according to the project schedule, through FY 2005.

The site-specific remedial action plans will describe regulatory compliance strategies for the sites where active remediation strategies are proposed. The remedial action plans will contain sufficient information for the Nuclear Regulatory Commission, States, and Tribes to concur upon the selection of the compliance strategy. Remedial action plans will be initiated just prior to finalization of environmental

assessments and publishing of the Findings of No Significant Impacts in the Federal Register. They are scheduled to begin in FY 1997 and continue through FY 2007.

Each site's compliance strategy will ultimately be consistent with the proposed action in the UMTRA Ground Water Programmatic Environmental Impact Statement. This impact statement will reflect the results of site-specific risk evaluations. The UMTRA Ground-Water Compliance Project, for purposes of creating a budget estimate, has proposed three primary compliance strategies. These strategies include no further action, passive, and active.

Although no decisions can be made prior to release of the programmatic environmental impact statement, budget preparation needs require that site-specific scenarios be addressed as described above. For budgeting purposes only, two sites were suggested for active compliance strategies. The remaining sites would have passive (natural flushing) strategies imposed, additional characterization, or no further action. This would mean that active remediation could begin as early as FY 2002, with completion possible by FY 2014.

Future assessment efforts for the UMTRA Surface Project will center around the assessment of new vicinity properties (particularly Climax Mill in Grand Junction, Colorado) and the certification and licensing of all completed disposal cells. Remediation will consist of completing those six sites started prior to FY 1995, starting the cleanup of the last five processing sites in FY 1995 and FY 1996, and completing cleanup of all sites by the end of FY 1998. Activities in FY 1999 will consist of finalization of site and vicinity property completion reports.

WASTE MANAGEMENT

Waste management at all UMTRA sites is conducted within the scope of environmental restoration activities.

NUCLEAR MATERIAL AND FACILITY STABILIZATION

There are no current or planned nuclear material and facility stabilization activities required at the UMTRA sites.

LANDLORD FUNCTIONS

Landlord activities are the responsibility of the owner at each site. In cases where DOE will maintain control of the site and continue long-term surveillance and maintenance, landlord costs are represented in the UMTRA life cycle cost estimate for the State in which that site is located.

PROGRAM MANAGEMENT

Program management supports management efforts for the National Environmental Policy Act process, site characterization and licensing public information/participation, quality assurance audits, program and management support for the technical assistance contractor, special studies, document control, technical assistance contractor site and technical management, cost and schedule controls, planning and preparation of the Federal budget, and the Environmental Management Progress Tracking System. Also included is indirect support required by the DOE Program Office for operations and coordination.

For further information on this site, please contact:

Public Participation Office

(505) 845-5951

Public Affairs Office

(505) 845-6202

Technical Liaison: Jody Metcalf

(505) 845-6146

NEW MEXICO UMTRA SITES

The Ambrosia Lake former processing site is one of 24 uranium mill processing sites designated by the Uranium Mill Tailings Radiation Control Act for remediation by the Department of Energy (DOE). Most uranium ore mined in the United States in the 1960's was processed by private firms for the Atomic Energy Commission, a predecessor of DOE. The Act was passed in 1978 in response to public concerns regarding potential health hazards from long term exposure to uranium mill tailings. It authorized the DOE to stabilize, dispose of, and control uranium mill tailings and other contaminated material at 24 uranium mill processing sites and vicinity properties. Uranium Mill Tailings Remedial Action (UMTRA) activities are funded through the Albuquerque Operations Office.

The cost estimate model used for this report provides costs for each of the UMTRA sites. All costs for waste management activities, program management, and relevant landlord activities attributable to DOE are provided for within the scope of environmental restoration. There are no Uranium Mill Tailings Radiation Control Act sites with either current or planned nuclear material and facility stabilization activity needs. Funding for all sites is 100 percent nondefense.

NORTH DAKOTA UMTRA SITES

The Belfield site and the Bowman site are 2 of 24 uranium mill processing sites designated by the Uranium Mill Tailings Radiation Control Act for the U.S. Department of Energy (DOE) remediation. Most uranium ore mined in the United States in the 1960's was processed by private firms for the Atomic Energy Commission, a predecessor of DOE. The Act was passed in 1978 in response to public concerns regarding potential health hazards from long-term exposure to uranium mill tailings. It authorized DOE to stabilize, dispose of, and control uranium mill tailings and other contaminated material at 24 uranium mill processing sites and vicinity properties.

Uranium Mill Tailings Remedial Action (UMTRA) activities are funded through the Albuquerque Operations Office.

The model used as an estimation tool for this report provides costs for each of the UMTRA sites located in each State. All costs for waste management activities, program management, and relevant landlord activities attributable to DOE are provided for within the scope of environmental restoration. There are no UMTRA sites with either current or planned nuclear material and facility stabilization activity needs. Funding for all sites is 100 percent nondefense. For a general discussion of UMTRA and associated costs, see the UMTRA Site Summary found in the New Mexico section.

Estimated Site Total

(Thousands of Current 1995 Dollars)*

	FY 1995	1996	1997	1998	1999	2000
Environmental Restoration	200	28,000	1,150	0	160	190

* Costs for FY 1995 reflect Congressional Appropriation, costs for FY 1996 reflect EM budget submission, costs for FY 1997-2000 reflect Budget Shortfall Scenario, costs for shaded area assume 3% annual inflation.

Five-Year Averages (Thousands of Constant 1995 Dollars)*

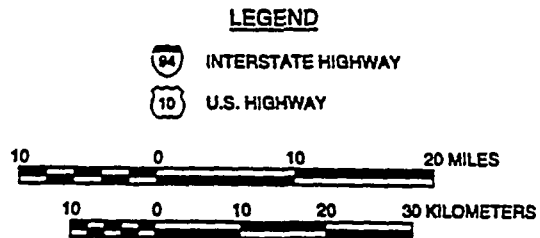
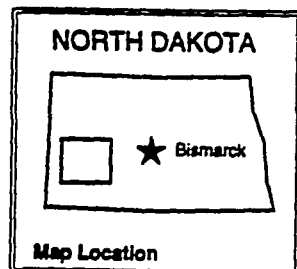
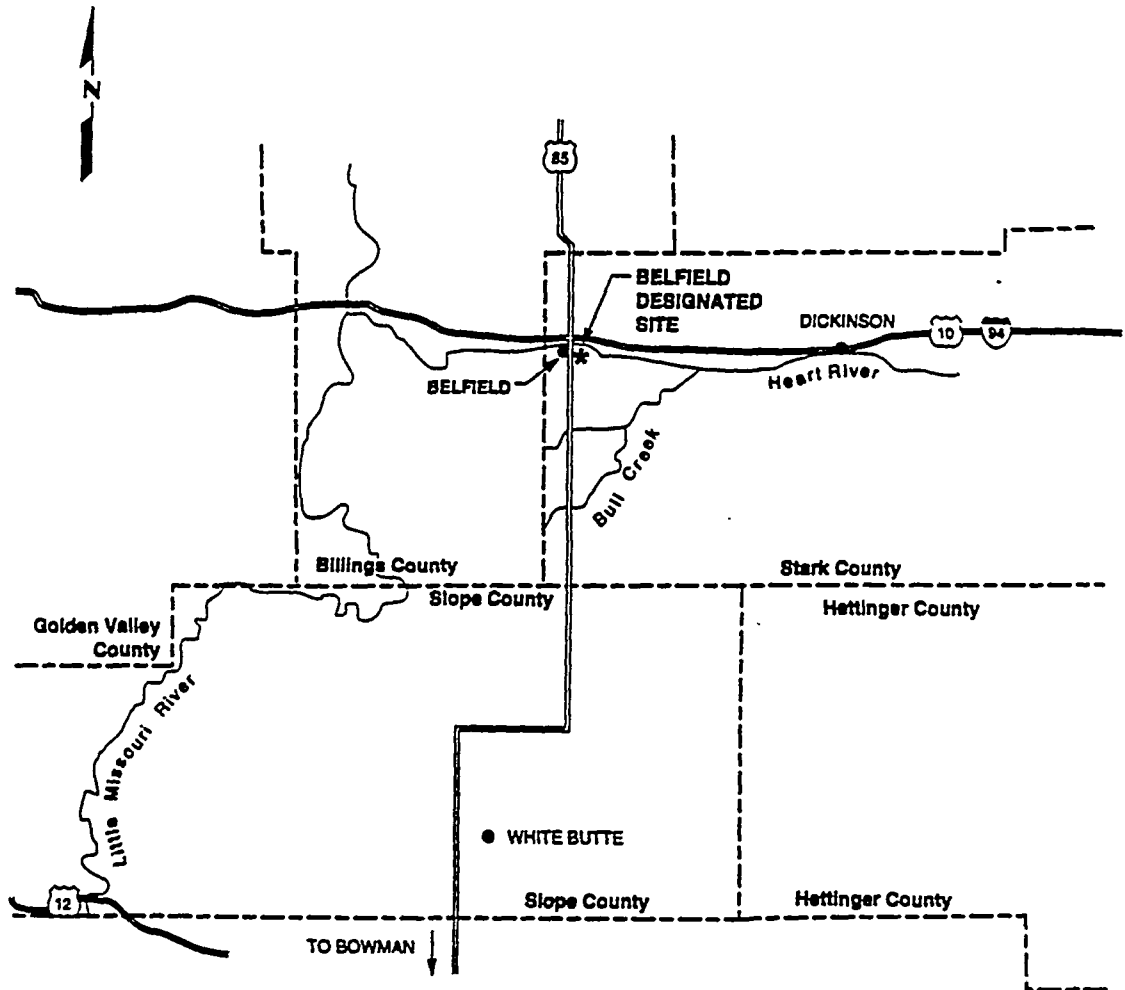
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	Life Cycle***
Environmental Restoration	4,204	516	0	0	0	0	0	27,805

** Costs reflect a five-year average in constant 1995 dollars, except in FY 1995 - 2000, which is a six-year average.

*** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

BELFIELD AND BOWMAN (Uranium Mill Tailings Remedial Action Project)

The Belfield site is located in southwestern North Dakota, one mile southeast of the Town of Belfield in Stark County. The former ashing site occupies 10.7 acres. The Bowman site is located seven miles west of Bowman, North Dakota. The site is located on nearly level land near the head of Spring Creek, a part of the Grand River drainage basin. The Bowman site is approximately 12 acres.



PAST, PRESENT, AND FUTURE MISSIONS

Union Carbide Corporation leased the Belfield site for an ashing operation from 1964 to 1966. Dakota Industries leased the site in 1968 for clay calcination operations to produce cat litter. In 1972, LP Anderson Construction Company of Miles City, Montana, purchased one of the buildings and leased a portion of the site for construction equipment, maintenance, and storage. Another building on the site housed a honey processing operation. Cenex Exploration, an agricultural cooperative, maintains an oil and gas exploration office and shop adjacent to the site. There is no discernible pile remaining.

During ashing operations from 1963 to 1967, the Bowman site was owned by Viola Soderstrom, who leased the property to Kermac Nuclear Fuels Corporation, a subsidiary of Kerr-McGee Oil Industries. The property was subsequently purchased by the Milwaukee Road and leased by Bowman Grain, Inc. Ashing operations were suspended in February 1967, and the Atomic Energy Commission Source Material License was terminated on May 16, 1967.

Site use will remain restricted until surface remediation and ground-water compliance is achieved.

ENVIRONMENTAL RESTORATION

No mill tailings pond or pile is present because the ash was shipped to another location. However, activities at these sites have resulted in contaminated soil, gravel, and rubble, as well as contaminated windblown soil. All activity has been suspended pending resolution of State funding issues. The costs for environmental restoration projects at this site are shown in the following table. All funding is from nondefense sources.

Environmental Restoration Projects

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							Life Cycle**
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
UMTRA-Ground Water - North Dakota	235	516	0	0	0	0	0	3,990
UMTRA-Soils - North Dakota	3,969	0	0	0	0	0	0	23,815
Total	4,204	516	0	0	0	0	0	27,805

*Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

**Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Nondefense Funding Estimate

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							Life Cycle**
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
Environmental Restoration	4,204	516	0	0	0	0	0	27,805

*Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

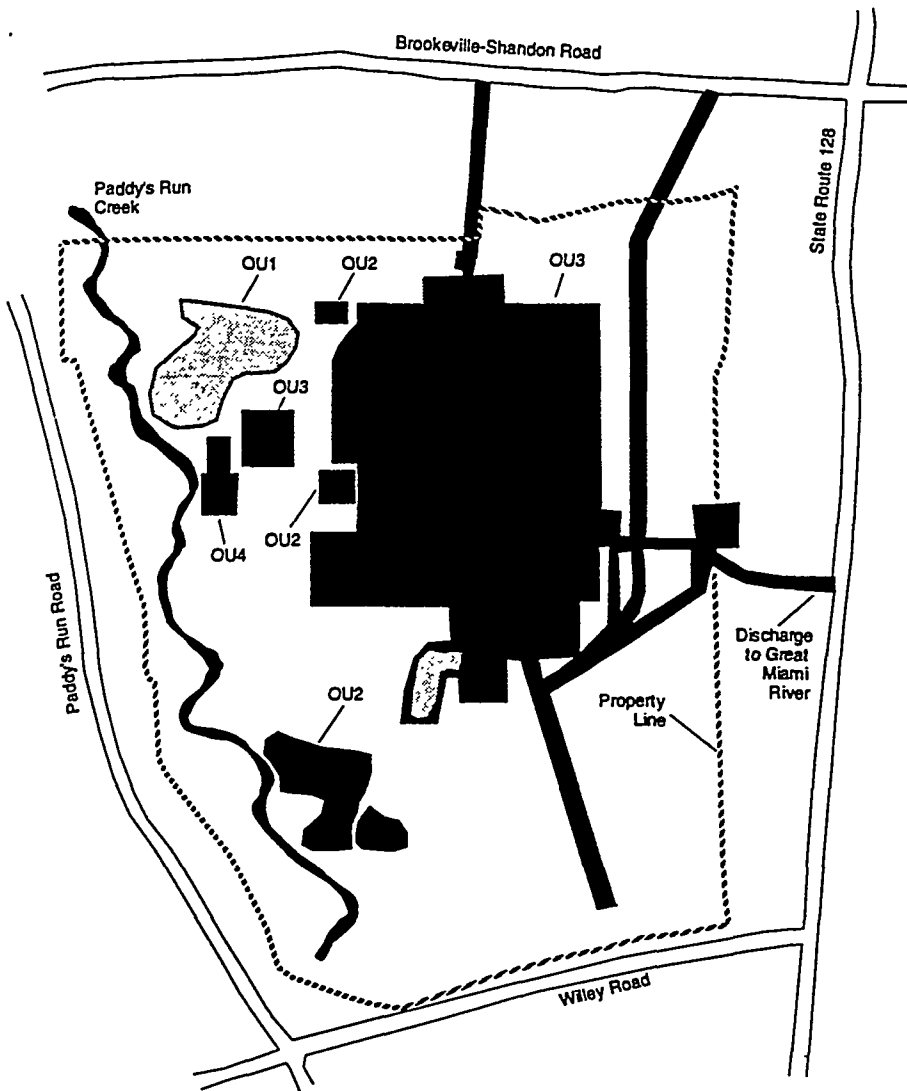
**Total Life Cycle is the sum of annual costs in constant 1995 dollars.

For further information on this site, please contact :

Public Participation Office	(505) 845-5951
Public Affairs Office	(505) 845-6202
Technical Liaison: Jody Metcalf	(505) 845-6146

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

The former Fernald Feed Materials Production Center is located on a 1,050-acre tract that overlaps the boundary between Hamilton and Butler Counties near the southwest corner of Ohio. It is approximately 20 miles northwest of Cincinnati. The Great Miami River flows nearby in a southerly direction, approximately one mile east of the site. Paddy's Run, a small stream, runs southward along the western boundary of the site. The Great Miami Aquifer flows beneath the Fernald site. The former production facilities and supporting infrastructure comprise approximately 136 acres of the 1,050-acre site.



Estimated Site Total

*(Thousands of Current 1995 Dollars)**

	FY 1995	1996	1997	1998	1999	2000
Environmental Restoration	159,000	177,700	187,400	210,400	195,700	327,600
Directly Appropriated Landlord	63,100	52,300	49,000	49,000	49,300	70,000
Program Management	84,500	77,100	65,400	66,200	65,200	76,100
Total	306,600	307,100	301,800	325,600	310,200	473,700

* Costs for FY 1995 reflect Congressional Appropriation, costs for FY 1996 reflect EM budget submission, costs for FY 1997-2000 reflect Budget Shortfall Scenario, costs for shaded area assume 3% annual inflation.

*Five-Year Averages (Thousands of Constant 1995 Dollars)***

	FY 1995 - 2000	2005	2010	2015	2020	2025	2030
Environmental Restoration	184,184	244,800	69,078	33,588	12,868	12,630	8,862
Directly Appropriated Landlord	51,515	57,840	45,560	24,680	3,360	2,088	2,506
Program Management	67,859	90,308	55,276	30,504	7,358	4,888	3,244
Total	303,558	392,948	169,914	88,772	23,586	19,606	14,612

	2035	2040	2045	2050	2055	2060	2065	Life Cycle***
Environmental Restoration	70	200	200	240	400	160	0	3,020,548
Directly Appropriated Landlord	4,176	1,253	0	0	0	0	0	1,018,403
Program Management	0	0	0	0	0	0	0	1,365,046
Total	4,246	1,453	200	240	400	160	0	5,402,034

** Costs reflect a five-year average in constant 1995 dollars, except in FY 1995 - 2000, which is a six-year average.
 *** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

PAST, PRESENT, AND FUTURE MISSIONS

The Fernald Feed Materials Production Center, later renamed the Fernald Environmental Management Project, was constructed in the early 1950's to convert uranium ore into uranium metal, and then to fabricate the uranium metal into target elements for reactors that produced weapons-grade plutonium and tritium. Production operations spanned more than 36 years until they were suspended on July 10, 1989. Following necessary notifications, the

facility was formally shut down on June 19, 1991. During the facility's production mission, over 500 million pounds of high-purity uranium products were yielded to support U.S. defense initiatives.

In 1986, the U.S. Environmental Protection Agency (EPA) and the Department of Energy (DOE) entered into a Federal Facility Compliance Agreement covering environmental impacts associated with site activities. The Fernald site was placed on EPA's National Priorities List in 1989. A Consent Agreement was signed by DOE and EPA in

1990 and amended in 1991. This agreement established five operable units, as follows:

- Operable Unit 1 - Waste Pit Area
- Operable Unit 2 - Other Waste Areas
- Operable Unit 3 - Former Production Area
- Operable Unit 4 - Silos 1 through 4
- Operable Unit 5 - Environmental Media

The Ohio EPA is an active participant in the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) process and is the lead agency overseeing the treatment, storage, and disposal of hazardous waste.

In addition to the five operable units, there is remnant production waste, referred to as legacy waste, which is stored in containers at the Fernald site. This waste has been designated for permanent disposal.

Fernald's current mission is environmental restoration, consistent with the remedies defined in a final record of decision for each operable unit and in an approved Treatment, Storage, and Disposal Plan.

The future use of all areas at Fernald is currently under consideration by the Fernald Citizens' Task Force. A preliminary recommendation is that there should be no new agricultural or residential uses on the Fernald property following its remediation. Evaluations are continuing regarding the potential for establishing recreational, commercial/industrial, or undeveloped open space (i.e., green space) on the portions of Fernald property outside the area of an engineered, onsite disposal facility. Formal recommendations on waste disposition and land use will be presented in a final report from the Task Force scheduled for release in July 1995.

All areas of Fernald, with the exception of an engineered, onsite disposal facility, are assumed to attain cleanup levels which provide

for: (1) the protection of persons engaged in on-property industrial and/or recreational uses, and (2) the protection of an offsite farmer. The remedies would provide a maximum estimated risk to a future industrial or recreational user of the Fernald property within an acceptable range of 10^{-5} to 10^{-6} . The engineered, onsite disposal facility will be established as a continuing, restricted access area. The Great Miami Aquifer is scheduled to be remediated and returned to its full beneficial use by FY 2028.

The projected life-cycle costs for the Fernald Environmental Management project are provided in the following table.

ENVIRONMENTAL RESTORATION

During production, many uranium-bearing materials were used in the manufacturing process. These materials included uranium concentrates, recyclable enriched residues, uranium hexafluoride, and a variety of recycled uranium metals (both depleted and enriched) from various facilities. In the production processes, Fernald produced large quantities of solid and liquid low-level radioactive waste. Air was the predominant pathway by which the facility released radioactive particles, but Fernald also routinely released radionuclides into the soil and water, as well. In addition to the former production facilities, the major sources of contamination include:

- six low-level waste storage pits;
- a bumpit;
- a clearwell;
- two concrete silos containing radium-bearing residues;
- one concrete silo containing metal oxides;
- the South Field area, which was a depository of soil and construction debris with low levels of radioactivity; and
- two flyash disposal areas.

Two lime sludge ponds and a solid waste landfill are additional sources of contamination.

Several primary release mechanisms – including air, wastewater discharge, spills, leaks, and land disposal – provided the vehicles for transport of contaminants to environmental media and, subsequently, to potential human and ecological receptors. Secondary releases, such as, resuspension in air of contaminated soil through wind action, contributed to further contaminant migration and transport to other media.

Water releases to the environment occurred through leaking wastewater lines, discharges into the Great Miami River and Paddy's Run, and stormwater runoff. Surface water runoff is a significant pathway for the migration of

contaminants in environmental media. There have been offsite environmental impacts to the Great Miami Aquifer and to surface soils adjacent to the site.

Risks to human and ecological receptors have been evaluated for the site as it presently exist and for simulated conditions up to 1,000 years in the future. The results demonstrate that existing concentrations of radiological and chemical contamination in both the source material and the environmental media pose risks to human and ecological receptors at levels sufficient to trigger the need for remedial actions.

Potential noncarcinogenic health effects for a waste site are assessed in terms of an EPA hazard index for each contaminant of concern. A threshold hazard index value of 1.0 (unitless

Environmental Restoration Projects

<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>								
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
Final Treatment/Storage/Disposal	8,659	3,660	3,660	2,722	2,094	2,094	1,256	
Operable Unit 1	49,930	48,322	60	66	60	66	66	
Operable Unit 2	27,969	43,838	900	720	0	0	0	
Operable Unit 3	51,699	112,598	29,650	0	0	0	0	
Operable Unit 4	21,038	1,508	0	0	0	0	0	
Operable Unit 5	24,889	34,874	34,808	30,060	10,714	10,470	7,540	
Total	184,184	244,800	69,078	33,588	12,868	12,630	8,862	
	2035	2040	2045	2050	2055	2060	2065	Life Cycle**
Final Treatment/Storage/Disposal	0	0	0	0	0	0	0	129,282
Operable Unit 1	30	0	0	0	0	0	0	542,931
Operable Unit 2	0	0	0	0	0	0	0	395,166
Operable Unit 3	0	0	0	0	0	0	0	1,021,434
Operable Unit 4	0	0	0	0	0	0	0	133,771
Operable Unit 5	40	200	200	240	400	160	0	797,961
Total	70	200	200	240	400	160	0	3,070,544

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

has been established as the level above which there is the potential for noncarcinogenic effects on exposed individuals. For current land use with access controls, the hazard index ranges from 1.8 to 260, depending on the receptor. For future land use – without any removal of contaminated sources, and with somewhat less restrictive controls than the site access controls now employed – the hazard index would range from 37 to 260.

Carcinogenic risk is the potential for a contaminant to induce human cancer and is expressed as an incremental lifetime cancer risk. Contaminants present in sufficient concentrations to create an excess lifetime cancer risk within or less than the range of 1 chance in 10,000 to 1 chance in 1,000,000 are considered acceptable to the EPA. For current land use with access controls, the incremental life cancer risk ranges from 1 in 100,000 for a site worker to 1 in 100 for an offsite farmer. For future land use – without any removal of contaminated sources, and with somewhat less restrictive controls than the site access controls now employed – the incremental lifetime cancer risk would range from 1 in 14,000 to 1 in 5.

These elevated risk factors, both carcinogenic and noncarcinogenic, support the need for environmental restoration efforts at Fernald.

Operable Units

A brief description and status of each operable unit and the low-level legacy waste restoration activities are given below:

Operable Unit 1

The Operable Unit 1 area consists of six waste pits, a burn pit, and a clearwell. All waste material would be excavated, treated by drying to meet waste acceptance criteria, then shipped to a commercial disposal facility. Contaminated surface soils and soils beneath the waste areas would be forwarded to Operable Unit 5 for final disposition. Residual water, which

includes surface water, perched ground water incidental to waste unit remediation, and residual process water, will be treated at Fernald's Advanced Wastewater Treatment Facility. All impacted Operable Unit 1 material is being processed as a low-level waste.

Both the Remedial Investigation and the Feasibility Study/Proposed Plan/Environmental Assessment were approved by the EPA, and the Operable Unit 1 Record of Decision was approved by the EPA on March 1, 1995. Remedial design work is underway. A field demonstration program has been initiated to evaluate dewatering and waste excavation techniques further. Remedial action activities are scheduled to commence during June 1996.

Operable Unit 2

Operable Unit 2 consists of five waste units and their associated berms, liners, and soils. Specifically, the waste units include the Solid Waste Landfill, the Lime Sludge Ponds, the Inactive Flyash Pile, the South Field Depository, and the Active Flyash Pile. Construction and operation of an engineered, onsite disposal facility is also an Operable Unit 2 function. All material in Operable Unit 2 waste units which exceeds the required cleanup levels will be excavated, processed for size reduction and moisture control, and disposed of in the onsite disposal facility. An exception will be an expected small fraction of excavated material that will exceed the onsite disposal facility waste acceptance criteria. This latter material will be shipped to a commercial disposal facility. Surface water and perched ground water incidental to waste unit remediation will be treated at Fernald's Advanced Waste Water Treatment Facility. All impacted Operable Unit 2 material is classified as low-level waste.

The Operable Unit 2 Remedial Investigation is approved by the EPA, and the Feasibility Study/Proposed Plan/Environmental Assessment is conditionally approved by the EPA. Additionally, the draft record of decision

is under review by the EPA. A predesign investigation has been initiated to determine the area with the most suitable geology for an engineered, onsite disposal facility. Remedial action activities are scheduled to commence during August 1996. Under current plans, Operable Unit 2 will be assigned the long-term surveillance and monitoring responsibility for any onsite disposal facility following completion of assigned remedial actions.

Active Operable Unit 2 environmental restoration activities that are being conducted as CERCLA Removal Actions include the South Field Surface Seep Control Project and continued maintenance of the Active Flyash Pile and the Paddy's Run Erosion Control Structure.

Operable Unit 3

Operable Unit 3 consists of all artificial aboveground and belowground structures at Fernald that are not included in the other operable units. This includes existing storage pads, roads, the wastewater treatment system, the sewer and electrical systems, railroads, fences, inventory, drums, and material piles. Most of these are located within the 136-acre former production area at the Fernald site.

There are 128 buildings designated for decommissioning and dismantling. Each structure is initially processed by the Fernald safe shutdown project to remove residual process wastes, and then gross contamination is removed from above-grade surfaces. Once gross decontamination is complete, all asbestos, electrical lines, and heating, ventilating, and air conditioning ductwork are removed. The structural components are then dismantled, followed by the structure's foundations and associated below-grade facilities. Most Operable Unit 3 materials are currently classified as low-level waste.

For Operable Unit 3, DOE estimates that 36 percent of low-level radioactive waste material will be shipped to the Nevada Test Site for

burial, 2 percent of waste will be recycled, and the remaining 62 percent will be placed in an onsite disposal facility. Existing facilities will be used for interim storage until the onsite disposal facility is ready to receive waste material. Evaluations are in progress to determine the feasibility of recycling structural and low-grade steels and disposing of concrete and asbestos siding in the onsite disposal facility. Contaminated soils will be excavated and dispositioned by Operable Unit 5. Any surface water and perched ground water that are generated incidental to facility remediation will be treated at the Fernald Advanced Waste Water Treatment Facility.

An Operable Unit 3 Interim record of decision has been approved by the EPA for the decommissioning and dismantling of plant area buildings. Most of the buildings in the former Fernald process area will be decommissioned and dismantled as an interim remedial action. Treatment and final disposition of the dismantled material will be defined in the final record of decision. The Remedial Investigation and Feasibility Study/Proposed Plan to support the final record of decision are in the development stage.

Active Operable Unit 3 environmental restoration activities being conducted as CERCLA removal actions include: safe shutdown; asbestos abatement; decommissioning and dismantling of the Plant 1 Ore Silos and Plant 7; the Plant 1 Storage Pad Upgrade project; and the removal and temporary storage of contaminated media at the former Fire Training Facility.

Operable Unit 4

The K-65 residues and cold metal oxides will be removed from Silos 1, 2, and 3 and treated in an onsite vitrification facility. The sludges from the decant sump tank will also be removed and

vitrified. Following treatment, the vitrified residues will be containerized and transported offsite for disposal at the Nevada Test Site. Silo 4 is empty except for some infiltration water.

Following removal of residues, the concrete silo structures and associated facilities will be demolished. Construction debris will be processed for size reduction and permanently stored in the Fernald onsite disposal facility. Contaminated soils immediately adjacent and under the silos would be forwarded to Operable Unit 5 for final disposition. Residual water, which includes surface water, perched ground water, and residual process water, will be treated at the Fernald Advanced Waste Water Treatment Facility.

All residue material in the silos and decant sump tank are classified as "by-product material" as defined in section 11, paragraph e(2), of the Atomic Energy Act of 1954, as amended. All contaminated soils, concrete debris, and ground water will be processed as low-level waste.

Both the Operable Unit 4 Remedial Investigation and the Operable Unit 4 Feasibility Study/Proposed Plan/Environmental Impact Statement are approved by the EPA. The final record of decision was signed by the EPA on December 7, 1994. As part of the remedial design phase, a pilot plant is being constructed to evaluate further the vitrification process. Construction of the pilot vitrification plant commenced during FY 1994. Remedial action activities were scheduled to commence during March 1995.

Operable Unit 5

Operable Unit 5 consists of contaminated soils (except those associated with Operable Unit 2), on-property and off-property ground water, surface water, flora, and fauna. Remedial activities involve excavation and transport to the onsite disposal facility soil that exceeds required cleanup levels; excavation of contaminated soil that exceeds the onsite waste

acceptance criteria and its shipment to a commercial disposal facility; extraction and treatment of contaminated storm water runoff. Operable Unit 5 operations will fund the construction of the Advanced Waste Water Treatment Facility. Most waste is tentatively designated as low-level waste, with a small fraction potentially classified as low-level mixed waste.

Cleanup levels for site soils are being established in the Operable Unit 5 Feasibility Study for a wide range of land use objectives. Final cleanup levels will be established in the Operable Unit 5 Record of Decision, once land use recommendations are formalized by the Fernald Citizens' Task Force.

The Remedial Investigation is conditionally approved by the EPA, and the Feasibility Study/Proposed Plan is undergoing review by the EPA. Remedial action activities are scheduled to commence during October 1996.

Active Operable Unit 5 environmental restoration activities that are being conducted as CERCLA Removal Actions include the removal and treatment of contaminated, perched ground water located beneath the former plant area; use of a surface water runoff control and treatment system for the Waste Pit Area; and use of an offsite ground-water migration control system to minimize migrations into the Great Miami Aquifer. The ground-water migration control system will extract ground water and treat surface waters prior to their subsequent discharge to the Great Miami River. Installation of additional advanced wastewater treatment capacity is integral to the removal actions.

Low-Level Legacy Waste

Fernald's legacy of low-level waste is in containerized storage. It consists largely of wastes generated as part of activities associated with former production operations and maintenance activities, utility operations, and

laboratory analyses. Approximately 80 percent of the 167,400 cubic yards of low-level waste material has been shipped to the Nevada Test Site as a CERCLA removal action. The remaining 20 percent is scheduled for disposal at the Nevada Test Site during FY 1995 and FY 1996.

That legacy waste which is classified as low-level mixed waste is being processed as a Federal Facility Compliance Act action. A draft treatment, storage, and disposal plan has been submitted to the Ohio EPA for review and approval. Low-level mixed waste associated with the hydrofluoric acid neutralization system, the uranyl nitrate hexahydrate treatment system, and the wastewater treatment system will be treated using existing, onsite facilities and will be shipped for final disposition at the Nevada Test Site. Waste designated for stabilization or chemical processing will be treated by a mobile vendor and disposed of at the Nevada Test Site. Selected low-level mixed waste was treated during FY 1993 and FY 1994 at the Toxic Substance Control Act incinerator at the DOE K-25 Site in Oak Ridge, Tennessee. The remaining waste is scheduled for final disposition from FY 1995 through FY 1997. Disposal of treated low-level mixed waste at existing commercial facilities is being explored.

WASTE MANAGEMENT

Treatment, Storage and Disposal Operations

Production operations at the former Fernald Feed Materials Production Center were suspended during FY 1989 and the facility was formally shut down during FY 1991. All current activities at Fernald are associated with environmental restoration. Fernald's waste management organizational costs are funded within the scope of environmental restoration activities. Legacy low-level waste are being

disposed as stated in the preceding section.

NUCLEAR MATERIAL AND FACILITY STABILIZATION

A facility stabilization activity titled "safe shutdown" was initiated at Fernald to place existing equipment and structures in the former plant area in a safe, shutdown configuration. Safe shutdown activities include program planning and scheduling; engineering; isolation of process equipment, piping systems and associated utilities; the removal and packaging of residual process or excess materials; and the disposition of materials to an approved onsite, interim, storage location. All safe shutdown activities fall under the responsibility of Operable Unit 3 and are funded within the scope of environmental restoration.

LANDLORD FUNCTIONS

Landlord provides for common environmental, safety, and health functions not associated with restoration activities. Responsibilities include the operation and maintenance of the Fernald steam plant; compressed air system; potable water treatment system; process water treatment system; cooling water system; sanitary waste treatment system; site utilities; office buildings and warehouses; vehicle maintenance; and maintenance of former plant area buildings, roads, and parking facilities. Maintenance of the remedial action construction infrastructure, such as, construction office facilities, laydown areas, interim storage areas, roads, and parking, are also landlord functions. Landlord is also responsible for site custodial services, porter service, the site laundry, offsite facility leases and maintenance, inventory control, and site security.

Environmental Restoration Activity Costs

Five-Year Averages (Thousands of Constant 1995 Dollars)*							
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030
Environmental Restoration TSD	8,659	3,660	3,660	2,722	2,094	2,094	1,256
Operable Unit 1							
Assessment	3	0	0	0	0	0	0
Remedial Actions	49,927	48,310	0	0	0	0	0
Surveillance and Maintenance	0	12	60	66	60	66	66
Operable Unit 2							
Assessment	75	0	0	0	0	0	0
Remedial Actions	27,894	43,658	0	0	0	0	0
Surveillance and Maintenance	0	180	900	720	0	0	0
Operable Unit 3							
Assessment	3,163	0	5,930	0	0	0	0
Facility Decommissioning	48,536	112,598	23,720	0	0	0	0
Operable Unit 4							
Assessment	1,088	0	0	0	0	0	0
Remedial Actions	19,950	1,470	0	0	0	0	0
Surveillance and Maintenance	0	38	0	0	0	0	0
Operable Unit 5							
Assessment	285	0	0	0	0	0	0
Remedial Actions	24,603	34,874	34,808	30,080	10,714	10,470	7,540
Surveillance and Maintenance	0	0	0	0	0	0	0
Total	184,184	244,800	69,078	33,588	12,868	12,630	8,862

	2035	2040	2045	2050	2055	2060	2065	Life Cycle**
Environmental Restoration TSD	0	0	0	0	0	0	0	129,382
Operable Unit 1								
Assessment	0	0	0	0	0	0	0	19
Remedial Actions	0	0	0	0	0	0	0	541,112
Surveillance and Maintenance	30	0	0	0	0	0	0	1,800
Operable Unit 2								
Assessment	0	0	0	0	0	0	0	450
Remedial Actions	0	0	0	0	0	0	0	385,656
Surveillance and Maintenance	0	0	0	0	0	0	0	9,000
Operable Unit 3								
Assessment	0	0	0	0	0	0	0	48,628
Facility Decommissioning	0	0	0	0	0	0	0	972,806
Operable Unit 4								
Assessment	0	0	0	0	0	0	0	6,529
Remedial Actions	0	0	0	0	0	0	0	127,051
Surveillance and Maintenance	0	0	0	0	0	0	0	192
Operable Unit 5								
Assessment	0	0	0	0	0	0	0	1,713
Remedial Actions	0	0	0	0	0	0	0	790,049
Surveillance and Maintenance	40	200	200	240	400	160	0	6,200
Total	70	200	200	240	400	160	0	3,020,548

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

PROGRAM MANAGEMENT

Fernald program management includes performing legal and public affairs functions to ensure conformance to applicable Federal and State laws and regulations, with due consideration of stakeholder concerns. Program management activities also include those associated with executive and technical management, business management required to implement the Project Management System per DOE Orders 4700.1 and 4700.5, management of contractual and related issues, quality assurance, regulatory and technology management, systems integration, DOE oversight, ongoing litigation, and regulatory oversight. Oversight of waste minimization activities is also a program management function, whereas actual implementation is part of the operating unit and legacy waste environmental activities.

Technology Development

Technology programs conducts vigorous technology development programs which have integrated several cost-saving improvements into Fernald activities in areas such as robotics and materials handling technology; cleanup and integrated demonstrations involving uranium in soils, including real-time monitoring and analysis; and decontamination by plant update. Technology programs also conducts advanced development work through special contracts with the Alliance of Ohio Universities and the Historically Black Colleges and Universities/Minority Institute Environmental Technology and Waste Management Consortium.

Landlord Cost Estimate

	Five-Year Averages (Thousands of Constant 1995 Dollars)*							Life Cycle**
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
Directly Appropriated Landlord	51,515	57,840	45,560	24,680	3,360	2,088	2,506	
	2035	2040	2045	2050	2055	2060	2065	
Directly Appropriated Landlord	4,176	1,253	0	0	0	0	0	1,016,403

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Program Management Cost Estimate

	Five-Year Averages (Thousands of Constant 1995 Dollars)*							Life Cycle**
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
Program Management	67,859	10,308	55,276	30,504	7,358	4,888	3,244	1,365,046

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995 - 2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

FUNDING AND COST INFORMATION

The following tables present funding information and major activity milestones for Fernald.

Defense Funding Estimate

Five-Year Averages (Thousands of Constant 1995 Dollars)*

	FY 1995 - 2000	2005	2010	2015	2020	2025	2030
Environmental Restoration	184,184	244,800	69,078	33,588	12,868	12,630	8,862
Directly Appropriated Landlord	51,515	57,840	45,560	24,680	3,360	2,088	2,506
Program Management	67,859	90,308	55,276	30,504	7,358	4,888	3,244
Total	303,558	392,948	169,914	88,772	23,586	19,606	14,612

	2035	2040	2045	2050	2055	2060	2065	Life Cycle**
Environmental Restoration	70	200	200	240	400	160	0	3,020,548
Directly Appropriated Landlord	4,176	1,253	0	0	0	0	0	1,016,403
Program Management	0	0	0	0	0	0	0	1,365,046
Total	4,246	1,453	200	240	400	160	0	5,402,034

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

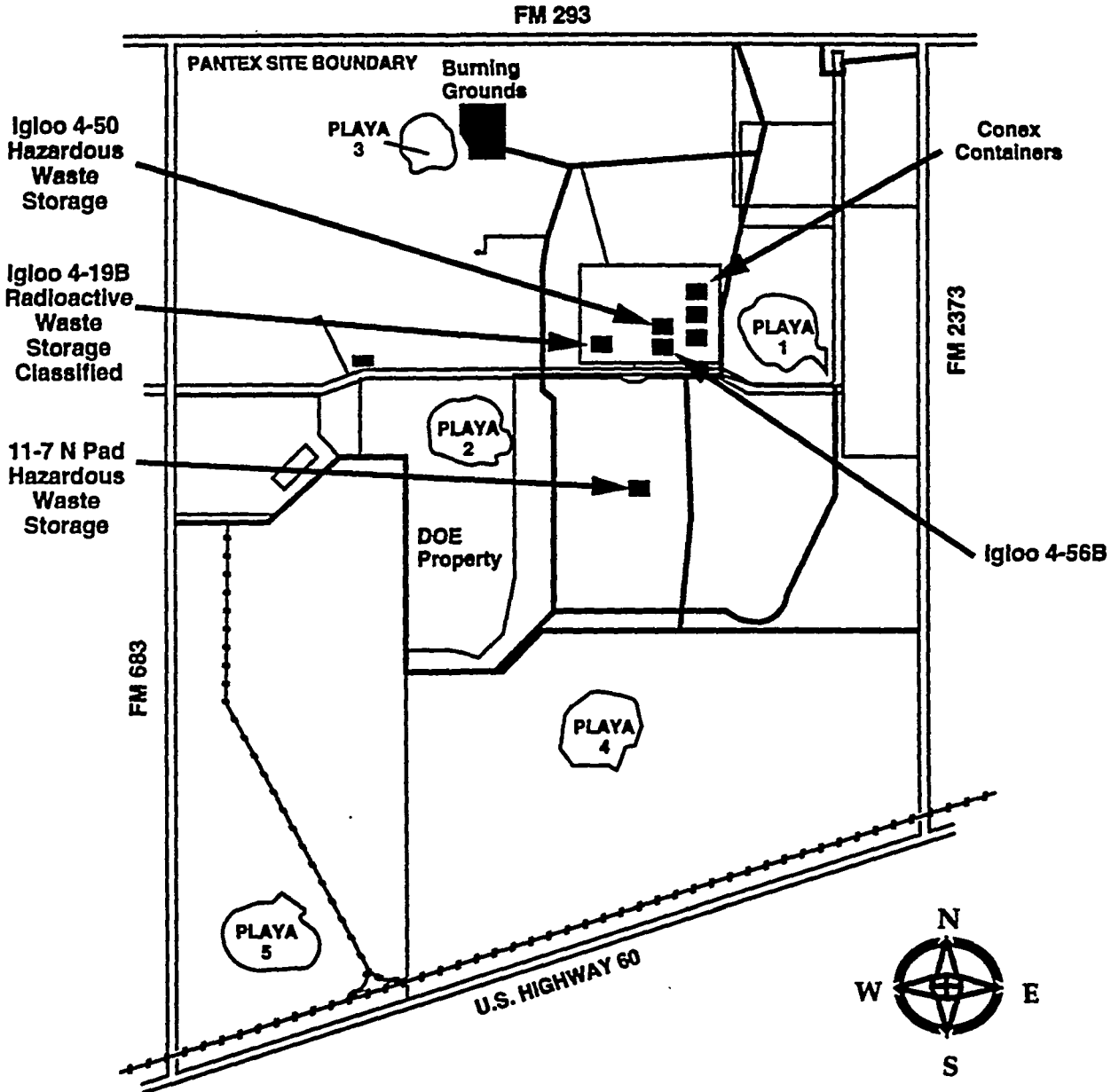
Major Activity Milestones

ACTIVITY	TASK	COMPLETION DATE
		Fiscal Year
Operable Unit 1 - Waste Pit Area	Final Record of Decision Signed by EPA	1995
	Remedial Action Starts	1996
	Remedial Action Ends	2004
Operable Unit 2 - Other Waste Areas	Final Record of Decision Signed by EPA	1995
	Remedial Action Starts	1996
	Remedial Action Ends: Waste Areas	2001
	Remedial Action Ends: Onsite Disposal Facility	2014
Operable Unit 3 - Former Production Area	Interim Remedial Action Starts	1995
	Final Remedial Investigation Report Submitted to EPA	1996
	Final Feasibility Study Report Submitted to EPA	1996
	Final Record of Decision Signed by EPA	1996
	Final Remedial Action Ends	2010
Operable Unit 4 - Silos 1 through 4	Vitrification Pilot Plant Project Started	1994
	Final Record of Decision Signed by EPA	1994
	Remedial Action Starts	1995
	Remedial Action Ends	2003
Operable Unit 5 - Environmental Media	Final Record of Decision Signed by EPA	1996
	Remedial Action Starts	1997
	Remedial Action Ends: Soils	2014
	Remedial Action Ends: Ground Water	2028
Legacy Waste	Site Treatment Plan Submitted to Ohio EPA	1995
	Removal Action Ends: Low-Level Waste	1996
	Removal Action Ends: Low-Level Mixed Waste	1997

For further information on this site, please contact: Public Participation Office (513) 865-3968
 Public Affairs Office (513) 865-3968
 Technical Liaison: Dave Lojek (513) 648-3127

PANTEX PLANT

The Pantex Plant is located in the panhandle of Texas, about 17 miles northeast of downtown Amarillo. The site covers about 16,000 acres.



Estimated Site Total

(Thousands of Current 1995 Dollars)*

	FY 1995	1996	1997	1998	1999	2000
Environmental Restoration	18,947	17,043	16,834	16,751	16,834	18,313
Waste Management	13,968	11,164	12,879	15,196	11,873	14,229
Nuclear Material and Facility Stabilization	2,530	2,630	2,630	2,630	2,630	2,630
Program Management	5,952	5,219	5,725	6,177	5,873	5,957
Total	40,497	36,136	31,270	34,774	37,430	33,129

* Costs for FY 1995 reflect Congressional Appropriation, costs for FY 1996 reflect EM budget submission, costs for FY 1997-2000 reflect Budget Shortfall Scenario, costs for shaded area assume 3% annual inflation.

Five-Year Averages (Thousands of Constant 1995 Dollars)**

	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
Environmental Restoration	11,130	872	0	10,949	2,737	0	0	
Waste Management	12,422	12,514	13,840	12,522	12,557	12,515	10,233	
Nuclear Material and Facility Stabilization	2,609	2,615	6,547	109	0	0	0	
Program Management	4,118	3,544	3,460	5,211	3,659	3,129	2,558	
Total	30,278	19,545	23,847	28,791	18,954	15,644	12,791	

	FY 2035	2040	2045	2050	2055	2060	2065	Life Cycle***
Environmental Restoration	0	0	0	0	0	0	0	139,572
Waste Management	897	0	0	0	0	0	0	449,920
Nuclear Material and Facility Stabilization	0	0	0	0	0	0	0	62,007
Program Management	224	0	0	0	0	0	0	133,637
Total	1,121	0	0	0	0	0	0	785,136

** Costs reflect a five-year average in constant 1995 dollars, except in FY 1995 - 2000, which is a six-year average.

*** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

PAST, PRESENT, AND FUTURE MISSIONS

The Pantex Plant was built by the U.S. Army in 1942 as a conventional bomb plant. It was decommissioned after World War II and sold to Texas Tech University as excess government property. In the 1950's, the Atomic Energy Commission recovered 10,000 acres of the site, renovated portions of the plant, and

constructed new facilities for the manufacture of high explosives used in nuclear weapons and for the final assembly of nuclear weapons. During the mid-1960's, the plant was expanded when it assumed weapons maintenance and modification tasks from plants closed in San Antonio, Texas, and Clarksville, Tennessee. The last expansion came with the closing of a sister plant in Burlington, Iowa in 1975. Pantex has been the only plant of its type since Burlington's closing in 1975.

The mission of the Pantex Plant is fabricating high explosives for nuclear weapons, assembling nuclear weapons, maintaining and evaluating nuclear weapons in the stockpile, and dismantling nuclear weapons as they are retired from the stockpile. At present the principal operation is disassembly of nuclear weapons.

The basic mission is not expected to change in the foreseeable future. The Pantex Plant will continue to be the only facility for the dismantlement and maintenance of the nation's nuclear weapons stockpile. It will also provide interim storage for plutonium in a facility the Department of Energy (DOE) plans to develop. The Pantex Plant is managed by DOE's Office of Defense Programs, which will continue to serve as the landlord.

ENVIRONMENTAL RESTORATION

The production of high-explosives components for nuclear weapons has resulted in the contamination of soils, primarily from organic solvents and high explosives. In addition, tests of weapons components have contaminated some areas with high explosives and heavy metals. The contaminants may migrate to subsurface soils and eventually to ground water. Ground-water contamination has been detected in the perched aquifer, located a few hundred feet above the Ogallala Aquifer. In May 1994, the U.S. Environmental Protection Agency (EPA) placed Pantex on the National Priorities List. The Amarillo Area Office is currently negotiating a tri-party Federal Facility Agreement with the EPA and the State of Texas Natural Resources Conservation Commission.

Environmental restoration activities at the Pantex Plant are conducted in compliance with a Resource Conservation Recovery Act (RCRA) permit issued by the Texas Natural Resources

Conservation Commission in April 1991. They began in 1992 and are expected to be completed by FY 2000 because the environmental restoration program has been accelerated.

Operable Units

Pantex has 144 solid waste management units grouped into 15 operable units for investigation purposes. The latter included 110 potential release sites identified at the plant. RCRA Facility Investigations have been completed for all operable units. For operable units PX-3 and PX-4, no further action is recommended. Unit PX-15, the Hypalon Pond, was closed in 1992. Voluntary corrective actions are being taken at several sites with no further actions planned at several other sites. Brief descriptions of the active operable units follow.

Operable Unit PX-1: Burning Ground Sites

No further action is recommended for all closed burning ground sites except for the flashing pits, which will require further investigation. A voluntary corrective action is planned to accelerate cleanup. Removal and disposal or incineration is planned for the contaminated soil. This project is scheduled for completion in fall 1997.

Operable Unit PX-2: High Priority Potential Release Sites

No further action is recommended for six of these potential release sites. However, a voluntary corrective action will be conducted at two sites. One is building FS-16, where the surface impoundment and sump will be removed; the other is the FS-22 container, which will also be removed. In both cases, sampling will be conducted in the area to confirm cleanup. One site, the concrete sump in building 12-68, requires further investigation.

A recommendation of no further action is expected to be submitted to the Texas Natural Resources Conservation Commission in the spring of 1996.

Operable Unit PX-5: Fire Training Area Burn Pits

A voluntary corrective action study recommended the removal and offsite disposal of contaminated soil. The investigation concluded the soil contamination at the Fire Training Area Burn Pits is restricted to the upper four feet. Remediation, with design starting in FY 1995, will involve the removal of shallow contaminated soil, sampling, and reclamation. Closeout is expected by fall 1995.

Operable Unit PX-6: Ground Water in Zone 12 North

An expedited site characterization is to be conducted by the Argonne National Laboratory. Three additional wells for monitoring perched aquifers and one well for monitoring the Ogallala aquifer were proposed. Ground-water monitoring is also conducted for several other operable units that are a potential source of contaminants to ground water.

Operable Unit PX-7: Landfills

Preliminary data packages are still being validated. The landfills are expected to be further investigated to determine levels of contamination. The extent of remediation will not be known until all investigations have been completed. It is nonetheless expected remediation can be completed by the year 2000.

Operable Unit PX-8: Ditches and Playas

Three of the six water flow systems in this operable unit require additional surface and subsurface sampling. Two of the six require additional sampling of surface areas only. The sixth flow system requires the drilling of

additional subsurface monitoring wells. This last activity will become part of the Zone 12 ground-water assessment, scheduled for summer 1997.

Operable Unit PX-9: Firing Sites

Soil investigations for the firing sites are scheduled for Spring 1995. They will be followed by surveying and recovering visible depleted uranium from surface and near surface soils. Any depleted uranium will be sent to the Nevada Test Site for disposal. A closeout of this operable unit is expected by summer 1997.

Operable Unit PX-10: Leaking Underground Storage Tanks at Buildings 12-35 and 16-1

Further investigation of potential sources of trichloroethylene is recommended, but it will be conducted under Operable Unit PX-12. On the basis of the RCRA Facility Investigation, corrective action is not recommended for the site of the underground storage tank at building 16-1. Additional field work is required to further characterize the site of the underground storage tank at building 12-35.

Operable Unit PX-11: Miscellaneous Sites with Explosives and Radioactive Materials

Soil investigations are in process and a voluntary corrective action is planned. It will combine in situ bioremediation, soil removal, and offsite disposal. The project is expected to be closed out in the summer of 1997.

Operable Unit PX-12: Miscellaneous Chemical Spills and Releases

No further action will be recommended for 8 of the 17 sites and voluntary corrective action is recommended for the remaining 9 sites. A one-

year treatability study is planned to study the ground water at Operable Unit PX-15, the Hypalon Pond. The project is scheduled for completion in Spring 1998.

Operable Unit PX-13: Supplemental Verification Sites

No further action was recommended for 7 of 8 supplemental verification sites. Site 8 in Zone 10, an abandoned landfill, is included in the RCRA Facility Investigation for Operable Unit PX-7 landfill because of its proximity to the sanitary landfills. Decisions of no further action are being pursued for spring 1996.

Operable Unit PX-14: Underground Storage Tanks at Other Locations

No further action was recommended for all sites in this operable unit except for underground storage tank 9 that requires fieldwork. Six additional borings will be drilled to determine the extent of contamination by petroleum hydrocarbons. A treatability study will be conducted at the site of this

underground tank. Ground-water monitoring will be conducted under Operable Unit PX-12. Additional investigations are underway to include bioventing operations. Closeout is expected by summer 1996.

Waste from Environmental Restoration

The assessment activities at 12 of 14 operable units have resulted in the determination that 97 percent of the waste material generated is nonhazardous. In situ remediation will be the primary technology used for remediation of the hazardous waste. As a result, this waste will not be sent to waste management for treatment and disposal.

Pantex has implemented strategies to reduce the amount of waste generated during investigations, as well as the amount of waste handled, treated, or disposed of during site cleanups. A key point of this strategy is minimizing the amount of waste generated

Environmental Restoration Activity Costs

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							<i>Life Cycle**</i>
	<i>FY 1995 - 2000</i>	<i>2005</i>	<i>2010</i>	<i>2015</i>	<i>2020</i>	<i>2025</i>	<i>2030</i>	
Environmental Restoration								
Assessment	5,488	0	0	0	0	0	0	32,930
Remedial Actions	5,641	872	0	0	0	0	0	38,210
Facility Decommissioning								
Facility Decommissioning	0	0	0	10,949	2,737	0	0	68,432
Total	11,130	872	0	10,949	2,737	0	0	139,572

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

during remedial feasibility investigations by using sonic drilling, geophysical and soil gas survey techniques, and other types of surveys that generate minimal waste.

WASTE MANAGEMENT

Pantex operations generate various types of waste. The waste produced by the assembly and dismantlement of weapons includes high explosives and solvents. These operations also produce radioactive process water, debris contaminated with radioactive materials, liquid and solid low-level waste, low-level mixed waste, hazardous waste, sanitary waste, heavy metals, and solvents. Waste is also produced by various support operations, such as the chemistry laboratories, maintenance, and the vehicle fleet.

Pantex does not currently generate any high-level radioactive waste or transuranic waste.

Four drums of transuranic waste generated from an isolated event are being stored at the plant and will be sent to another DOE site for storage until they can be shipped to the Waste Isolation Pilot Plant for disposal.

In 1993, the quantities of waste managed at Pantex were 130 cubic meters of low-level radioactive waste; 37.5 cubic meters of low-level mixed waste; 1615.26 metric tons of hazardous waste regulated by RCRA, the State of Texas, or the Toxic Substances Control Act; and 304 metric tons of sanitary waste. In the future, the volume of operations-generated waste is expected to decrease due to waste minimization efforts and reduced dismantlement levels.

Waste Treatment

For low-level mixed waste, Pantex has developed a site treatment plan, as required by the Federal Facility Compliance Act. The plan

Waste Management Activity Costs

<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>								
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
Treatment								
Low-Level Mixed Waste	1,456	1,466	1,466	1,477	1,512	1,470	1,286	
Low-Level Waste	4,547	4,579	4,579	4,579	4,579	4,579	3,774	
Hazardous Waste	6,280	6,327	7,654	6,325	6,325	6,325	5,060	
Sanitary Waste	140	141	141	141	141	141	113	
Total	12,422	12,514	13,840	12,522	12,557	12,515	10,233	
	2035	2040	2045	2050	2055	2060	2065	Life Cycle**
Treatment								
Low-Level Mixed Waste	454	0	0	0	0	0	0	54,394
Low-Level Waste	443	0	0	0	0	0	0	162,852
Hazardous Waste	0	0	0	0	0	0	0	227,754
Sanitary Waste	0	0	0	0	0	0	0	4,920
Total	897	0	0	0	0	0	0	449,920

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

calls for the development and use of (1) existing onsite facilities, (2) commercial treatment, and (3) onsite treatment using mobile treatment units. The engineering and fabrication of the mobile treatment units will start in FY 1996. Validation and startup will occur in FY 1998, with regular treatment operations beginning in FY 2000. Mobile treatment units are expected to require upgrading every 12 years (in FY 2010 and FY 2022).

A proposed Hazardous Waste Treatment and Processing Facility is designed for low-level waste, mixed waste, and hazardous waste. It will also accommodate the mobile treatment units. Construction is anticipated to be completed in FY 1999, with processing beginning in FY 2000.

Waste contaminated with high explosives is treated at the Pantex Plant burning grounds. Burning ground ash is packaged and disposed of offsite. At present, the burning grounds are being upgraded, with completion expected in FY 1997. Alternatives to burning, such as base hydrolysis and molten-salt extraction, are being explored.

Treatment for low-level radioactive waste consists of stabilization and solidification to meet the acceptance criteria for the Nevada Test Site. Low-level waste is shipped to Nevada Test Site for disposal.

Waste Storage

A RCRA hazardous waste staging facility has been designed and is planned for completion in FY 1996. This facility will provide storage for 1,600 drums of hazardous, mixed, and low-level radioactive waste. The staging facility will require upgrading in FY 2026.

Waste Disposal

For the near future, two quarterly shipments of low-level waste will be shipped to the Nevada Test Site annually. Hazardous waste is shipped monthly and one shipment of low-level mixed waste was made in FY 1994.

NUCLEAR MATERIAL AND FACILITY STABILIZATION

The facility stabilization and maintenance process began at Pantex in 1995. All eight Pantex facilities have begun stabilization. Some of these facilities include a chlorination building, a digester, explosives machining, synthesis buildings, and an electrical substation. It is assumed for the purposes of this report that the remaining facility (a sewage tank) will begin the stabilization process in 1996. This report assumes the stabilization and maintenance process at Pantex will be completed by 2015.

Nuclear Material and Facility Stabilization Cost Estimate

	<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>							<i>Life Cycle**</i>
	<i>FY 1995 - 2000</i>	<i>2005</i>	<i>2010</i>	<i>2015</i>	<i>2020</i>	<i>2025</i>	<i>2030</i>	
Nuclear Material and Facility Stabilization	2,609	2,615	6,547	109	0	0	0	62,007

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

LANDLORD FUNCTIONS

The Department's Office of Defense Programs is the landlord at Pantex and is responsible for associated costs and activities.

site consume approximately 20 percent of the total budget. Program management activities included in the budget for the Environmental Management program consist of general program management, quality assurance, waste minimization, public participation, and activities related to the environment, safety, and health.

PROGRAM MANAGEMENT

Pantex has no separate funding for program management. All program management activities are performed within the budgets for waste management and environmental restoration activities. This estimate employed a factor based on current and anticipated program needs to create an independent cost category. For FY 1995-FY 2000, program management activities at the

FUNDING AND COST INFORMATION

The following tables present funding information and major activity milestones for Pantex.

Program Management Cost Estimates

<i>Five-Year Averages (Thousands of Constant 1995 Dollars)*</i>								
	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
Program Management	4,118	3,544	3,460	5,211	3,659	3,129	2,558	
	2035	2040	2045	2050	2055	2060	2065	Life Cycle**
Program Management	224	0	0	0	0	0	0	133,637

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Defense Funding Estimate

Five-Year Averages (Thousands of Constant 1995 Dollars)*

	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	
Environmental Restoration	11,190	872	0	0	0	0	0	
Waste Management	12,422	12,514	13,840	12,522	12,557	12,515	10,233	
Nuclear Material and Facility Stabilization	2,609	2,615	6,446	0	0	0	0	
Program Management	4,118	3,544	3,460	5,211	3,659	3,129	2,558	
Total	31,901	19,545	23,746	17,733	16,216	15,644	12,791	

	2035	2040	2045	2050	2055	2060	2065	Life Cycle**
Environmental Restoration	0	0	0	0	0	0	0	71,140
Waste Management	897	0	0	0	0	0	0	449,920
Nuclear Material and Facility Stabilization	0	0	0	0	0	0	0	60,957
Program Management	224	0	0	0	0	0	0	133,637
Total	1,121	0	0	0	0	0	0	715,654

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Nondefense Funding Estimate

Five-Year Averages (Thousands of Constant 1995 Dollars)*

	FY 1995 - 2000	2005	2010	2015	2020	2025	2030	Life Cycle**
Environmental Restoration	0	0	0	10,949	2,737	0	0	68,432
Nuclear Material and Facility Stabilization	0	0	101	109	0	0	0	1,050
Total	0	0	101	11,058	2,737	0	0	69,482

* Costs reflect a five-year average in constant 1995 dollars, except in FY 1995-2000, which is a six-year average.

** Total Life Cycle is the sum of annual costs in constant 1995 dollars.

Major Activity Milestones

ACTIVITY	TASK	COMPLETION DATE
Environmental Restoration:		Fiscal Year
Misc Chem Spills and Release Sites	Permit Modification Based on No Further Action/Voluntary Corrective Action	1998
Landfills	Complete Corrective measures construction	1998
Fire Training Area Burn Pits	Permit Modification Based on No Further Action/Voluntary Corrective Action	1995
Firing Sites	Permit Modification Based on No Further Action/Voluntary Corrective Action	1997
Former Cooling Tower	Permit Modification Based on No Further Action	1995
Misc HE/Rad	Permit Modification Based on No Further Action/Voluntary Corrective Action	1997
Hypalon Pond	Permit Modification Based on No Further Action	1995
Ditches and Playas	Permit Modification Based on No Further Action/Voluntary Corrective Action	1997
High Priority Potential Release Sites	Permit Modification Based on No Further Action/Voluntary Corrective Action	1996
OSTP Sludge Beds	Permit Modification Based on No Further Action	1995
Supplemental Verification Sites	Permit Modification Based on No Further Action	1996
Leaking USTs at Bldgs 12-35 and 16-1	Permit Modification Based on No Further Action	1995
Underground Storage Tanks at Other Locations	Permit Modification Based on No Further Action/Voluntary Corrective Action	1996
Zone 12 Ground Water	Complete corrective measures	1999
Burning Grounds	Permit modification based on No Further Action	1996
Waste Management:		Fiscal Year
Proposed Site Treatment Plan	Submit to State of Texas	1995
Hazardous Waste Treatment & Processing Facility	Complete Construction	1999
Mobile Treatment Units	Final Design (Title II) Complete	1996
Hazardous Waste Staging Facility	Complete Construction	1996
All Waste Management Activities	Complete	2030

For further information on this site, please contact:

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