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Remedial Investigation/Feasibility Study for Surface Impoundments Operable Unit Waste Area Grouping 1 Oak Ridge National Laboratory Oak Ridge, Tennessee

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APPENDIX A

HISTORICAL OPERATION OF SURFACE IMPOUNDMENTS

1. INTRODUCTION

Operations at ORNL were originally projected to last 1 year. For this reason, original plans for management of all radioactive liquid wastes generated from plant processes consisted of storage in large, underground Gunite tanks in the North and South Tank Farms. However, as the period and scope of operations at ORNL expanded, the need became apparent for a better liquid-waste management strategy. That strategy ultimately evolved during the period of plant operations. From 1943 until 1948, waste management included waste minimization, separation of waste streams, precipitation, sedimentation, and dilution in natural water systems (i.e., White Oak Creek). These practices included the use of impoundments, constituting SIOU. In 1949, more sophisticated treatment systems and monitoring programs were added to the strategy to limit the discharge of radioactivity to White Oak Creek. SIOU continued to be an integral part of the waste management strategy at ORNL until 1990, when the last impoundments were taken out of service (except for emergency use).

2. WASTE TYPES

Liquid wastes were divided into three primary waste streams: (1) metal wastes, (2) radiochemical wastes, and (3) process wastes. A fourth type of waste was unofficially categorized a "warm waste." Metal wastes were radioactive and primarily contained U with smaller quantities of Pu and Th, which have long half-lives. These wastes were stored for the future retrieval of their transuranic components.

Radiochemical waste primarily contained fission-product radionuclides having half-lives significantly shorter than those of the metal-waste radionuclides. Radiochemical wastes contained ^{137}Cs and ^{90}Sr, which have relatively long half-lives (approximately 30 years), in addition to other radionuclides having short half-lives [i.e., ^{131}I (8 days), ^{141}Ce (28 days), ^{143}Ce (33 hours), ^{103}Ru (41 days), ^{140}Ba (12.8 days), and ^{140}La (40 hours)], as well as various metals and small amounts of organics (Binford and Orfi 1979).

Process waste streams consisted primarily of effluents that contained trace quantities of metals and solvents and little or no radioactivity. Several ORNL operations generated these process wastes: reactor operations, radioisotope processing, hot-cell operations, and general research and development. Process waste streams were the least radioactive of all laboratory liquid wastes except for sewage and stormwater. However, some radiochemical waste entered

the process water system through equipment failure, human error, or other accidents (Browder 1959).

"Warm waste," in use during early operations (Browder 1949), was moderately radioactive and represented a transition between process waste and radiochemical waste. Depending on the level of radioactivity, warm waste was handled in the same manner as either process waste or radiochemical waste.

3. USE OF SURFACE IMPOUNDMENTS

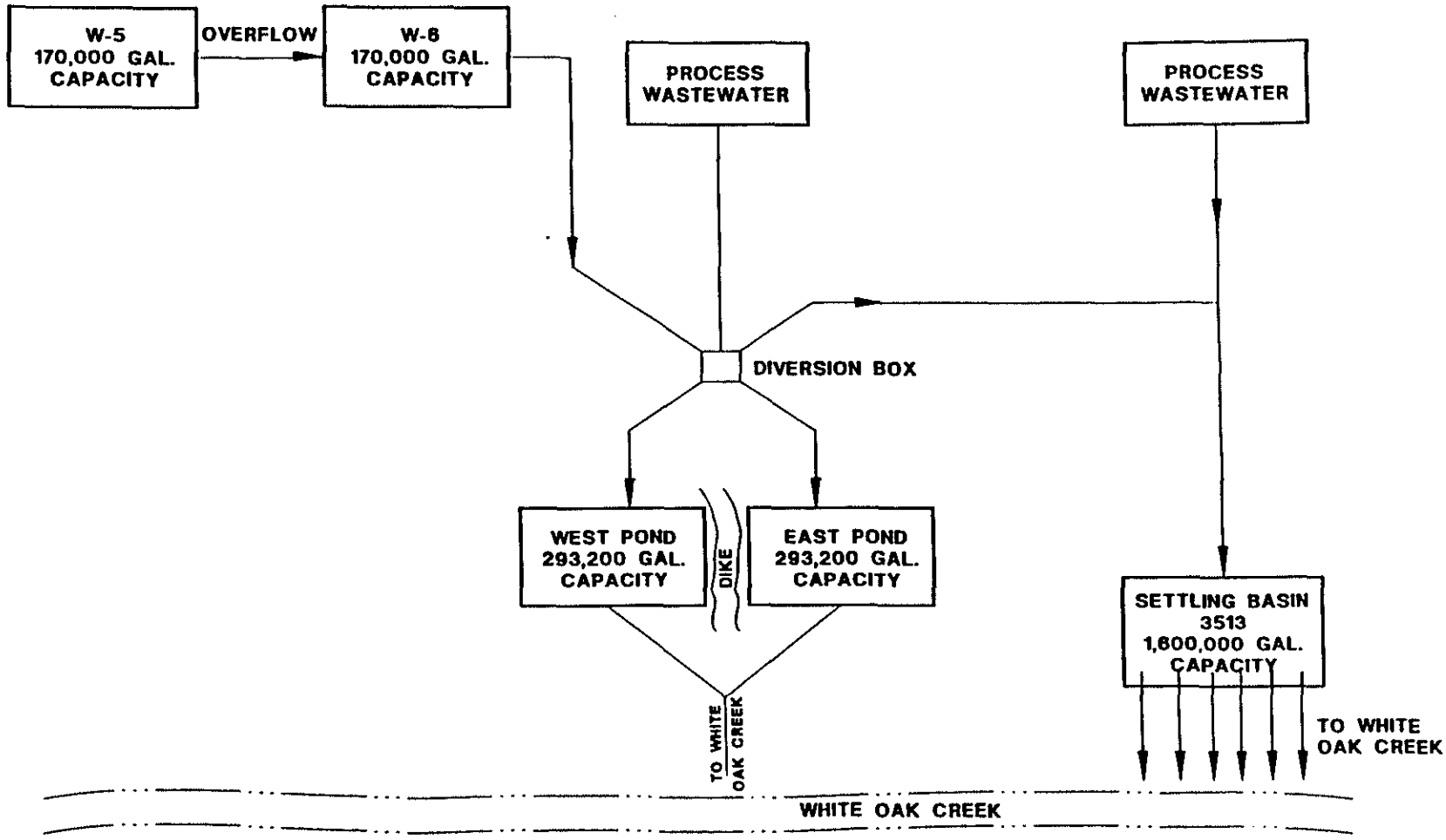
Radiochemical wastes and metal wastes were stored in separate Gunite storage tanks as a first step in the waste management process. However, only radiochemical wastes were discharged from the Gunite tanks to the impoundments. As the waste management strategy evolved, process wastewater was also added to the impoundments.

3.1 INITIAL OPERATION

The first impoundment was Impoundment 3524 (the equalization basin), which was part of the original construction of the facility in 1943. The basin originally consisted of two 1,109,113 L (293,000-gal)-capacity impoundments separated by a berm. These impoundments first were named the east-west basins and served as backup storage for Gunite tanks W-4 and W-5 in the South Tank Farm. Wastewater was stored in the impoundments to allow for decay of short-lived radionuclides before discharge into White Oak Creek.

3.2 1944–1949 OPERATIONS

In 1944, Impoundment 3513—a settling basin—was added to provide settling space for precipitated activity and a facility for diluting partially decayed and dissolved radioactive wastes with large volumes of nonactive waste (process wastewater) before discharge to White Oak Creek. Figure A.1 shows a flow schematic of the waste treatment scheme in 1944. The supernatant from the Gunite tanks was discharged to a diversion box located north of Impoundment 3524 (the east-west basins). Monitored wastes considered to have elevated levels of radioactivity were diverted to the east-west basins for storage to allow further decay. Waste streams having lower activity levels were discharged into Impoundment 3513 (Browder 1949).



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Schematic of operations
Surface Impoundments OU 1944-1948

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Oak Ridge, Tennessee

Fig. A.1

#01/10NOV94/1-1

The supernatant diverted into Impoundment 3513 entered through six pipes along the north side of the impoundment. Fly ash and lime soda were added to remove an additional 80–85 percent of the radioactivity from the waste solutions.

Based on the analysis of historical photographs (Figs. A.2 and A.3), this impoundment originally contained a baffle system of four flow channels that ran north-south and had a series of flow-over weirs. The baffles created basin retention times sufficient to allow the particulates to settle; only the uppermost portion of the water column would flow into the next cell. These baffles were removed in the late 1950s, probably in 1957 when the wastewater facility was built. The effluent from this facility was discharged into the northwest corner of the impoundment through a single outfall.

3.3 1949–1954 OPERATIONS

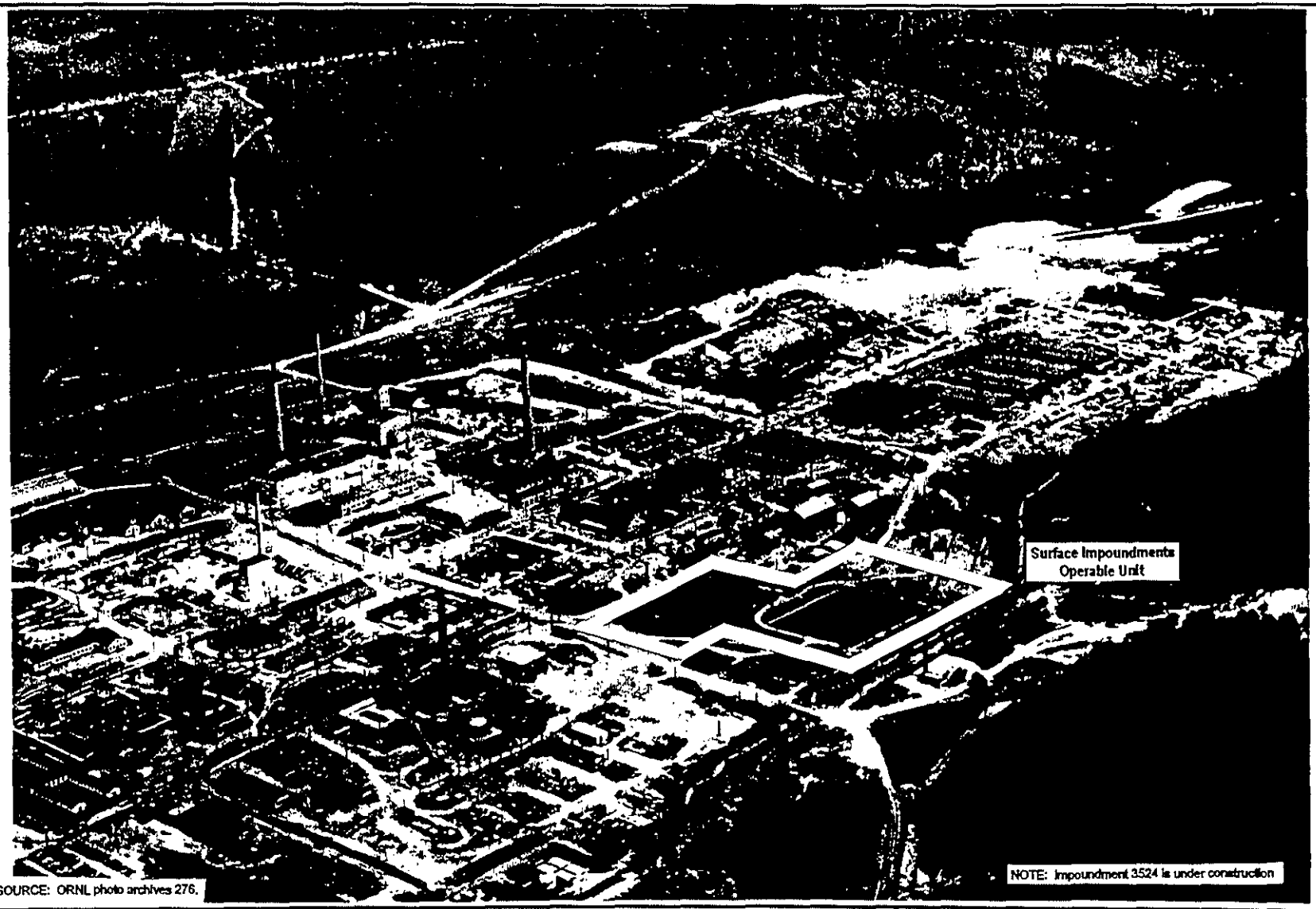
In June 1949, an evaporation stage was added to the process for wastes stored in the Gunite tanks. A pot-type evaporator concentrated the waste. The evaporator condensate then was discharged to the diversion box, which directed wastewater to either Impoundment 3524 (the east-west basins) or Impoundment 3513 (the settling basin). In 1953, the berm dividing the east-west basins was removed to increase the storage capacity of the impoundment (Coobs 1986). In 1954, the evaporator was taken out of service, and the impoundments ceased to receive wastes from the Gunite tanks. The flow schematic for this period of operation is shown in Figure A.4.

3.4 1954–1957 OPERATIONS

From 1954 through 1957, Impoundments 3524 and 3513 received process wastewater from various facilities. The process wastewater was monitored, and waste having an activity level greater than 25,000 counts/min•mL was diverted to Impoundment 3524 for storage to allow for decay of radionuclides (Horton 1984). An overflow line was added to the south berm of Impoundment 3524 to allow discharge of overflow to Impoundment 3513 (Browder 1959). The flow schematic for this period of operation is shown in Figure A.5.

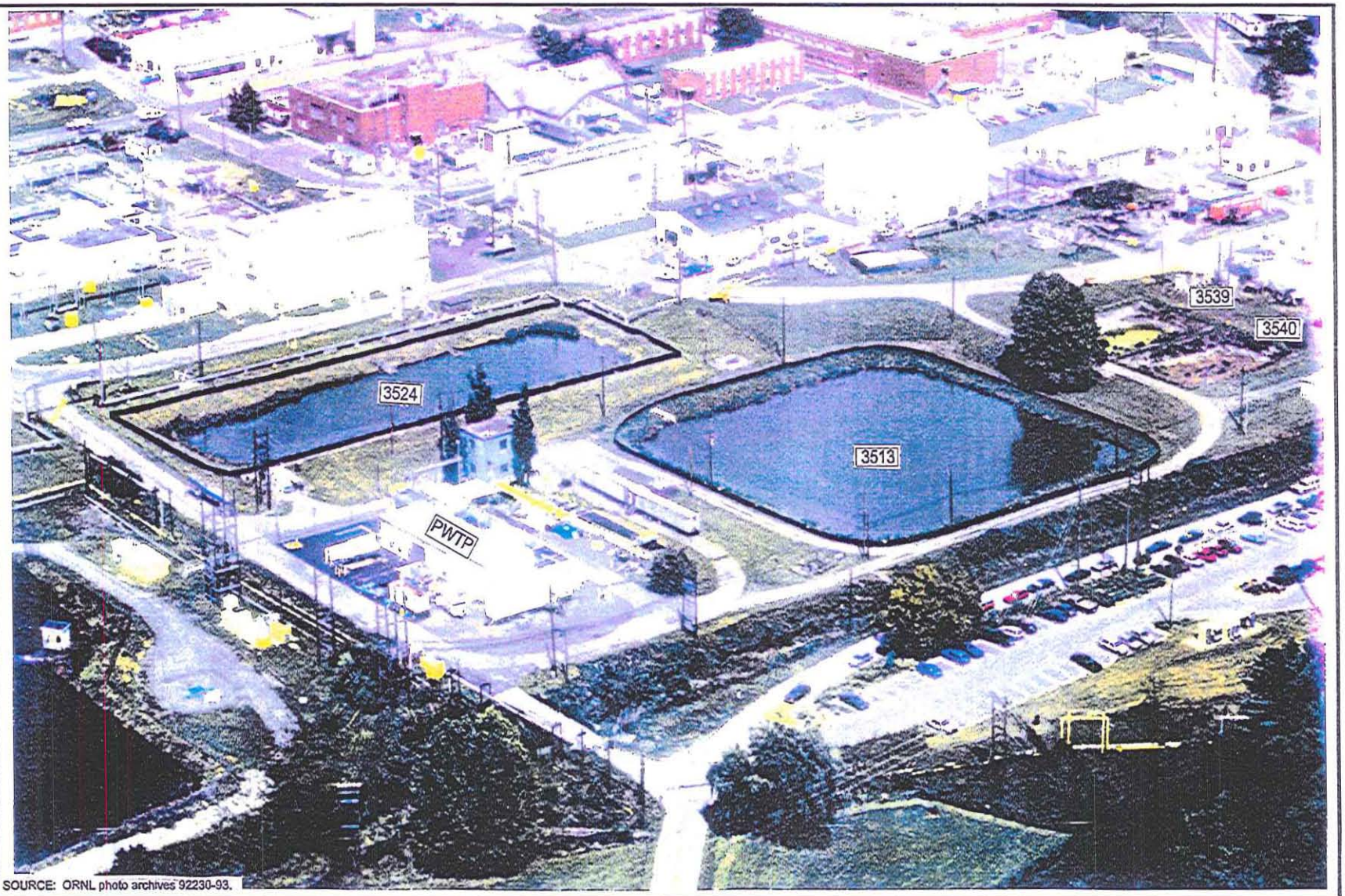
3.5 1957–1976 OPERATIONS

In 1957, a newly completed wastewater treatment plant began operations to reduce the level of radioactive contamination in the low-activity process wastewater discharged to White Oak Creek. In January 1959, an automatic diversion valve fed the entire process wastewater flow to the treatment plant whenever the level of radioactivity in the waste exceeded 1.3 mCi/L. When the activity level was below the set point, the automatic valve diverted the waste around the



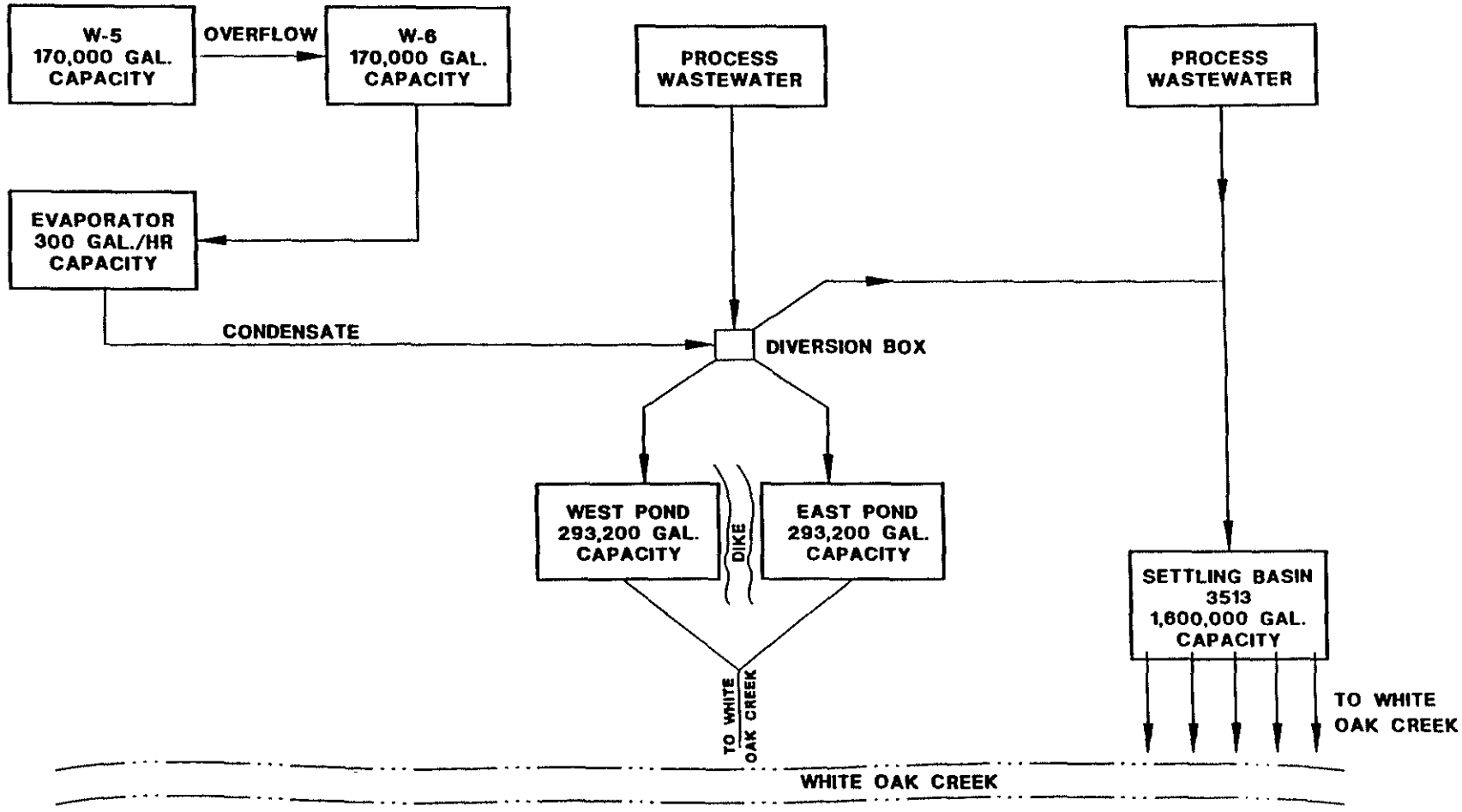
SOURCE: ORNL photo archives 276.

JE	Fig. A.2	1942 aerial view of Surface Impoundments Operable Unit DOE - ORNL, WAG 1, Surface Impoundments ~ Oak Ridge, Tennessee	DOCUMENT ID: 35H830 4002-15 / FS	DRAWING ID: 95-11356.CDR	DRAWING DATE: APRIL 21, 1995 Ba



SOURCE: ORNL photo archives 92230-93.

JE Fig. A.3	1993 aerial view of Surface Impoundments Operable Unit DOE - ORNL, WAG 1, Surface Impoundments - Oak Ridge, Tennessee	DOCUMENT ID: 35H830 4002-15 / FS	DRAWING ID: 95-11357.CDR	DRAWING DATE: APRIL 21, 1995 Ba



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Schematic of operations
Surface Impoundment OU 1949-1954

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Oak Ridge, Tennessee

Fig. A.4

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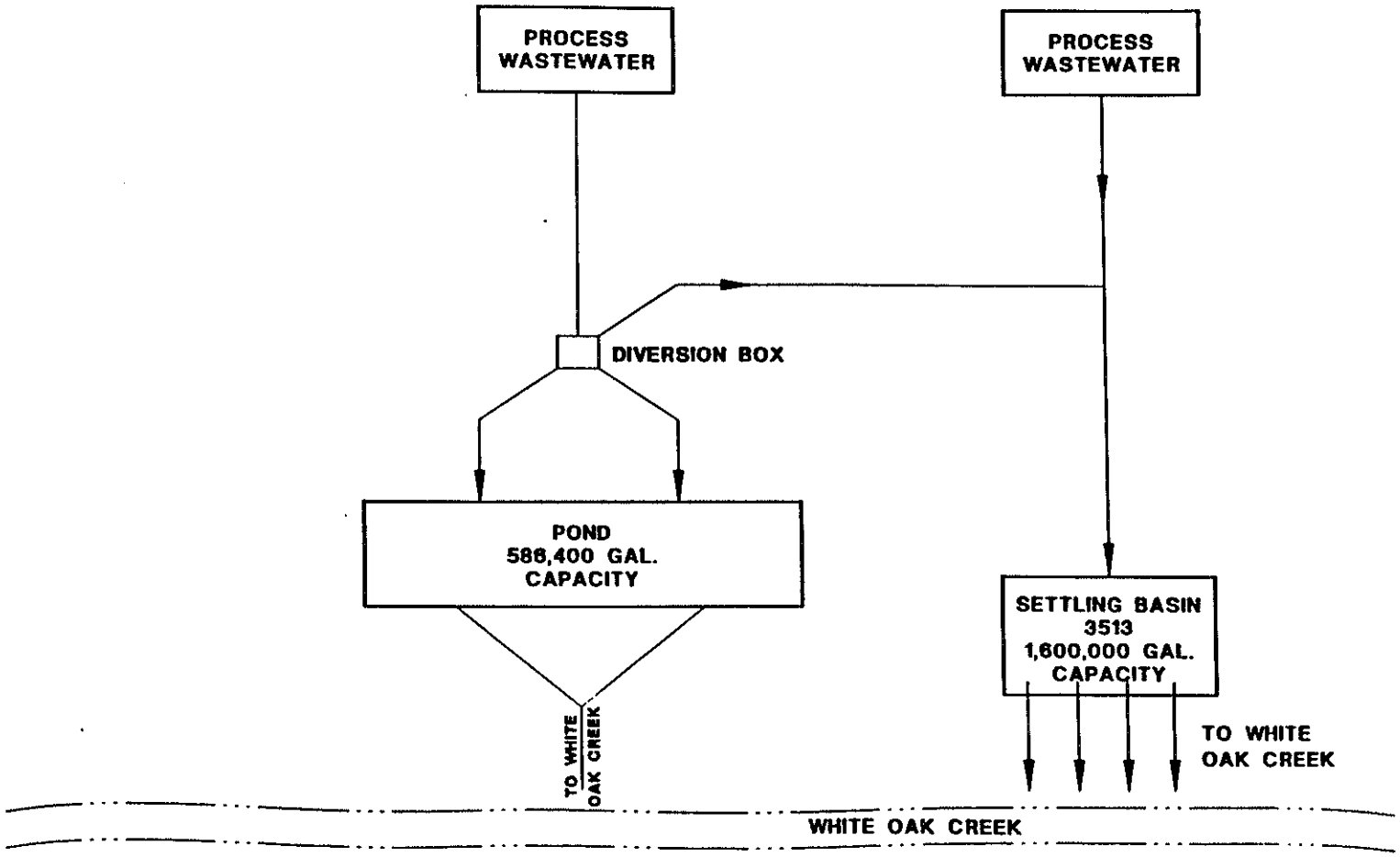

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Schematic of operations
Surface Impoundments OU 1954-1957

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Oak Ridge, Tennessee

Fig. A.5

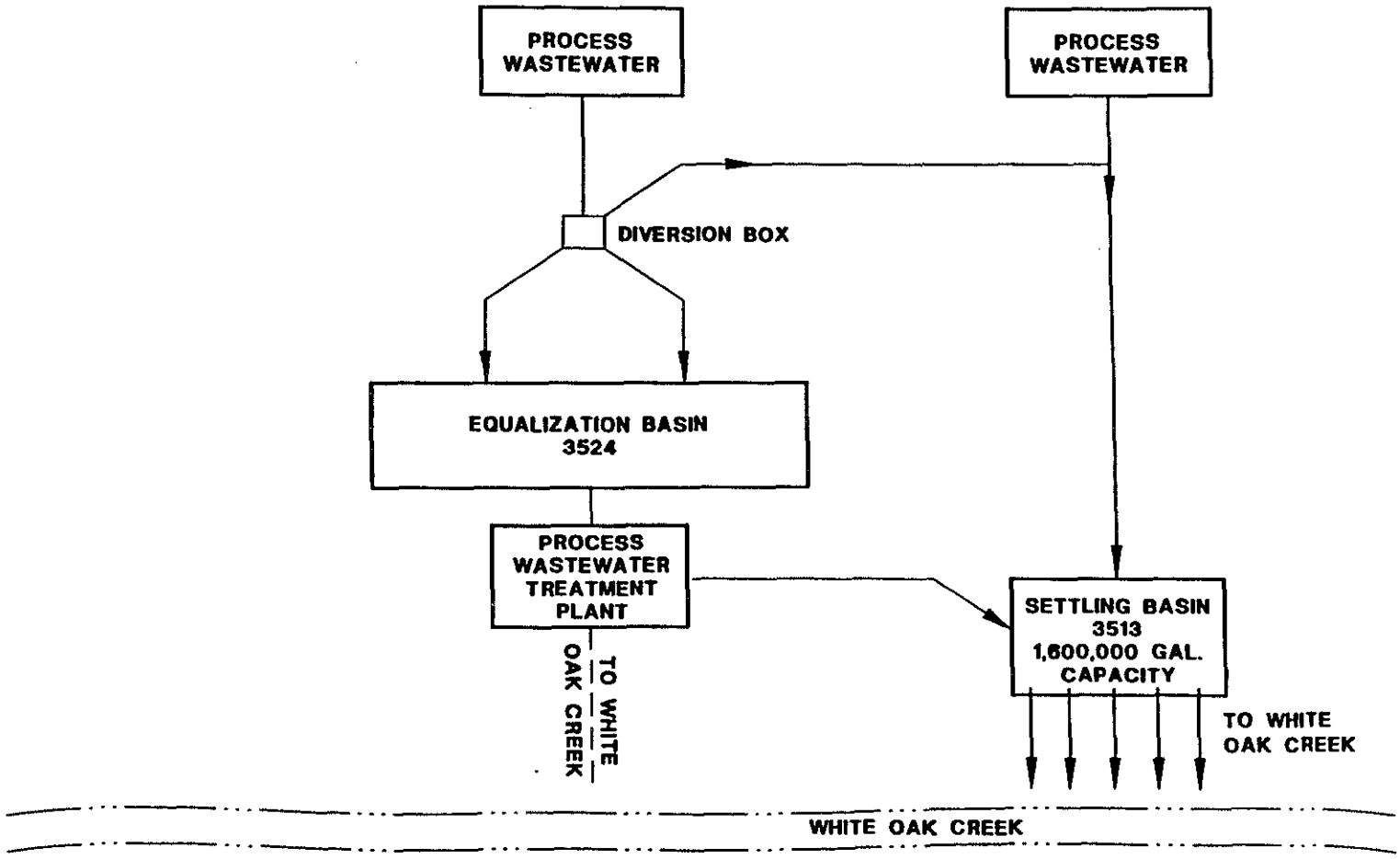
A603/11NOV94/1

treatment plant and to Impoundment 3513. Impoundment 3524 was used as an equalization basin for the wastewater treatment plant (Fig. A.6). This impoundment was expanded westward in 1959 and the height of the berms was raised to increase the holding capacity of the impoundment. The 2,649,759-L (700,000-gal)-capacity equalization basin minimized fluctuations in the composition of the plant influent and supplied waste to the treatment plant as needed. The effluent from the plant was discharged into Impoundment 3513, where particulates were allowed to settle before discharge into White Oak Creek (Browder 1959; Coobs 1986).

In October 1964, two 655,000-L (170,000-gal) waste impoundments (3539 and 3540) were constructed to hold process wastewater from the Building 4500 complex. These impoundments were used as a dual-surge basin system designed to alternately receive and discharge process waste streams. If the concentration of radioactivity were to reach a certain level, the water would be pumped to Impoundment 3524 for treatment in the wastewater treatment plant. Otherwise, the wastes would be released into White Oak Creek (Coobs 1986). During the plant's operation, all of the wastes were diverted to White Oak Creek because of their low levels of radioactivity. The flow schematic for this period of operation is shown in Figure A.7.

3.6 1976–1990 OPERATIONS

Operation of the wastewater treatment plant ceased in 1976 when a new process wastewater treatment plant came into operation. Impoundment 3513 was removed from service in 1976, shortly after the original wastewater treatment plant ceased operations. Impoundment 3524 continued to be used as an equalization impoundment for the new process wastewater treatment plant. It continued operations until 1989, when tanks were constructed to store the incoming waste. Impoundments 3539 and 3540 were removed from service in 1990, when the effluent from the Building 4500 complex was rerouted to the waste storage tanks. Impoundments 3524, 3539, and 3540 are currently used for emergency storage of wastes if the storage tanks are full. New storage tanks are scheduled to be constructed to provide emergency storage; when this is accomplished, the impoundments will be removed from service.



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Schematic of operations
Surface Impoundments OU 1957-1964

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Fig. A.6

A-14

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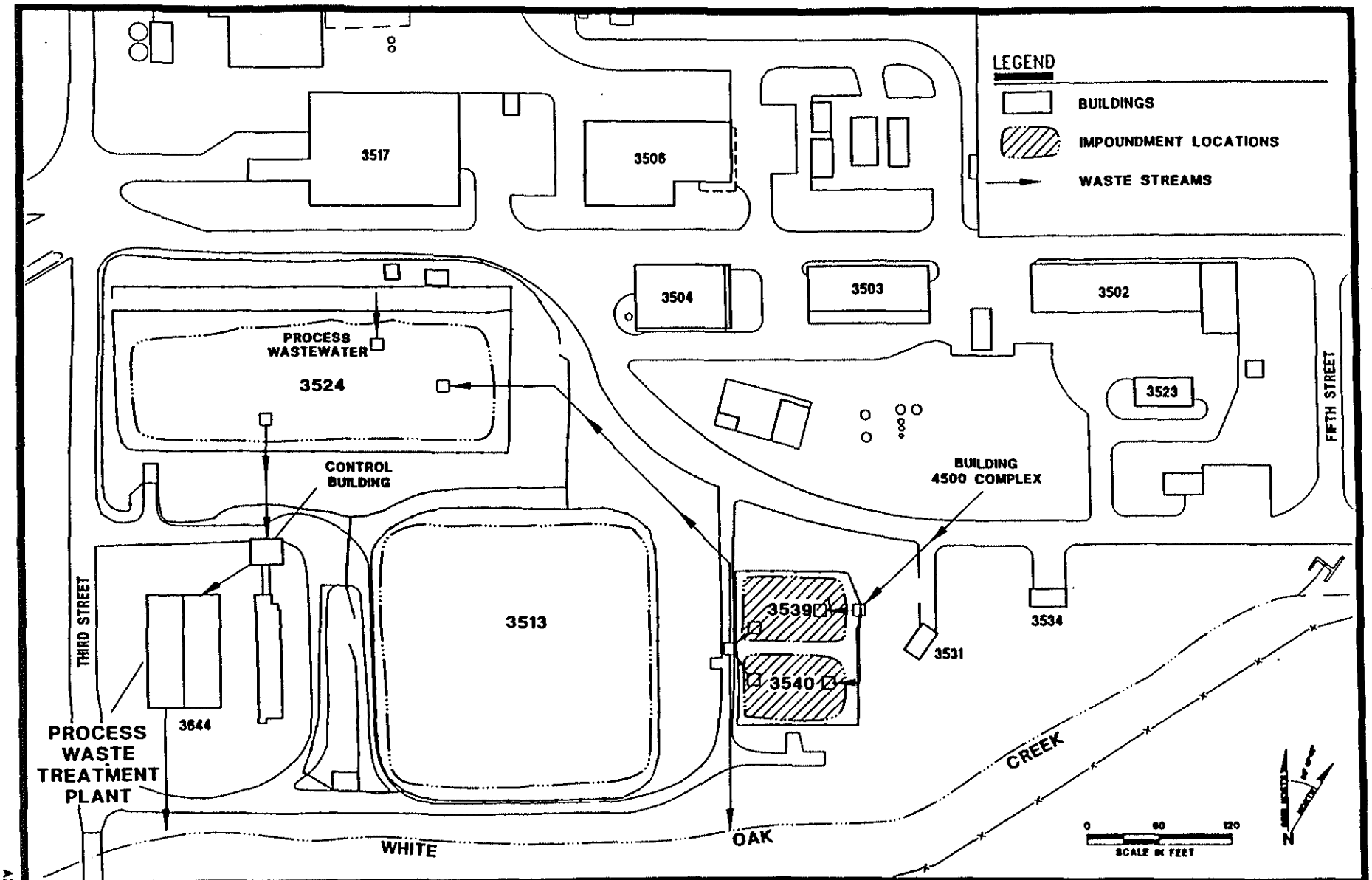

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Schematic of operations
Surface Impoundments OU 1964-1989
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Fig. A.7

A2036/14NOV94/118

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APPENDIX B

FIELD INVESTIGATION

1. FIELD INVESTIGATION

Interpretations and summaries presented in the SIOU field investigation are based on data from various historical investigations conducted to define the contamination at the individual impoundments. This information is supplemented by additional data collected as part of this recent investigation to address data gaps identified as part of the review of the historical investigation.

This appendix summarizes all available information addressing the nature and extent of contamination of the various environmental media in the SIOU. This includes a detailed discussion of the regulatory initiative and initial project scoping activities that explain how the SIOU is integrated into the ORNL ER Program. Chapter 1 discusses the regulatory initiative and project scoping activities. Chapter 2 summarizes all historical investigations addressing contaminated media at the SIOU. Chapter 3 summarizes supplemental sampling of contaminated media conducted during 1994 investigations to address data gaps identified in the historical investigations.

The information to identify the contaminants of potential concern and the concentrations of the contaminants of potential concern is derived from several investigations summarized in this appendix. No single investigation completely evaluates contaminants of potential concern for any individual impoundment or for all impoundments. In order to support the risk assessments and the FS, it is necessary to provide a single set of information for the contaminants of potential concern in each impoundment. A detailed discussion of these contaminants of potential concern and the computations and technical assumptions is available at the DOE Information Resource Center in central files.

2. REGULATORY INITIATIVE

Until 1984, all environmental compliance activities at ORNL and other ORR facilities followed guidelines established by the Atomic Energy Commission (now DOE) under the authority of the Atomic Energy Act of 1954. EPA was given jurisdiction on many environmental matters previously regulated by Atomic Energy Commission and its successor agencies based on a court decision in April 1984. EPA issued a permit on September 15, 1986, to DOE under Section 3005(c) of RCRA that mandated that all facilities on the ORR incorporate RCRA corrective action programs to investigate and clean up hazardous waste problem areas. When the RCRA permit was issued, EPA granted the Tennessee Department of Health and Environment (TDHE) (now TDEC) primacy to administer its own RCRA-regulated program.

In 1987, TDHE and EPA evaluated whether Impoundments 3524, 3539, and 3540 should meet the hazardous waste permitting requirements for RCRA. Impoundment 3513 had stopped receiving waste in 1977, before RCRA requirements were legislated.

The impoundments would be required to meet RCRA permitting requirements if the impoundments had been used to store RCRA hazardous waste after November 19, 1980. Samples of the discharges to the impoundments were analyzed to determine if these waste streams represented hazardous waste. In order to determine if hazardous waste had been disposed into the impoundments during previous operations, process knowledge concerning the standard operations at the plant and the types of wastes likely to be generated by the previous research and development studies were evaluated. In addition, sludge and surface water samples were taken from the impoundments. In July 1987, TDHE determined that the impoundments are not subject to interim status requirements under RCRA since they have not stored hazardous waste since November 19, 1980 (Tiesler 1987).

ORR was proposed for inclusion on CERCLA NPL November 21, 1989 [54 *Federal Register* (FR) 48184]. Specifically, CERCLA [Sect. 120(e)(1)] requires that federal facilities on the NPL go through the CERCLA investigation process to confirm and quantify the nature and extent of contamination, and then evaluate appropriate response actions to remedy releases or threatened releases of hazardous substances to the environment from all facilities. Once ORR was placed on the NPL, CERCLA became the primary regulation for investigating and remediating SIOU. RCRA requirements and other applicable regulations are incorporated in the CERCLA process. This RI/FS report is being developed as part of the CERCLA process to satisfy these requirements.

Because of the number of regulatory programs and regulatory agencies involved, DOE, EPA, and TDEC have negotiated an FFA for ORR that satisfies the requirements for an interagency agreement under Section 120 of CERCLA, 42 USC Para. 9620 (DOE 1992g). The purpose of the FFA is to ensure that remedial activities, including assessments, characterization, alternative selection, and implementation, will meet the integrated requirements of CERCLA and RCRA, as well as the requirements of the NEPA as implemented under DOE Order 5400.4. To establish these requirements, it was agreed that "integrated" documents would be developed to satisfy all applicable or relevant and appropriate requirements (ARARs). To facilitate consistency in integrating the various requirements into documents, DOE-Oak Ridge Operations established an environmental restoration division. Under the direction of this division, the ORR O&M contractor, Energy Systems appointed site program management teams to each DOE-Oak Ridge Operations facility to manage the daily operations specific to each facility's program.

To better coordinate the DOE ER Program, DOE and TDEC formulated an oversight agreement/agreement-in-principle. As stated in the final oversight agreement (Tennessee and DOE 1991), TDEC was designated lead regulatory agency for RCRA and shares an oversight role as a third party to the FFA in the CERCLA process. This agreement (1) ensures compliance with the applicable state and local environmental laws and (2) ensures Tennessee citizens that their health, safety, and environment are protected through an independent enforcement agency.

2.1 SCOPING OF FIELD INVESTIGATIONS

Two workshops were conducted to evaluate the current data available for the surface impoundments and to determine what additional data would be required. The meeting results are documented in two meeting reports (CDM Federal Programs 1994a; 1994b). DOE and its contractors, EPA, and TDEC attended the meeting.

It was determined that additional data was required for the following purposes:

- estimation of risk associated with exposure of human receptors and ecological populations to chemicals associated with the impoundments,
- evaluating the potential for incorporating the sediments into a grout mixture, and
- modeling leaching of contaminants from the sediments for the purpose of evaluating migration of contaminants through groundwater.

The amount of radionuclides present in the impoundments presents a significant potential risk to human health. Therefore, the impoundments must be remediated regardless of the risk associated with exposure to chemicals. However, EPA felt that the baseline risk assessment should assess risks associated with exposure to chemicals and radionuclides. Therefore, sediments were collected from all the impoundments and analyzed for target analyte list (TAL)/ target compound list (TCL) constituents in addition to polychlorinated biphenyls and pesticides. The data were also used for screening purposes to determine if the sediments may be classified as RCRA and/or Toxic Substances Control Act hazardous wastes.

Fish were collected from the impoundments and analyzed for both chemical and radioactive constituents. The data were used to evaluate potential risk to piscivorous wildlife feeding in the impoundments.

Sediment samples were analyzed for various physicochemical parameters including carbonate, sulfate, ortho-phosphate and total organic carbon (TOC). Data were collected to evaluate the groutability of the sediment. Although grouting was not evaluated as a potential remedial action (given that sediment samples were being collected for other purposes) obtaining this additional information would not delay the project.

Data were collected for the purposes of modeling contaminant migration through groundwater. Interstitial water samples were analyzed for radionuclides to determine the concentrations that may leach into groundwater. In addition, samples were taken in White Oak Creek and analyzed for chemical and radionuclide constituents. The data were used to validate the groundwater models used in the baseline risk assessment.

2.2 ORR ER PROGRAM

EPA's participation in ORNL environmental restoration activities began in September 1986 when EPA issued its RCRA permit for the ORNL Hazardous Material Storage Area, Building 7652. This permit gave EPA enforcement authority for ORNL corrective action through RCRA Section 3004(u). As the first phase of the RCRA Section 3004(u) Corrective Action Program, ORNL submitted to EPA a RCRA Facilities Assessment that identified approximately 250 solid waste management units. Because of the large number of sites, ORNL proposed grouping geographically contiguous or hydrologic unit-defined solid waste management units into waste area groupings. This concept initially resulted in 20 waste area groupings, including Waste Area Grouping 1.

2.3 WASTE AREA GROUPING AND OPERABLE UNIT STRATEGY

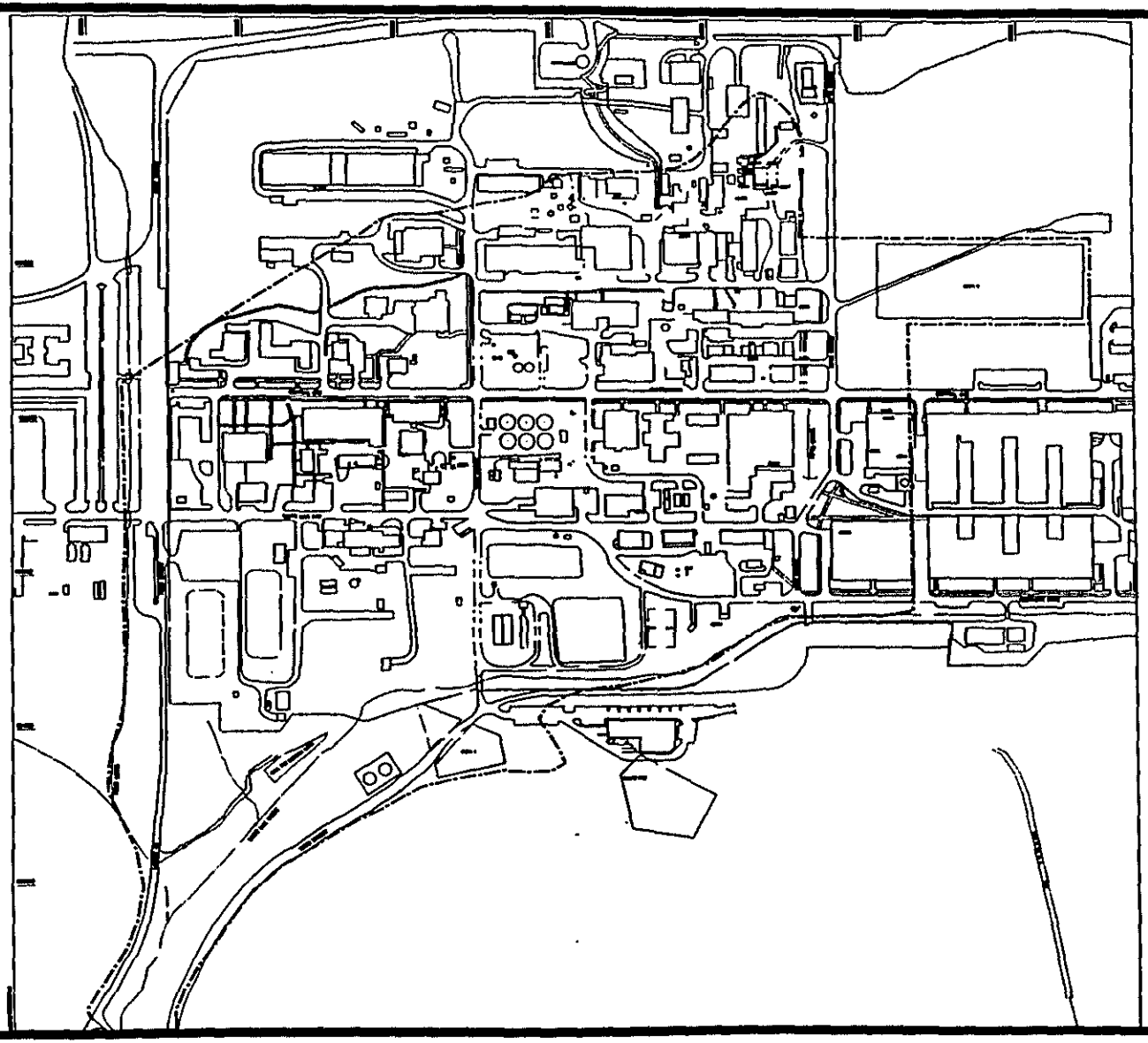
SIOU is within Waste Area Grouping 1 at ORNL, which includes most of the original ORNL research and development facilities and associated waste management units. Waste Area Grouping 1 is approximately 150 acres (60.7 ha) (Fig. B2.1). To address the complex remediation management issues that result from the large number of sites within a waste area grouping, the concept of the operable unit was developed in accordance with the FFA (DOE 1992g). According to the FFA, an operable unit is a discrete remedial action that contributes to the final remediation of a facility or site. Each operable unit should be a discrete, identifiable action with a controllable scope. Where possible, the physical media and waste units in each operable unit should be geographically distinct from those in other operable units to minimize the potential for recontamination. However, because of the complexity of Waste Area Grouping 1, some overlap of operable units is inevitable and potentially desirable to assure the final remediation of Waste Area Grouping 1.

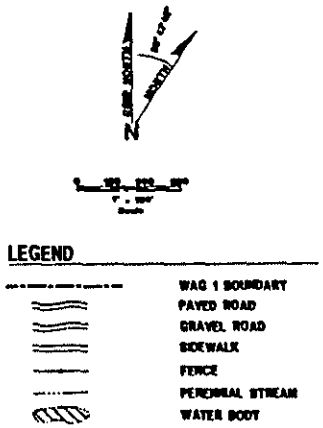
An operable unit is a flexible definition that can be used to focus remediation of specific site issues. However, an operable unit is not defined with firmly established elements or boundaries. The boundaries of the operable unit can be optimized on the basis of new information or alternatives evaluation.

The Waste Area Grouping 1 RI Plan indicated that Waste Area Grouping 1 RI data would be collected in phases (Energy Systems 1989). The results of the Waste Area Grouping 1 Phase I RI are documented in three reports: the operable unit Strategy Document (DOE 1992a); the Preliminary Risk Assessment Report (DOE 1992h); and the Site Characterization Summary Report (DOE 1992b, 1992c, 1992d, 1992e, and 1992f). On the basis of information collected and documented in the Site Characterization Summary Report, 10 operable units have been defined for Waste Area Grouping 1, as described in the operable unit Strategy Document and shown in Figure B2.2.

For purposes of this report, SIOU consists of four impoundments: Waste Holding Basin 3513, Equalization Basin 3524, the Process Waste Pond (north) 3539, and the Process Waste Pond (south) 3540, and the adjacent surface soils. Adjacent surface soils are defined as within radiological hazard warning fences which surround the impoundments. Soils not included within the final remedial action will be addressed under the 3000 Watershed Soils Operable Unit.

SIOU also does not include evaluation of the groundwater in the vicinity except to determine the effect of groundwater on the potential remediation techniques selected for SIOU.





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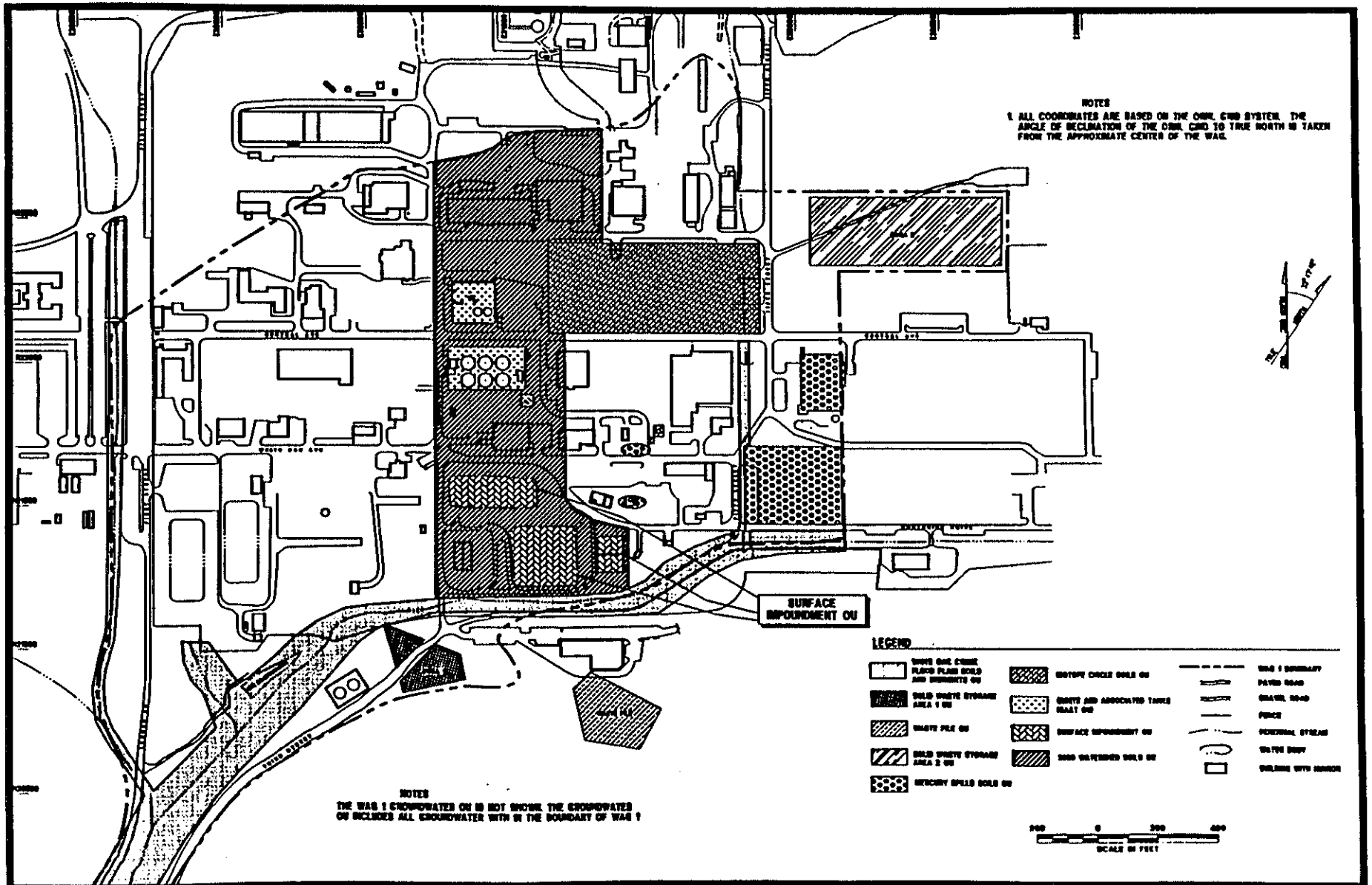
Waste Area Grouping 1 boundaries

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Fig B2.1.

A2029/16NOV94/550



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Operable units in Waste Area Grouping 1 at ORNL

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Fig B2.2.

A573/26OCT93/7900

Remediation of the groundwater will be addressed under a groundwater operable unit because remedial technologies are unique to the groundwater medium.

3. HISTORICAL INVESTIGATIONS

This appendix evaluates the nature and extent of contamination associated with SIOU, based primarily on information obtained from published reports of previous investigations. In presenting previously published information, a brief summary is provided of the scope and approach of the investigations, and the relevant results are summarized and evaluated. The reader is referred to the published reports for details on previous investigations. As a result of the evaluation of the historical information, additional data needs were identified necessary to support the risk assessment and FS. Additional sampling of environmental media was conducted as part of the 1994 field investigation, and a summary of this field sampling effort and results is also presented.

Evaluation of the nature and extent of contamination can address contamination at the source as well as in various environmental media, including soils, groundwater, surface water, and sediments. The "source" at SIOU is predominantly sediments accumulated in the ponds. Surface water present in the impoundments in contact with the sediment is included in the discussion of the "source" for each pond. However, the impoundments are open systems where there is a constant exchange between the surface water and groundwater, as well as the influx of precipitation.

The evaluation of the nature and extent of soil contamination is limited to the immediate proximity of the impoundments. However, the selected remedial alternative may provide for the treatment of the impoundment sediments without disturbing the nearby soils. In that case, nearby contaminated soils could be included in the 3000 Watershed Soils Operable Unit or another operable unit could be defined. (Refer to Sect. 1.3 for a discussion of the concepts associated with the Waste Unit Grouping and the Operable Unit Strategy.)

Because remediation of contaminated groundwater in Waste Area Grouping 1 is addressed under a separate groundwater operable unit, additional characterization of the groundwater is planned under the Waste Area Grouping 1 Groundwater Operable Unit. For the purpose of the RI/FS for SIOU, the need to address the nature and extent of groundwater contamination is limited to evaluating the effect of groundwater on the potential remediation method selected. Data available from the Site Characterization Summary Report (DOE 1992b) are considered adequate for this purpose.

3.1 PREVIOUS INVESTIGATIONS

3.1.1 Impoundment 3524

Braunstein et al. (1984) conducted the first reported investigation of Impoundment 3524. The investigation focused solely on characterizing the radiological content of the sediment. Francis and Sealand (1987a) conducted additional sampling in Impoundment 3524 to further characterize the radiological content of the sediment. Kitchings and Owenby (1986) collected sediment samples from Impoundment 3524 for testing following the extraction procedure (EP) Toxicity procedures for metals, pesticides/herbicides, and organic constituents. To provide additional information on the chemical composition of the sediment in Impoundment 3524, samples of sediment were collected as part of the 1994 RI for chemical analysis of inorganic and organic constituents, as well as conducting additional radiological analyses. Chapter 4 presents results of the 1994 RI sampling.

3.1.1.1 Sediments

Radiological contaminants. Braunstein et al. (1984) investigated Impoundment 3524 in support of evaluation of alternatives to continued operation of the impoundment. The investigation focused on obtaining an estimate of the radioactivity in the sediments to support evaluation of strategies for the eventual decontamination and decommissioning (D&D) of the impoundment.

For the investigation, 24 cores of impoundment sediment were collected using a 7.25-cm (2.8-in.) inside diameter plastic tube. The plastic tube was driven into the sediment until refusal. In most cores the tube reportedly penetrated to the natural clay underlying the impoundment. Upon withdrawal of each tube, excess water was drained from the tube, the top was cut level with the top of the sediment as determined visually, and both ends were capped. All tubes were frozen to maintain sediment stratification. Table B3.1 lists the length and calculated volume of each core.

The thickness of the sediment layer varies with the location in the impoundment with the thickest deposits present in the eastern and northern portions. This is consistent with the presence of rock outcrop at the western end of the pond preventing excavation. The relatively thicker deposits along the northern portion may be related to the presence of the inlet pipes there. Braunstein et al. (1984) estimated the sediment volume in Impoundment 3524 as 1.06×10^3 m^3.

To prepare the sediment samples for analysis, holes were drilled through the wall of the plastic tube with a cork borer and a cylindrical section of the core was removed by driving the cork borer completely through the core. The volume of core extracted using the cork borer was

Table B3.1. Length of cores from Impoundment 3524

Core number	Core length cm (ft)	Core volume liters	Core number	Core length cm (ft)	Core volume liters
1	40.6 (1.33)	1.676	13	34.9 (1.14)	1.441
2	34.3 (1.13)	1.416	14	29.2 (0.96)	1.205
3	68.6 (2.25)	2.832	15	43.2 (1.42)	1.783
4	83.8 (2.75)	3.459	16	139.7 (4.58)	5.767
5	64.8 (2.13)	2.675	17	134.6 (4.42)	5.557
6	45.7 (1.50)	1.867	18	33.0 (1.08)	1.362
7	26.7 (0.88)	1.102	19	49.5 (1.62)	2.043
8	31.8 (1.04)	1.313	20	38.1 (1.25)	1.573
9	48.9 (1.60)	2.019	21	55.9 (1.83)	2.308
10	106.7 (3.50)	4.405	22	59.7 (1.96)	2.464
11	95.3 (3.13)	3.934	23	29.2 (0.96)	1.205
12	27.9 (0.92)	1.152	24	20.3 (0.67)	0.838

Source: Braunstein et al. 1984.

determine to be 24 cm^3. One sample was taken 10 cm (4 in.) from the top and from the bottom of each core. In addition, the core was screened using radiation survey instruments, and additional samples were collected from any area with "higher-than-average activity." If zones of higher activity were not found, a sample was taken from the midpoint of each core except for very shallow cores where only the samples from the ends were taken. Each sample was allowed to air dry and the dry weight was recorded. The dry sediment samples were analyzed for ^{241}Am, ^{137}Cs, ^{60}Co, ^{154}Eu, ^{90}Sr, and gross alpha activity. The reported results for each radioisotope's activity are discussed in Chapter 5.

Braunstein et al. (1984) estimated the radionuclide inventory in the impoundment on the basis of volume of sediment instead of weight to avoid the uncertainty in the variation of the density of the sediment with location and depth in the impoundment. Since the sample volumes were 24 cm^3, this is a straightforward approach for estimating inventory. The activity of each radionuclide per cubic centimeter for each sample was calculated from the information in Table B3.2. Activities reported as less-than-or-equal-to quantities were considered absolution values (i.e., a value reported as $\leq 2.00 \times 10^2$ is considered 2.00×10^2). The estimated inventory for each radionuclide was calculated from the product of the weighted average activity and the estimated sediment volume (1.06×10^3) m^3, and is also shown in Table B3.2.

Francis and Sealand (1987a) conducted additional sampling of sediment in Impoundment 3524 to determine waste classification in support of corrective actions. Grab samples of sediment were collected from 10 locations in Impoundment 3524 using a 3-L stainless-steel dipper attached

Table B3.2. Estimated inventory of radionuclides in Impoundment 3524

Radionuclide	Total activity	
	(GBq)	(curie)
Gross alpha	406	11
Cesium-137	3,774	102
Europium-154	33.5	0.9
Americium-241	170	4.6
Cobalt-60	83.2	2.2
Strontium-90	1,073	29

Source: Braunstein et al. 1984.

to a 12-ft-long pole. A single composite sample was prepared for analysis by air drying the individual sediment samples and mixing aliquots of equal weights.

Francis and Sealand (1987a) provided a second estimate of the inventory based on the reported activity for the composite sample and the estimated sediment volume of 1×10^6 L reported by Braunstein et al. (1984). Francis and Sealand also used in the calculation the bulk density and water content values derived from data reported by Stansfield and Francis (1986a) for Impoundment 3513. The estimated inventory is reported in Table B3.3. The inventory estimated by Francis and Sealand is approximately a factor of 2 lower than the inventory reported by Braunstein et al. Since the estimated sediment volume is the same, the difference in inventory could be attributed to the sampling approach used by Francis and Sealand that preferentially collects samples from the upper zones as well as the assumptions concerning bulk density and water content required for the calculation.

The statistical treatment of the sediment concentrations presented by Braunstein et al. (1984) and Francis and Sealand (1987a), along with the data collected by the 1994 sampling event are presented in Chapter 5.

Metals contaminants. Prior to the current investigation the only previous study to address the metal composition of the sediments in Impoundment 3524 was Kitchings and Owenby 1986. Kitchings and Owenby reported that sediments were collected during January and February 1986 to determine the EP Toxicity status of seven separate surface impoundments at ORNL, including Impoundment 3524. The sediment samples were composited for each impoundment and then split into three portions, which were extracted by EP Toxicity procedures and analyzed for metals, pesticides/PCBs, and all organics except volatiles. Sediment samples were not analyzed for total metal concentrations. Results for metals indicated no values for any analyte exceeded the EP Toxicity limits. These data are, therefore, not reproduced in this report.

Table B3.3. Estimated inventory of radionuclides in Impoundment 3524

Radionuclide	Estimated inventory[a]	
	GBq	(Ci)
Gross Alpha	160	4.2
Gross Beta	2,900	78
Cesium-137	1,700	45
Europium-152	14	0.4
Europium-154	5.3	0.1
Plutonium-238	7.7	0.2
Plutonium-239	96	2.6
Americium-241	83	2.2
Cobalt-60	29	0.8
Strontium-90	860	23
Estimated total inventory	2,800	75

Source: Francis and Sealand 1987.

[a]Estimated inventory based on 1×10^6 L of sediment (Braunstein et al. 1984) with a bulk density of 1.2 g/cm^3 and water content of 80%.

Organic contaminants. Kitchings and Owenby 1986 also analyzed extracts from the EP Toxicity testing of the three splits of sediment from Impoundment 3524 for pesticides/herbicides and non-VOCs. All values for pesticides and herbicides were reported below analytical detection limits and well below EP Toxicity limits. No non-VOCs were identified. These analytical results are, therefore, not reproduced in this report.

Kitchings and Owenby also evaluated the presence of VOCs by analyzing water present above the sediment in the sample containers and by analyzing the sediment material after leaching. Three VOCs were identified at low concentrations: benzene (< 4.4 to 6.0 μg/L; average = < 4.8 μg/L), chloroform (< 1.6 to 119.0 μg/L; average = 32.6 μg/L), and methylene chloride (5.0 to 288.0 μg/L; average = 79.2 μg/L). No other analyses were reported above detection limits and are, therefore, not reproduced in this report.

3.1.1.2 Surface water

Kitchings and Owenby 1986 is the only investigation bearing on the composition of the surface water in Impoundment 3524. Kitchings and Owenby reported samples of influent water to Impoundment 3524 were collected at the time of the investigation to determine the impoundment's regulatory status. Analyses of the influent water were conducted for metals and pesticides and herbicides with EP total organic halides (TOX) limits, and/or VOCs. Only barium (0.10 μg/L) and a few VOCs [specifically chloroform (7.9 μg/L); 1,2-dichloroethene (2.8 μg/L); methylene chloride (23.0 μg/L); and trichloroethene (2.2 μg/L)] were identified at concentrations

above the analytical detection limits. No compound exceeded the regulatory limits. The remaining data are, therefore, not reproduced in this report.

3.1.2 Impoundment 3513

Tamura, Sealand, and Duguid (1977) conducted the first reported investigation of Impoundment 3513. The investigation focused solely on characterizing the radiological content of the sediment. Huang et al. (1984) conducted additional sampling of sediment in Impoundment 3513 as well as collecting soil samples from the area around the perimeter of the impoundment. Huang et al. only reported results for radiological constituents; nonradiological constituents were analyzed but not reported at the time. Francis (1986) calculated a revised estimate of the inventory of radiological constituents using the analytical results reported by Tamura et al.; no additional samples were collected. Stansfield and Francis (1985, 1986a) presented the results of additional sampling of sediment and surface water conducted in Impoundment 3513 to characterize the nonradiological constituents. Stansfield and Francis (1986b) summarized existing information on Impoundment 3513 and included the previously unpublished data for nonradiological constituents in sediment analyzed as part of the investigation reported by Huang et al. Francis and Sealand (1987a) conducted additional sampling in Impoundment 3513 to further characterize the radiological content of the sediment. To provide information on the chemical composition of the sediment in Impoundment 3513, samples of sediment were collected as part of the 1994 RI investigation for chemical analyses of inorganic and organic constituents, in addition to conducting radiological analyses. Results of the 1994 RI sampling are presented in Chapter 4.

3.1.2.1 Sediments

Radiological contaminants. Tamura et al. (1977) conducted an air investigation of Impoundment 3513 in support of its planned decommissioning. The objective of the investigation was to provide an initial inventory of $^{239,240}Pu$, ^{90}Sr, and ^{137}Cs to support decommissioning decisions.

For the investigation, cores of sediment were collected at 15 locations within the impoundment. At each location a core of sediment was collected using a 3.5-cm (1 3/8-in. inside diameter) aluminum tube. The tubes were "...driven into the sediment until the hard bottom of the original floor was reached." Measurements of the depth to the top of the sediment or to the bottom of the impoundment are not reported and apparently were not made. Upon withdrawal of the aluminum tube, the bottom of the core was sealed with a cork and the core was frozen.

To prepare the sediment samples for analysis, the core was allowed to partially thaw at room temperature for approximately 30 minutes and the sediment was then pushed out of the

tube. The exposed sediment core was then separated into sections based on visual appearance, which suggested differences in sediment character. Tamura et al. (1977) identified five zones. The uppermost (surface) zone referred to as Zone 1 by Tamura et al. consisted of a very loose, lightweight material. Zone 2 consisted of a dark, organic-appearing material. Zone 3 also contained dark, organic-appearing material intermixed with whitish-gray strata. The whitish-gray material increased in prominence with depth (Zone 4). The lowest zone, referred to as Zone 5, consisted of dense, compact material.

The dense, compact material collected from the bottom of most cores (Zone 5) had a relatively low moisture content (approximately 40 percent or less) compared to other sections (generally greater than 70 percent). Tamura et al. (1977) interpret this low-moisture content material as representing the natural clay underlying the impoundment.

The zones above the original bottom of the impoundment represent the accumulated material settled as a result of operations or as a result of natural biologic activity. The impoundment supports a diverse, freshwater ecosystem that includes mixed phytoplankton, benthic algae, and a diverse assemblage of aquatic invertebrates (Stansfield and Francis 1986b). The impoundment has served as a radioecological research site to study the behavior of actinides and fission products in freshwater ecosystems (Garten 1981, Garten et al. 1982, Trabalka et al. 1987). The very loose, lightweight material identified in Zone 1 probably represents an active growth zone that includes benthic algae as well as organic detritus. The dark, organic-appearing material reported in Zones 2 and 3 represents the accumulated organic detritus as well as precipitated and flocculated material. It is speculated that the whitish-gray material identified in Zones 3 and 4 represents the fly ash and soda lime originally added to the impoundment to precipitate radionuclides.

The length of each section was measured and then the section was placed in a plastic bottle and weighed. The sections were then centrifuged, the supernate decanted, and the remaining material was reweighed, dried in an oven at 105°C, and the final dry weight recorded. The measured length for each section and the reported wet (gross) and dry weights are listed in Table 3.4. From the measured section lengths, inside diameter of the aluminum tube, and gross weights reported for each section, the bulk density of the material can be calculated. Several of the sections have a calculated bulk density less than 1.0. This is not considered realistic for water saturated material although Francis and Sealand 1987b also report bulk densities less than 1.0 for sediment from another unrelated impoundment. It is speculated that material was lost and not accounted for in transferring the section into the plastic bottle due to partial thawing of the core.

Table B3.4. Sediment data from Impoundment 3513

Core number	Core length (centimeter)	Core oven dried weight (gram)
1-1	83.82	402.95
1-2	69.85	354.20
1-3	99.06	360.40
1-4	87.63	219.97
1-5	73.66	198.08
2-1	76.2	345.05
2-2	86.36	382.20
2-3	63.5	78.55
2-4	85.09	358.74
2-5	122.682	84.98
3-1	76.2	198.50
3-2	108.712	291.90
3-3	86.36	296.10
3-4	78.232	177.14
3-5	70.612	307.95

Source: Tamura et al. 1977.

The dried sediment samples were analyzed for ^{90}Sr, ^{137}Cs, and gross alpha activity reported as $^{239,240}Pu$. The results obtained for the $^{239,240}Pu$ are semi-quantitative and based on the assumption that 80 percent of the alpha activity measured is attributed to $^{239,240}Pu$. The reported analytical results for each radioisotope are discussed in Chapter 5.

Tamura et al. (1977) made a preliminary estimate of the $^{239,240}Pu$, ^{137}Cs, and ^{90}Sr inventory in Impoundment 3513 based on the data obtained from the cores. The inventory calculation is based on the area of the pond and avoids the uncertainty in the volume of sediment due to the variation in the thickness of sediment observed in the cores. The data for each radionuclide were then plotted on the transect of the impoundment, and contour lines were drawn to delineate three levels of Pu activity, three levels of Cs activity, and four levels of Sr activity. Since the sediment cores were not collected to the outer edge of the pond, the contour lines are drawn assuming that the concentration at the outer perimeter is equal to the nearest sample point. The estimate also only includes the material within the flat bottom of the impoundment and does not include an additional contribution based on sediment on the sloping sides.

The inventory for the impoundment was determined by multiplying the area for each level of activity by the average activity per unit area for each level of activity derived from the cores. Following this procedure, the total calculated inventory for $^{239,240}Pu$ was 185 GBq (5.0 Ci), for

^{137}Cs was 7430 GBq (200.8 Ci), and for ^{90}Sr was 1243 GBq (33.6 Ci). These activities correspond to 81.5 g of $^{239,240}Pu$, 2.3 g of ^{137}Cs, and 0.24 g of ^{90}Sr.

Huang et al. (1984) conducted an additional characterization investigation at Impoundment 3513 in support of D&D activities. Five sediment cores were collected to estimate the radionuclide inventory of the impoundment. At each location a sediment core was collected by hammering a 2.5-cm (1-in.) diameter plastic tube into the sediment until refusal. Excess water was drained from the core and the sediment in each core was composited. The composited core was analyzed for ^{137}Cs, ^{60}Co, ^{154}Eu, ^{239}Pu, ^{238}Pu, ^{241}Am, ^{244}Cm, and ^{90}Sr. The activities reported by Huang et al. (1984) are on a wet weight basis and are not directly comparable to the values reported by Tamura et al. (1977), which were reported on a dry weight basis.

During the sediment sampling the thickness of the sediment was estimated by Huang et al. (1984). A string with a small weight was used to measure the water depth. The total depth of the sediment and water was measured by pushing a solid rod into the sediment until refusal. The thickness of the sediment layer is the calculated difference between the total depth and water depth. The average thickness of the sediment layer determined by this method was reported as approximately 50 cm. Huang et al. noted that this method does not consider the low-density interface zone identified by Tamura et al. (e.g., Zone 1).

Huang et al. (1984) made a preliminary estimate of the radionuclide inventory in Impoundment 3513 based on the radionuclide activities reported and the volume of sediment present in the impoundment estimated from the average thickness of the sediment. Based on the estimated 50 cm average thickness of sediment, approximately 2×10^6 L of (wet) sediment was estimated. The inventory was calculated using the following equation:

$$\text{Inventory} = C \times V \times D$$

where

C = average concentration of radionuclides,
V = total volume (mL) of the moist sediment,
D = density of the moist sediment (1.1 g/mL for sediment samples).

The estimated inventories for radionuclides in the sediment are presented in Table B3.5.

The inventory for ^{137}Cs, ^{90}Sr, and ^{239}Pu are in general agreement between Tamura et al. (1977) and Huang et al. (1984), although the estimates in the latter are noted to be approximately 40 percent less than that reported by Tamura et al. Huang et al. noted that this difference is partially due to the decay of ^{137}Cs and ^{90}Sr, which can account for approximately half of the

Table B3.5. Estimated inventory of radionuclides in Impoundment 3513

Radionuclide	Estimated inventory	
	(GBq)	(Ci)
Cesium-137	5,000	130
Cobalt-60	50	1
Strontium-90	700	20
Plutonium-238	4	0.1
Plutonium-239	100	3
Americium-241	20	0.5
Curium-244	5	0.1
Europium-154	8	0.2

Source: Huang et al. 1984.

difference. However, the primary difference as noted by Huang et al. is related to the different estimates in the sediment thickness and hence calculated volume of sediment reported by the two investigations. Huang et al. estimates approximately one-third less sediment volume, and this is probably due to the method for estimating the sediment depth that misses what Tamura et al. report as Zone 1.

Francis (1986) used the data of Tamura et al. (1977) to re-evaluate the inventory for Impoundment 3513 and the relationship between the activity of specific radionuclides and bulk density with depth. In re-evaluating the data of Tamura et al., Francis apparently assumed that the sample identification number correlated with the zones (sediment horizons) that Tamura et al. described. As previously discussed in presenting the data of Tamura et al., this does not appear to be the case. As a result, considering the distribution of radionuclides strictly with depth biases the interpretation. The major difficulty with this approach is that native clay material from Zone 5 with lower radioactivity from the bottom of cores with short lengths is included with higher radioactivity material from other zones in longer cores and obscures any trend.

Francis and Sealand (1987a) conducted additional sampling of sediment in Impoundment 3513 to also determine waste classification in support of corrective actions. Grab samples of sediment were collected from eight locations in Impoundment 3513. Samples were collected using a 3-L stainless-steel dipper attached to a 12-ft-long pole. A single composite sample was prepared for analysis by air drying the individual sediment samples, grinding a portion of the samples using a mortar and pestle to pass a 1-mm sieve, and mixing aliquots of equal weights.

Francis and Sealand (1987a) estimated the inventory based on the reported activity for the composite sample and an estimate of the sediment volume derived from measurements taken by Stansfield and Francis (1986b). The mean sediment depth was assumed to be 64 cm, which results in an estimated wet sediment volume of 2.3×10^6 L. Using a bulk density of 1.2 g/cm^3 and a moisture content by weight of 83 percent, the dry sediment weight is calculated as 4.7×10^8 g. The estimated inventory is reported in Table B3.6. The inventory of plutonium estimated by Francis and Sealand is comparable to that reported by Tamura et al. (1977) [148 GBq compared to 185 GBq (4 Ci compared to 5 Ci)]. The inventory for cesium and strontium estimated by Francis and Sealand is approximately a factor of 2 lower than reported by Tamura et al. [3330 GBq and 481 GBq (90 Ci and 13 Ci) as compared to 7,400 GBq and 1,110 GBq (200 Ci and 30 Ci), respectively]. Because the estimate of the sediment volume based on the average thickness of the sediment layer appears reasonable, the difference in inventory is attributed to the sampling approach used by Francis and Sealand that preferentially collects samples from the upper zones, as well as decay of ^{137}Cs and ^{90}Sr.

Trabalka et al. (1987) summarized results of a long-term investigation of the behavior of actinide elements in Impoundment 3513 conducted from March 9, 1977 to May 27, 1982. As part of the investigation, sediment samples were collected at 24 locations set out on a 10-m grid in the impoundment. Sediment samples were taken with a sediment sampler and an aliquot representing the zero to 5 cm depth in the sediment column collected from each sample. The individual aliquots were homogenized and divided for radiological analyses, organic content determination and frozen storage. For determination of the radiological content, subsamples from the individual aliquots were leached with nitric acid and analyzed for isotopes of U, Pu, Am, and Cm. Trabalka et al. grouped the sediment samples based on location in the impoundment. "Samples collected from scoured or eroded areas (located in shallow water exposed to prevailing winds) contained thin sediment deposits with higher (^{244}Cm excepted) and more variable actinide concentrations than unscoured areas (the primary sediment stratum)." Trabalka et al. considered the scoured areas to represent exposure of older deposits resulting from wave action. The analytical results for samples from scoured and unscoured areas and pooled results are presented in Table B3.7.

Metals contaminants. As part of the investigation of Impoundment 3513 conducted by Huang et al. 1984, samples from the five cores of sediment collected were analyzed for selected hazardous metals from the priority pollutant list (Sittig and Marshall, 1981) and PCBs. Results reported by Huang et al. are presented in Table B3.8. Analyses were performed on wet samples. Results reported by Huang et al. are on a dry weight basis calculated from the wet weight assuming values for bulk density and moisture content. Huang et al. also made a preliminary

Table B3.6. Estimated inventory of radionuclides in Impoundment 3513

Radionuclide	Estimated inventory	
	(GBq)	(Ci)
Gross alpha	140	3.8
Gross beta	3,900	100
Cesium-137	3,300	88
Europium-154	4.4	0.1
Plutonium-238	3.6	0.1
Plutonium-239	150	4
Americium-241	33	0.9
Cobalt-60	20	0.5
Strontium-90	470	13
Estimated total inventory	4,000	110

Source: Francis and Sealand 1987a.

estimate of the inventory of the hazardous metals using the procedure described previously. Estimated inventories for the metals are listed in Table B3.8.

Stansfield and Francis (1985) reported on the results of an extensive evaluation of Impoundment 3513 to provide information to support decisions to define if the sediment could be classified as a hazardous waste under CERCLA or RCRA regulations. To obtain the necessary information, samples of sediment from the impoundment were collected from five locations within the impoundment during two separate sampling events. During the first sample event conducted in November 1984, a 3.0 in. (7.62 cm) diameter aluminum tube was driven into the native clay material underlying the impoundment. The clay material served to plug the tube to allow withdrawal of the core. During the second sampling event conducted in February 1985 a 1.5 in (3.81 cm) diameter aluminum tube was used. For the second sampling event, a wooden plug was attached to a line running through the tube. The use of the plug permitted collection of the sediment material without including the clay material. Core samples were transferred to 0.5 gallon glass containers in the field. More than one core sample was required at each location during each sampling event to obtain the necessary volume of material for the planned testing.

Sediment samples were leached following the EP Toxicity extraction procedure and the extract analyzed for the eight elements (As, Ba, Cd, Cr, Pb, Hg, Se, Ag) listed under the National Interim Primary Drinking Water Standards (NIPDWS). To support additional evaluation the concentration of nonregulatory elements were also determined for the extracts as well as determining the concentration of regulatory and nonregulatory elements in the sediments. Analyses were typically performed on the individual samples or extracts on individual samples. The average concentration calculated from five sediment samples and corresponding extracts on

Table B3.7. Radionuclide activities in surface sediment (0 to 5 cm) from Impoundment 3513

Radionuclide	Unscoured N = 18 (Bq/g)[a]	Scoured N = 6 (Bq/g)[a]	Pooled estimates N = 24	
			(Bq/g)[a]	(ng/g)[b]
Uranium-233,234	4.0 ± 0.55	7.8 ± 3.0	5.0 ± 0.87	1.6 ± 10^{1}
Uranium-238	3.1 ± 0.15	2.3 ± 1.0	1.2 ± 0.27	1.0 ± 10^{5}
Plutonium-238	1.7 ± 0.32	6.2 ± 3.3	2.8 ± 0.87	4.4 ± 10^{-3}
Plutonium-239,240	16 ± 1.7	98 ± 57[c]	33 ± 12	1.3 ± 10^{1}
Americium-241	5.2 ± 0.90	30 ± 17	11 ± 4.2	9.4 ± 10^{-2}
Curium-244	13 ± 1.7	8.3 ± 3.8	12 ± 1.6	3.8 ± 10^{-3}

Source: Trabalka et al. 1987.

[a]Activities reported as arithmetic mean (dry weight) ± 95% confidence limit.
[b]Based on mass spectrometry results on selected samples: $^{238}U/^{235}U/^{234}U$ = 99.3/0.69/0.006% and $^{239}Pu/^{240}Pu/^{241}Pu$ = 94/5.7/0.3%, respectively.
[c]N = 5, one high value (360 Bq/g) removed by Chauvenet's criterion.

individual samples are summarized in Table B3.9. Results for sediment concentration are reported on a dry weight basis (samples dried overnight at 110°C). An inventory was calculated by Stansfield and Francis based on the analytical results and an estimated 2,350,000 L of sediment with a bulk density of 1.2 g/cc and a moisture content of 83 percent. Stansfield and Francis indicate that the values for sediment volume, bulk density, and moisture content were determined as part of the investigation.

Results reported by Stansfield and Francis 1985 indicate that the concentration in the EP Toxicity extract of all constituents with regulatory limits except mercury were below the appropriate concentration limit. The concentration of mercury in the extract was approximately ten times higher than the limit, which could indicate the sediment was a hazardous material under the RCRA regulations at that time. The concentration of selenium in the extract was below the analytical detection level. However, the detection level for the specific samples exceeded the regulatory limit by 1 to 2 mg/L.

Organic contaminants. As part of the investigation conducted by Stansfield and Francis 1985 a single composited sediment sample was leached following the EP Toxicity extraction procedure for the six herbicides and pesticide (Endrin, Lindane, Methoxychlor, Toxaphene, 2,4-D, 2,4,5-TP Silvex) listed under the NIPDWS. To evaluate the potential for other organic compounds to be present, the EP Toxicity extracts from the individual sediment samples were also analyzed for "Total Toxic Organics" which was defined as the "...summation of all quantifiable concentrations greater than 0.01 mg/L of a large selection of volatile and semivolatile compounds as listed in the July 15, 1983 Federal Register Vo. 48 (No. 137)." The concentration

Table B3.8. Reported concentrations and estimated inventory of metals and PCBs in Impoundment 3513

Chemical	Average concentration (mg/kg)[a]	Highest concentration (mg/kg)	Inventory (kg)
Arsenic	2	3	0.88
Cadmium	7.2	10	3.2
Chromium	440	700	190
Lead	420	1,000	190
Mercury	56	100	25
Selenium	2.8	4	1.2
Antimony	2.4	3	1.1
Copper	150	200	67
Zinc	130	200	55
PCBs	16	26	7.2

Source: from Huang et al. 1984.

[a]Concentrations reported on dry weight basis, calculated from wet weight assuming a bulk density of wet sediment as 1.1 g/cc and a ratio of dry to wet weight of 0.2.

PCB = polychlorinated biphenyl

of PCBs in the sediments were also measured to support evaluation of remedial alternatives. The sediments were not analyzed for any other organic compounds. The concentration of the pesticides and herbicides, as well as the average total toxic organics in the EP Toxicity extracts, were all less than the associated detection limits, except for lindane (0.003 mg/L). These data are, therefore, not reproduced in this report. The average concentration of PCBs was 7.0 mg/kg.

3.1.2.2 Surface water

Huang et al. (1984) reported that the surface water in Impoundment 3513 contained 300 Bq/L of ^{90}Sr activity and 400 Bq/L of ^{137}Cs activity.

As part of the investigation conducted by Stansfield and Francis (1985) a sample of the surface water in Impoundment 3513 was collected from a location in the center of the impoundment. The sample was collected from both the lower and upper depths using a stainless steel, bottom loading bailer. The composited, unfiltered surface water sample was analyzed for the parameters defined by the NIPDWS as well as those established to determine groundwater quality and as indicators of groundwater contamination. In addition to gross alpha activity and gross beta activity required by the NIPDWS regulations, separate analyses were conducted for specific alpha-, beta- and gamma-emitting isotopes. Results for chemical constituents are summarized in Table B3.10. Results for radionuclides are summarized in Table B3.11.

Table B3.9. Metal concentrations in sediment and EP Toxicity extracts from Impoundment 3513 sediment samples

Element	Average sediment concentration (mg/kg)	Inventory (kg)[a]	Average extract concentration (mg/L)
Arsenic	< 80	38.2	1.80[b]
Barium	378	181	0.764
Cadmium	13.1	6.3	0.086[b]
Chromium	1,056	506	0.216[b]
Lead	2,800	1,342	1.12[b]
Mercury	NA		2.99
Selenium	< 160	73.51	3.60[b]
Silver	48	23.0	0.636[b]
Aluminum	34,600	16,587	1.86[b]
Boron	NA		0.90[b]
Beryllium	30.2	14.5	0.01[b]
Calcium	152,000	71,910	1,900
Cobalt	12.2	5.9	1.00[b]
Copper	826	396	0.18[b]
Iron	12,800	6,136	0.72[b]
Gallium	< 200	95.9	4.60[b]
HF	144	64.2	0.56[b]
Potassium	10,800	5,178	2.08[b]
Lanthanum	NA		2.10[b,c]
Lithium	95.2	45.6	1.80[b]
Magnesium	11,400	5,465	106
Manganese	3,030	291	8.92
Molybdenum	19.4	9.3	0.18[b]
Sodium	1,166	559	13.2[b]
Nickel	63.8	30.6	0.56[b]
Phosphorus	12,580	6,031	2.70[b]
Antimony	< 120	57.5	2.70[b]
Scandium	NA		0.63[b,c]
Silicon	138,260	66,281	10.7
Tin	NA		0.84[b,c]
Strontium	200	95.9	2.14
Titanium	2,080	997	0.18[b]
Vanadium	137	65.7	0.27[b]
Zinc	632	303	1.09
Zirconium	101	48.4	0.55

Source: Stansfield and Francis 1985.

[a]Inventory calculated based on 2,350,000 L of sediment with a bulk wet density of 1.2 g/cc, and a moisture content by weight of 83%.
[b]Calculation of average value includes use of reported detection limit for nondetect results.
[c]Concentration for result reported on a single composite sample.

Table B3.10. Chemical constituents in Impoundment 3513 surface water

Constituent	Concentration (μg/L)	Constituent	Concentration (μg/L)
Inorganic constituents - metals			
Antimony	< 0.3	Magnesium	14.3
Arsenic	< 0.001	Manganese	0.46
Barium	0.0636	Mercury	0.0003
Beryllium	0.0029	Molybdenum	< 0.02
Boron	< 0.1	Nickel	< 0.06
Cadmium	< 0.001	Potassium	2/4
Calcium	75.3	Selenium	0.016
Chromium	0.07	Silver	< 0.07
Cobalt	< 0.02	Strontium	0.099
Copper	0.352	Titanium	< 0.02
Iron	1.38	Vanadium	< 0.03
Lead	0.15	Zinc	0.118
Lithium	< 0.2	Zirconium	< 0.06
Sodium	< 0.5		
Inorganic constituents - anions			
Chloride	0	Phosphate	1.64
Fluoride	1	Sulfate	27.0
Nitrate	< 1	HF	< 0.06
Organic constituents			
Total organic carbon	14.7	Methoxychlor	< 0.0002
Total organic halogen	0.67	Toxaphene	< 0.0002
Endrin	< 0.0001	Phenol	< 0.001
Lindane	< 0.0001	PCBs	0.0006

Source: Stansfield and Francis 1985.

Table B3.11. Radiological constituents in Impoundment 3513 surface water

Constituent	Activity (Bq/L)	Constituent	Activity (Bq/L)
Gross alpha	16.0	Americium-241	3.4
Gross beta	910	Curium-244	2.6
Cesium-137	290.0	Radium-226	0.12
Strontium-90	420.0	Uranium-234	1.6
Cobalt-60	5.2	Uranium-235	0.16
Plutonium-238	0.15	Uranium-238	0.61
Plutonium-239	4.1		

Source: Stansfield and Francis 1985.

Evaluation of the reported results for radionuclides indicate that the bulk of the radioactivity present in the surface water is attributed to beta-emitting radionuclides. Most of the beta activity is due to ^{90}Sr (420 Bq/L) and ^{137}Cs (290 Bq/L), which have activities comparable to that reported by Huang et al. For the chemical constituents, concentrations reported for chromium, lead, and selenium in the unfiltered samples were observed to be above the NIPDWS limits. Silver was below the analytical detection level, but the detection level is greater than the regulatory limit. All other chemical constituents were below maximum allowable NIPDWS limits. The concentration of TOX was relatively high (0.67 mg/L) and a detectable concentration of PCBs (0.0006 mg/L) was reported.

As part of the long-term investigation of the behavior of actinide elements in Impoundment 3513 reported by Trabalka et al. (1987) surface water samples were routinely collected approximately once a month from March 9, 1977 to May 27, 1982. Additional samples were periodically collected to observe changes in water chemistry due to an algal bloom that occurred in 1977, and the accidental release of waste solution containing actinide elements to the impoundment in 1978. During each sampling event, paired water samples were collected near the center of the impoundment from just under the surface and from a depth of 1 m. Samples were filtered through a 0.22 μm filter before analysis. Samples were analyzed for selected chemical constituents and isotopes of U, Pu, Am, and Cm.

During the approximately 5 years the investigation was conducted the concentration of constituents in solution were observed to vary seasonally as well as with the algal bloom and the input of actinides due to the accidental release. Trabalka et al. presented a summary of the chemistry of the surface water in the period from November 7, 1977, to November 14, 1978, which was after the effects of the algal bloom but before the accidental release. The mean concentrations and range for field measured parameters, major chemical constituents and minor chemical constituents are listed in Table B3.12. The mean activities and calculated concentration for isotopes of U, Pu, Am, and Cm in surface water for the period February 10 to November 14,

Table B3.12. Concentration of chemical constituents (in μm/L) in surface water of Impoundment 3513[a]

Major constituents			Trace constituents		
Constituent	Mean[b]	Range[b]	Constituent	Mean[b]	Range[b]
Na^+	290	210 - 380	SiO_2	7.0	0.03 - 63
K^+	66	39 - 100	NO_3-N	3.1	0.29 - 87
Ca^{2+}	500	300 - 670	NH_3-N	2.6	1.4 - 9.6
Mg^{2+}	750	560 - 970	Total P	0.94	0.29 - 1.9
HCO_3^-	1,700	1400 - 2100	PO_4-P	0.32	0.03 - 1.1
CO_3^{2-}	140	9 - 330	Mn	0.046	0.005 - 0.20
DOC[c]	860	530 - 1500	Fe	0.047	0.007 - 0.12
SO_4^{2-}	130	87 - 200	Zn	0.12	0.004 - 0.91
Cl^-	190	130 - 260	**Field measurements**		
F^-[d]	23	11 - 32	Temperature (°C)	17.6	2.9 - 30.4
OH^-	12	0.79 - 40	pH	9.1	7.9 - 9.6

Source: Trabalka et al. 1987.

[a]Samples collected from November 7, 1977 to November 14, 1978.
[b]Concentrations are arithmetic means and ranges (N = 23).
[c]Dissolved organic carbon, reported as carbon.
[d]Samples collected from September 27, 1978 to June 29, 1979 (N = 19).

1978, are listed in Table B3.13. Trabalka et al. also reported estimated values for the distribution coefficient, K_d, based on the mean activities in the sediment and the surface water. The K_d values are discussed further during the evaluation of contaminant mobility presented in Appendix C.3.

3.1.3 Impoundments 3539 and 3540

The only previously reported investigations at Impoundments 3539 and 3540 were conducted by Kitchings and Owenby 1986 and by Francis and Sealand (1987a). Kitchings and Owenby 1986 collected sediment samples from Impoundment 3540 for testing following the EP Toxicity procedures for analysis of metals, pesticides/herbicides, and organic constituents. The Francis and Sealand investigation focused on characterizing the radiological content of the sediment. To provide information on the chemical composition of the sediment in Impoundments 3539 and 3540 sediment samples were collected as part of the 1994 RI investigation for chemical analyses of inorganic and organic constituents in addition to conducting additional radiological analyses. Results of the 1994 RI sampling event are presented in Chapter 4.

Table B3.13. Concentration of radionuclide constituents in surface water of Impoundment 3513[a]

Radionuclide	Concentration Bq/m³	Concentration Moles/L	K_d estimate[b] mL/g
Uranium-238	720	2.4×10^{-7}	1.7×10^{3}
Plutonium-238	5.5		5.2×10^{5}
Plutonium-239,240	65	1.0×10^{-13}	5.1×10^{5}
Americium-241	85	2.9×10^{-15}	1.3×10^{5}
Curium-244	2000	2.7×10^{-15}	5.9×10^{3}

Source: Trabalka et al. 1987.

[a]Samples collected from February 10 to November 14, 1978.
[b]K_d = pooled concentration in surface sediment from Table B3.12 (Bq/g); concentration in filtered surface water (Bq/m³) $\times 10^{-6}$m³/mL.

3.1.3.1 Sediments

Radiological contaminants. Francis and Sealand (1987a) conducted the only previously reported sampling of sediment in Impoundments 3539 and 3540 for analysis of radiological contaminants. The sampling was conducted to determine waste classification in support of corrective actions. Grab samples of sediment were collected from eight locations in both Impoundments 3539 and 3540. Samples were collected using a 3-L stainless steel dipper attached to a 12-ft-long pole. A single composite sample for each impoundment was prepared from the samples collected. The reported activity for radionuclides detected in the Impoundments 3539 and 3540 composite samples are listed in Tables B3.14 and B3.15, respectively.

Francis and Sealand (1987a) estimated the inventory for both impoundments based on the reported activity for the composite sample and an estimate of the sediment volume. The estimate of the sediment volume is based on a mean sediment depth assumed to be 46 cm, although Francis and Sealand do not report taking measurements of the sediment thickness and the source of this number is uncertain. The estimated wet sediment volume is 7.4×10^4 L for Impoundment 3539 and 7.6×10^4 L for Impoundment 3540. The estimated inventories for Impoundments 3539 and 3540 are listed in Tables B3.14 and B3.15, respectively. A statistical analysis of the Francis and Sealand (1987a) data and the data obtained during the 1994 RI sampling event is presented in Chapter 5.

Metals contaminants. Prior to the 1994 investigation, the only previous study to address the inorganic composition of the sediments in Impoundments 3539 and 3540 was Kitchings and Owenby (1986). Kitchings and Owenby reported that sediment was collected during January and February 1986 to determine the EP Toxicity status of seven separate surface impoundments at

Table B3.14. Estimated inventory of radionuclides in Impoundment 3539

Radionuclide	Estimated inventory[a]	
	(GBq)	(Ci)
Gross alpha	1.1	0.03
Gross beta	0.62	0.02
Cesium-137	0.01	< 0.01
Americium-241		
Cobalt-60	0.01	< 0.01
Strontium-90	0.04	< 0.01
Estimated total inventory	0.6	< 0.03

Source: Francis and Sealand 1987a.

[a]Estimated inventory based on 7.4×10^4 L of sediment with a mean sediment depth of 46 cm, bulk density of 1.2 g/cm^3, and water content of 80%.

ORNL (3539 and 3540, plus five additional impoundments). The sediment samples were composited for each impoundment and then split into three portions, extracted by EP Toxicity procedures and analyzed for metals. The analytical results indicate that no value for any analyte exceeded the EP Toxicity Limits, so these data are, therefore, not reproduced in this report.

Organic contaminants. In the Kitchings and Owenby (1986) investigation, the sediment samples were composited for each impoundment and then split into three portions, extracted by

Table B3.15. Estimated inventory of radionuclides in Impoundment 3540

Radionuclide	Estimated inventory[a]	
	(GBq)	(Ci)
Gross alpha	0.55	0.01
Gross beta	0.55	0.01
Cesium-137	0.07	< 0.01
Europium-152	0.01	< 0.01
Europium-154	< 0.01	< 0.01
Americium-241	< 0.01	< 0.01
Cobalt-60	0.01	< 0.01
Strontium-90	0.11	< 0.01
Estimated total inventory	< 0.2	< 0.06

Source: Francis and Sealand 1987a.

[a]Estimated inventory based on 7.6×10^4 L of sediment with a mean sediment depth of 46 cm, bulk density of 1.2 g/cm^3, and water content of 80%.

EP Toxicity procedures, and analyzed for pesticides/herbicides and all non-VOCs. Volatile organics were determined in the following manner from the sludge samples from each impoundment: (1) solution in three of the sample bottles directly above the sludge was analyzed and (2) leached sludge samples were analyzed.

The reported concentrations for pesticide/herbicide concentrations in the EP Toxicity extracts for Impoundments 3539 and 3540 are presented in Table B3.16 and B3.17, respectively. The results indicate that for both impoundments, the concentrations of pesticides/herbicides are generally below the analytical detection limit, and well below the EP TOX limit. Only one analysis for an extract from Impoundment 3540 had detectable levels of pesticide (2,4-D reported at 11.0 μg/L). No non-VOCs were detected in the extract from either impoundment, so these data are not reproduced in this report. The VOCs methylene chloride and 1,2-dichloroethene (3.00 μg/L) were detected in one of the leached sediment samples from Impoundment 3540. The VOC chloroform (5.10 μg/L) was detected in one of the solution samples taken from the sample bottles (2.40 μg/L) while 1,2-(trans)dichloroethene was detected in all three samples (5.40 to 8.00 μg/L). No other results for the VOCs were above detection limits.

3.1.3.2 Surface water

The only investigation that evaluated the composition of the surface water in Impoundments 3539 and 3540 is Kitchings and Owenby (1986). Kitchings and Owenby reported samples of influent water to Impoundment 3540 were collected at the time of the investigation to determine the regulatory status of Impoundments 3539 and 3540. Since influent water to Impoundments 3539 and 3540 is from a common source, only a single sample was collected. Analyses of the influent water were conducted for metals and pesticides and herbicides with EP Toxicity limits, and for VOCs. The metals barium (0.05 μg/L) and selenium (0.21 μg/L) as well as a few VOCs [specifically chloroform (130.8 μg/L); 1,2-dichloroethane (2.8 μg/L); dichlorobromomethane (5.2 μg/L); methylene chloride (8.4 μg/L); and trichloroethylene (4.2 μg/L)] were identified at concentrations above the analytical detection limits, but no compound exceeded the regulatory limits.

3.2 SURFACE AND SUBSURFACE SOILS

Analytical data for surface and subsurface soils are limited for SIOU. Although four investigations conducted in this area have included the collection and analysis of soil samples, none of the surveys provide a complete or comprehensive suite of soil analyses. Two of these investigations were focused specifically on radiological parameters in surface soils surrounding the impoundments [Huang et al. (1984) at Impoundment 3513 and Uziel, Williams, and Tiner (1989) at Impoundment 3524]. These investigations are discussed in detail in Section 3.2.1.

Table B3.16. Comparison of pesticide/herbicide concentrations in EP TOX extracts

Station	Analysis	Maximum (µg/L)	Minimum (µg/L)	Average (µg/L)	Limit (µg/L)
3539	Endrin	< 0.2	< 0.2	< 0.2	20
3539	Lindane	< 2.0	< 2.0	< 2.0	400
3539	Methoxychlor	< 8.0	< 8.0	< 8.0	10,000
3539	2,4-D	< 10.0	< 10.0	< 10.0	10,000
3539	2,4,5-TP Silvex	< 10.0	< 10.0	< 10.0	1,000
3539	Toxaphene	< 5.0	< 5.0	< 5.0	500

Source: Kitchings et al. 1986.

Tamura et al. 1977 collected samples of subimpoundment soil as part of cores of sediment taken from Impoundment 3513. The data for the subimpoundment soils are discussed in greater detail in Chapter 5.

The fourth and most recent investigation of soils was part of the Site Characterization Summary Report Investigation (DOE 1992b, 1992c, 1992d, 1992e, 1992f) where 10 soil borings were used to define the limits of SIOU. Six of these borings were drilled to screen soils near the impoundments, but one of these was not sampled and analyzed. The four remaining borings were drilled to investigate areas where contamination of surface soils was suspected, a leak in a waste transfer pipeline was known, and contamination of subsurface soils was suspected due to the presence of a waste transfer pipeline. None of these areas are related to the operation of the impoundments. The Site Characterization Summary Report investigation also conducted a radiation survey of the area.

Table B3.17. Comparison of pesticide/herbicide concentrations in EP TOX extracts

Station	Analysis	Maximum (µg/L)	Minimum (µg/L)	Average (µg/L)	Limit (µg/L)
3540	Endrin	< 0.2	< 0.2	< 0.2	20
3540	Lindane	< 2.0	< 2.0	< 2.0	400
3540	Methoxychlor	< 8.0	< 8.0	< 8.0	10,000
3540	2,4-D	11.0	< 10.0	< 10.0	10,000
3540	2,4,5-TP silvex	< 10.0	< 10.0	< 10.0	1,000
3540	Toxaphene	< 5.0	< 5.0	< 5.0	500

Source: Kitchings et al. 1986.

The scope of the Site Characterization Summary Report Investigation was very broad and intended only to serve as a screening of soils rather than define the nature and extent of contamination. Surface and subsurface soil samples were collected and analyzed for radiological parameters, metals, and organics. Data collected during the Site Characterization Summary Report Investigation are the only existing data where soils were analyzed for metals and organics. Because of the limited data available, a detailed interpretation of the distribution of contaminants in soils is not possible; however, reasonable conclusions have been drawn in some instances where information suggests a likely source of contamination.

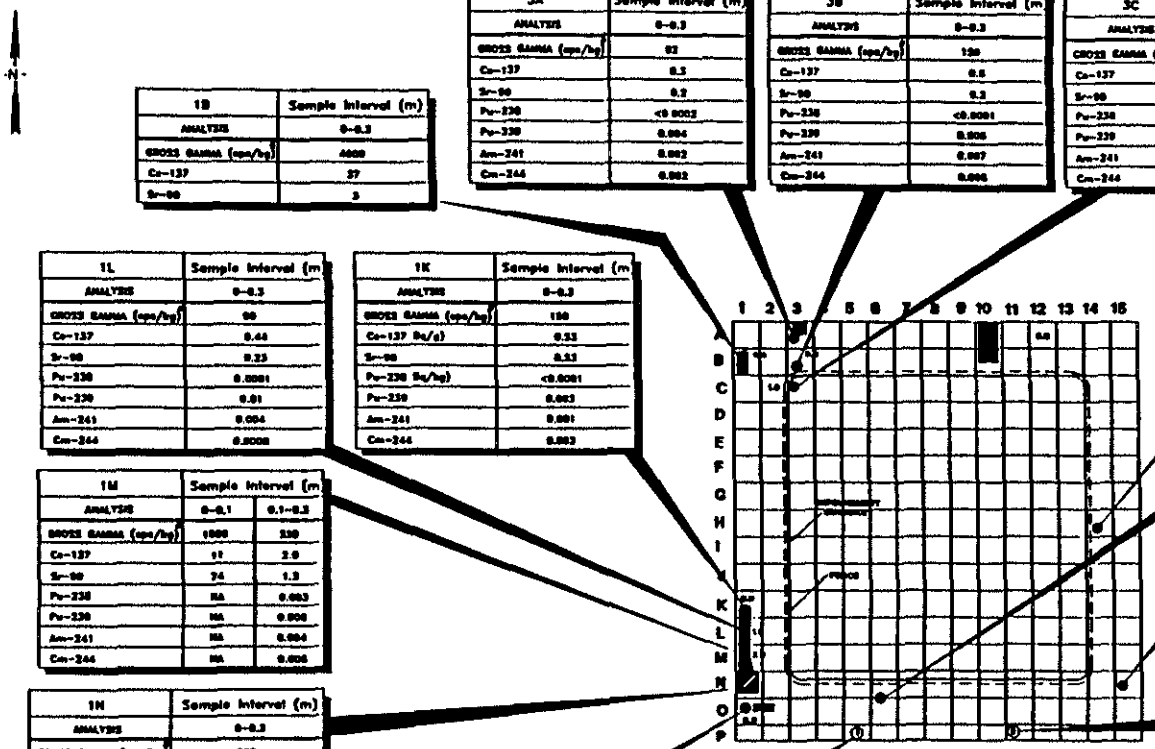
Related to the collection of soil samples, samples of the bedrock beneath Impoundment 3513 were collected to evaluate if contaminants were migrating into the bedrock from the Impoundment (Francis and Stansfield 1986a, Francis and Hyder 1987). Samples of the bedrock material were analyzed for gross alpha and gross beta activity, as well as ^{90}Sr, gamma-emitting radionuclides, and mercury.

Many of the constituents measured in soils are naturally occurring components of the soil matrix. In order to differentiate between naturally occurring constituents and site-related contaminants, soil analytical results are compared to reference (background) levels. Background levels for soil constituents have been developed as part of the Background Soil Characterization Project (DOE 1993a,b,c). Analytical results from those borings installed to monitor the impoundments were also compared qualitatively to sediment/sludge samples collected in 1994 from the impoundments as an indicator of potential sources of contamination.

3.2.1 Radiological Contamination

As part of the investigation of Impoundment 3513 conducted in support of D&D activities, Huang et al. (1984) conducted a surface soil radiological survey of contamination. To support the investigation, a 6 by 6 m sample grid shown in Figure B3.1 was set up over the area of the investigation. Each grid block was given an alphanumeric designation to identify sample locations. Surface beta-gamma radiation levels were made with Geiger-Müller and Victoreen 440 survey meters.

Based on the surface radiological survey results, contaminated areas were identified and are shown on Figure B3.1 as shaded areas. A soil sample was collected using hand coring and deep soil coring techniques from each contaminated surface area for analysis of radionuclide content. Soil sample locations are shown on Figure B3.1, and the samples are identified by the alphanumeric designation for the grid block. In addition to the soil samples collected from areas of contamination, two deep soil cores were taken between the impoundment and White Oak Creek to determine if any significant radioactivity had migrated toward the creek. These two core sites



3A	Sample Interval (m)
ANALYSIS	0–0.3
GROSS GAMMA (cps/kg)*	92
Cs-137	0.5
Sr-90	0.2
Pu-238	<0.0002
Pu-239	0.004
Am-241	0.002
Cm-244	0.002

3B	Sample Interval (m)
ANALYSIS	0–0.3
GROSS GAMMA (cps/kg)*	120
Cs-137	0.6
Sr-90	0.3
Pu-238	<0.0001
Pu-239	0.006
Am-241	0.007
Cm-244	0.006

3C	Sample Interval (m)
ANALYSIS	0–0.3
GROSS GAMMA (cps/kg)*	410
Cs-137	3.4
Sr-90	0.5
Pu-238	0.0003
Pu-239	0.03
Am-241	0.005
Cm-244	0.002

14H	Sample Interval (m)			
ANALYSIS	0–0.3	0.3–0.6	0.6–1.2	1.2–1.8
GROSS GAMMA (cps/kg)*	4600	1200	270	170
Cs-137	48	0.5	3.3	1.1
Sr-90	NA	0.44	1.7	0.5
Pu-238	NA	18	4	3
Pu-239	NA	200	30	20
Am-241	NA	20	6	3
Cm-244	NA	10	7	1

1B	Sample Interval (m)
ANALYSIS	0–0.3
GROSS GAMMA (cps/kg)*	4600
Cs-137	27
Sr-90	3

1L	Sample Interval (m)
ANALYSIS	0–0.3
GROSS GAMMA (cps/kg)*	90
Cs-137	0.44
Sr-90	0.23
Pu-238	0.0001
Pu-239	0.01
Am-241	0.004
Cm-244	0.0008

1K	Sample Interval (m)
ANALYSIS	0–0.3
GROSS GAMMA (cps/kg)*	150
Cs-137 Bq/g)	0.33
Sr-90	0.13
Pu-238 Bq/kg)	<0.0001
Pu-239	0.003
Am-241	0.001
Cm-244	0.003

8N	Sample Interval (m)				
ANALYSIS	0–0.3	0.3–0.6	0.6–1.2	1.2–1.8	1.8–2.4
GROSS GAMMA (cps/kg)*	3000	1100	300	230	200
Cs-137	44	7.6	1.7	1.4	1.3
Sr-90	0.6	0.4	1.5	3.0	1.4
Pu-238	0.007	0.0001	<0.0003	0.0004	0.0004
Pu-239	0.3	0.07	0.02	0.01	0.01
Am-241	0.1	0.01	0.001	0.009	0.005
Cm-244	0.003	0.004	0.000	0.006	0.01

1M	Sample Interval (m)	
ANALYSIS	0–0.1	0.1–0.3
GROSS GAMMA (cps/kg)*	1000	330
Cs-137	11	2.0
Sr-90	24	1.3
Pu-238	NA	0.003
Pu-239	NA	0.006
Am-241	NA	0.004
Cm-244	NA	0.006

15N	Sample Interval (m)
ANALYSIS	0–0.3
GROSS GAMMA (cps/kg)*	77
Cs-137	0.35
Sr-90	0.15
Pu-238	<0.0001
Pu-239	0.003
Am-241	0.0004
Cm-244	0.004

1N	Sample Interval (m)
ANALYSIS	0–0.3
GROSS GAMMA (cps/kg)*	900
Cs-137	7.4
Sr-90	NA

1O	Sample Interval(m)
ANALYSIS	0–0.3
GROSS GAMMA (cps/kg)*	2100
Cs-137	10
Sr-90	0.43
Pu-238	0.001
Pu-239	0.04
Am-241	0.009
Cm-244	0.001

DEEP CORE 1	Sample Interval (m)						
ANALYSIS	0–0.3	0.3–0.6	0.6–1.2	1.2–1.8	1.8–2.4	2.4–3.1	3.1–3.7
GROSS GAMMA (cps/kg)*	46	43	26	25	30	20	12
Cs-137	0.12	NA	0.01	NA	NA	NA	NA
Sr-90	0.03	NA	<0.02	NA	NA	NA	0.23
Pu-238	0.001	NA	NA	NA	NA	NA	ND
Pu-239	0.001	NA	NA	NA	NA	NA	ND
Am-241	0.002	NA	NA	NA	NA	NA	ND
Cm-244	0.0003	NA	NA	NA	NA	NA	ND

DEEP CORE 2	Sample Interval (m)						
ANALYSIS	0–0.3	0.3–0.6	0.6–1.2	1.2–1.8	1.8–2.4	2.4–3.1	3.1–3.7
GROSS GAMMA (cps/kg)*	49	46	31	29	40	31	33
Cs-137	NA	NA	NA	NA	NA	<0.01	NA
Sr-90	NA	NA	NA	NA	NA	0.07	NA
Pu-238	NA	NA	NA	NA	NA	0.001	3×10^{-9}
Pu-239	NA	NA	NA	NA	NA	<0.0001	$<1\times10^{-9}$
Am-241	NA	NA	NA	NA	NA	0.001	3×10^{-9}
Cm-244	NA	NA	NA	NA	NA	0.0004	3×10^{-9}

LEGEND

* Total gamma activity between the 100- and 1500-kev energy range. Measured in counts per second (cps) per kilogram of moist soil.

Activities Reported in Bq/g

CONTAMINATED AREAS OUTSIDE FENCE

SAMPLING SITES

DEEP CORE LOCATION

Source: HUANG et al. 1984.

Radiological contamination in soil at Impoundment 3513

Oak Ridge National Laboratory
Oak Ridge, Tennessee

CDM FEDERAL PROGRAMS CORPORATION
a subsidiary of Camp Dresser & McKee Inc.

Fig B3.1.

JP1018/10NOV94/0000

identified as deep cores 1 and 2 are located in grid blocks 5P and 11P, respectively, as shown on Figure B3.1.

All reported analytical results for soil samples are shown in Figure B3.1. Gross gamma levels are reported in counts per second per kilogram on moist soil. Activities for ^{137}Cs, ^{90}Sr, ^{238}Pu, ^{239}Pu, ^{241}Am, and ^{244}Cm are reported in becquerels/gram. All weights are on a dry weight basis.

The primary radionuclides identified in the soil samples are ^{137}Cs, with activity levels up to 48 Bq/g (grid block 14H, sample interval 0 to 0.3 m), and ^{90}Sr, with activity levels up to 74 Bq/g (grid block 1M, sample interval 0 to 0.1 m). Activities of the alpha-emitting transuranic radionuclides (^{238}Pu, ^{239}Pu, ^{241}Am, and ^{244}Cm) were generally less than 0.08 Bq/g with ^{239}Pu being the predominant radionuclide present. The highest alpha activity for ^{239}Pu of 0.5 Bq/g (14 pCi/g) was reported for grid block 6N, sample interval 0 to 0.3 m. Elevated ^{239}Pu activity of 0.2 Bq/g (5 pCi/g) was reported for grid block 14H, sample interval 0.3 to 0.6 m.

The highest reported gross gamma values were detected in soil samples from locations 1B and 14H. The predominant radionuclide reported in this sample was ^{137}Cs (37 Bq/g), with ^{90}Sr present with an activity approximately an order of magnitude lower (3 Bq/g). The 1B location is where Huang et al. (1984) indicated that two underground, low-level, waste transfer lines intersect. One of the lines had recently leaked and had been repaired. At the time of the site survey, a strip of freshly excavated soil was present at this location. One of the low-level waste transfer lines runs south along the western side of Impoundment 3513 to an active weir box located in grid block 1N. Soil contamination reported in grid blocks 1B, 1K, 1L, 1M, 1N, and 1O are all attributed to the presence of the transfer line.

High gross gamma values were also reported for the samples from the 0 to 0.3 m interval in both grid block 14H (4,600 cps/kg) and grid block 6N (3,800 cps/kg). The predominant radionuclide reported for these samples was ^{137}Cs, although the highest transuranic activities levels are also reported at these locations. Although elevated activities are reported in the upper sample intervals, activities for all radionuclides decrease with depth indicating the source of the activity is probably a surface release. Both of these samples were apparently collected inside the fence surrounding Impoundment 3513. Huang et al. (1984) speculate that fluctuation in the water level in the impoundment occasionally results in surface water covering the sampled area.

Samples from grid blocks 14H and 6N as well as the two deep cores were collected to evaluate if radionuclides were migrating from Impoundment 3513. Although elevated activities are reported for several radionuclides in the upper sample intervals at 14H and 6N, activities for

all radionuclides decrease with depth, indicating the source of that activity is probably a surface release. The results reported for the deep cores do not indicate any significant surface contamination. Strontium-90 was detected in sample intervals at or near the bottom of both deep cores. A water sample collected at the bottom of deep core 2 had a reported 0.033 Bq/g of ^{90}Sr, which Huang et al. (1984) interpret as indicating the possibility of some migration of ^{90}Sr from the impoundment.

Uziel et al. (1989) conducted a surface radiological survey of contamination at Impoundment 3524. To support the investigation a sample grid was set up dividing the area of the impoundment into 15-m (50-ft) grid blocks based on the ORNL coordinate system. Gamma exposure rate scans were made for each grid. Gamma exposure rate measurements were also taken at selected points within the grids along with beta-gamma dose rates and alpha activity levels.

Measurements were taken of gamma exposure levels using an NaI scintillation probe. Measurements were made at 100 cm and 5 cm above ground surface. To differentiate the effect of gamma radiation emanating from the sediments present in the impoundment from radiation sources in the surrounding area, surface gamma exposure levels were also taken with the NaI detector inserted into a cylindrical lead shield with an open end facing the ground surface.

The NaI detector provides a measure of the total gamma radiation field at a location derived from all potential sources in the area. To support interpretation of the gamma exposure levels collected using the NaI detector, surface beta-gamma radiation levels and alpha radiation levels were directly measured.

Measurements of gamma exposure levels reported by Uziel et al. (1989) determined that exposure rates at 100 cm above ground surface at 84 grid point locations ranged from 190 to 2,900 μR/hour. Gamma exposure rates at ground surface at 85 grid locations ranged from 120 to 2,900 μR/hour. For comparison, background gamma exposure rates determined from uncontaminated locations ranged from 8 to 13 μR/hour at 100 cm, and from 10 to 17 μR/hour at ground surface.

Gamma exposure rates at 1 m above ground surface were consistently higher than surface exposure rates, and unshielded surface exposure rates were significantly higher than lead-shielded surface rates. This result was interpreted as indicating the measurements taken at 100 cm and unshielded surface measurements included radiation emanating from the nearby impoundments.

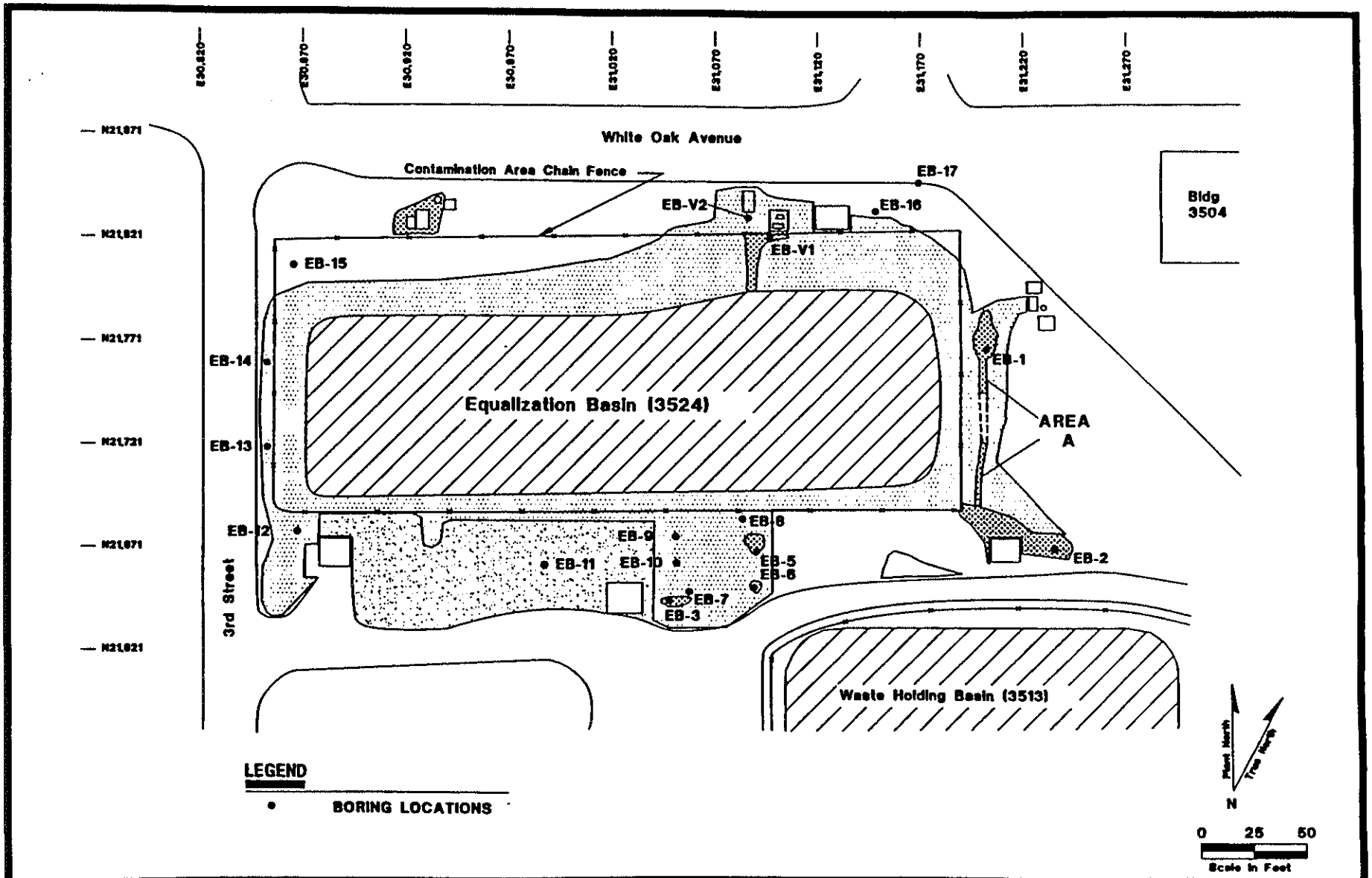
Gamma exposure rates were also observed to vary over the entire study area in response to the water level in the impoundment. When the water level was relatively low, exposure rates at the contamination area fence were 810 and 710 μR/hour at 1 m and 460 and 500 μR/hour at the surface (at grid points 51 and 62). Exposure rates at the same locations after a rainfall with the water level in the impoundment within 0.3 m of the top of the berm were 190 and 150 μR/hour at 1 m and 160 and 120 μR/hour at the surface.

The surface beta-gamma measurements were used to delineate contaminated areas around Impoundment 3524. The resulting interpretation by Uziel et al. (1989) is shown in Figure B3.2. Shading in Figure B3.2 depicts contaminated areas within the area investigated. Light shading was used to indicate that the entire area was contaminated, with progressively darker shading defining areas of increasing beta-gamma contamination. Specific radiation levels were not assigned to define the areas but selected surface gamma exposure levels are shown to illustrate the variation in measured exposure levels.

To provide additional information on the nature of the soil contamination, Uziel et al. (1989) collected 30 soil samples from 17 locations shown on Figure B3.3. All samples were analyzed for gross beta activity, gross alpha activity, ^{60}Co, and ^{137}Cs. Six samples were also analyzed for ^{134}Cs, ^{152}Eu, ^{154}Eu, and ^{155}Eu. The surface sample (0–5 cm) from location EB-1 reportedly had high alpha activity (1,000 dpm/100 cm^2) and was analyzed for plutonium and uranium isotopes. The analytical results for all samples are summarized in Figure B3.3.

The results for analysis of the soil samples are consistent with the surface beta-gamma data; areas with high gamma exposure rates are associated with soil samples that have high gross beta activity. The highest gross beta activity for soil samples (930 Bq/g) is reported for location EB-2, which is located southeast of Impoundment 3524 in the area with the highest gamma exposure rate (6,500 μR/hour). Cesium-137 is the only gamma-emitting radionuclide reported that contributes significantly to the gross beta activity. Analyses for ^{90}Sr were not conducted as part of the investigation. Uziel et al. (1989) consider that rough estimate of ^{90}Sr activity can be calculated from the difference between the gross beta activity and the ^{137}Cs activity.

In general, gross beta activity decreased with depth, suggesting that the source of the radioactivity was a surface release. The single exception was at location EB-6. Uziel et al. (1989) described the EB-6 location as a low-lying area directly south of Impoundment 3524 that remained moist during the course of the field investigation. At EB-6 the ^{137}Cs activity was found to increase with depth from 0.72 Bq/g for the sample interval 0–15 cm, to 4.9 Bq/g for the sample interval 30–46 cm. Apparently, leaching of ^{137}Cs from the sediments in Impoundment 3524 may be contributing to the increase in radioactivity with depth.



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Soil and vegetation sample locations at Impoundment 3524

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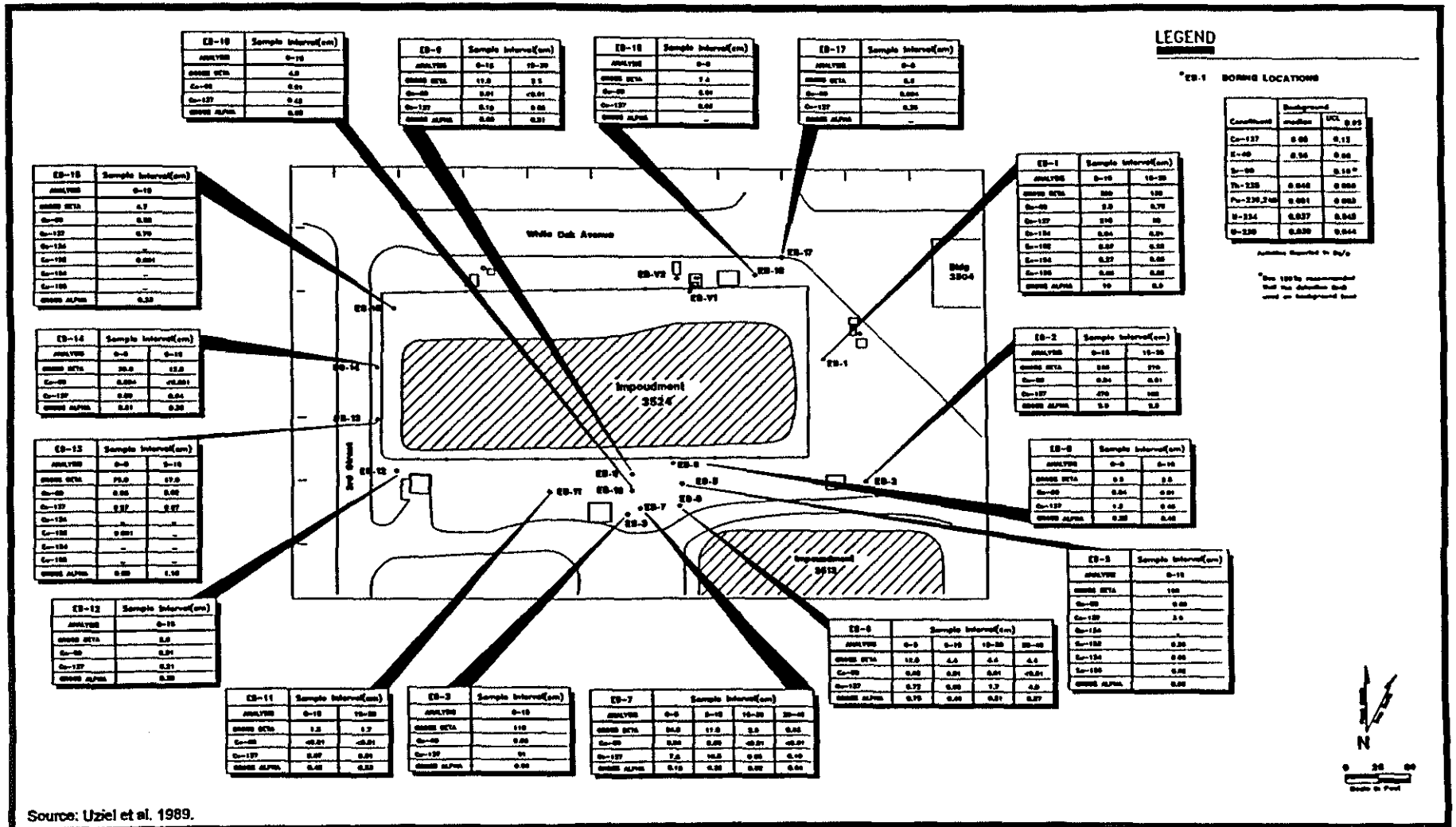
Fig B3.2.

A2037/16NOV94/1=1



Source: Uziel et al. 1989.

Radiological contamination in soil at Impoundment 3524

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Fig B3.3.

A1183A/18NOV94/1e1

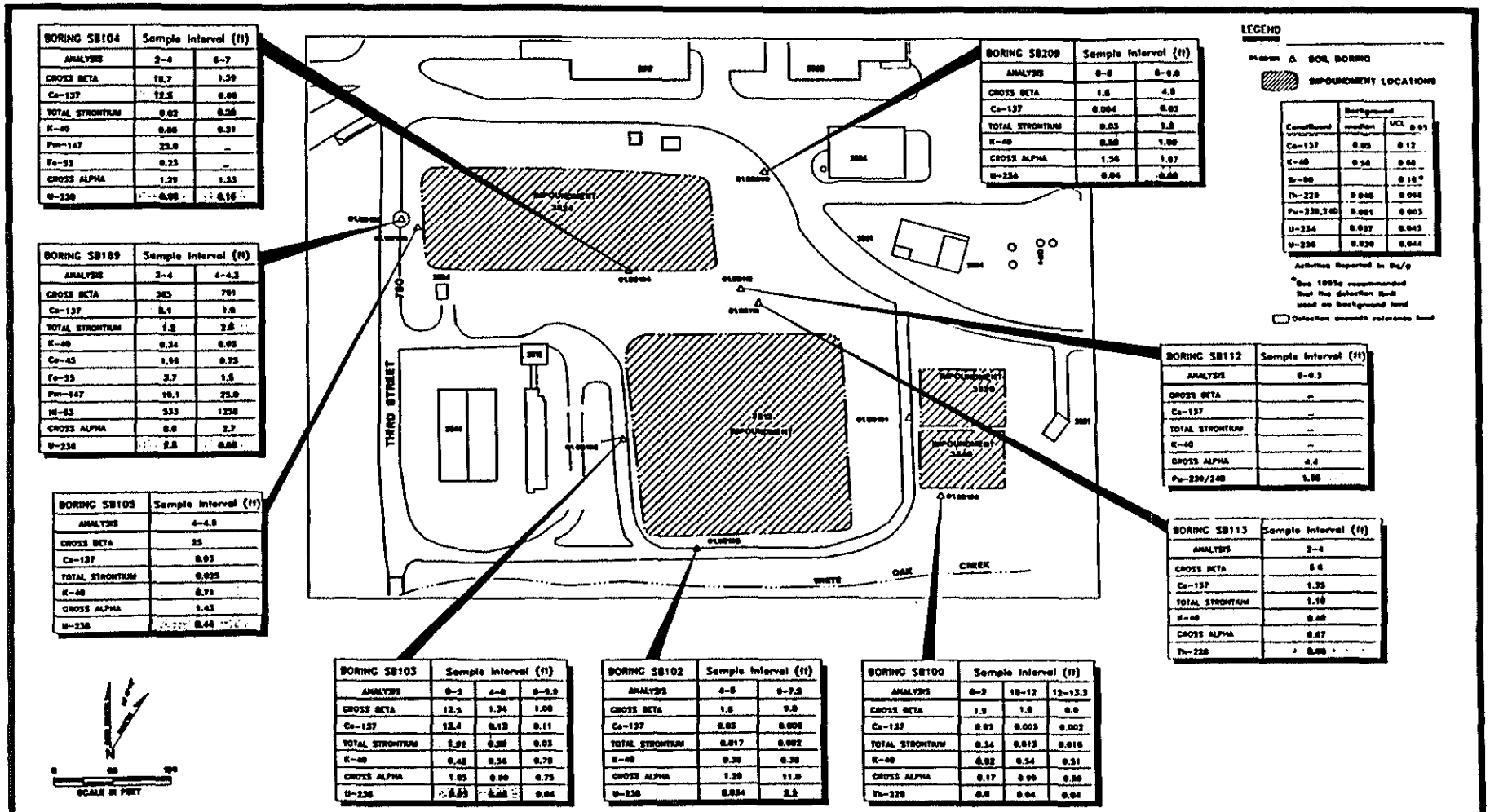
Isotopic analysis for plutonium and uranium of the surface soil sample (0–5 cm) from location EB-1 indicates that the elevated gross alpha activity detected at this location is attributed primarily to ^{239}Pu reported at 5.2 Bq/g. Elevated activity levels for ^{238}Pu and the isotopes of uranium were also reported. Gross alpha activity decreases with depth at location EB-1, and the source of activity is probably attributed to a surface release.

The Site Characterization Summary Report Investigation (DOE 1992b, 1992c, 1992d, 1992e, 1992f) located the nine soil borings shown in Figure B3.4 within 50 ft of SIOU. Radiological contaminants in soil were measured for selected sample intervals through analysis of gross alpha and gross beta activity as well as a variety of individual alpha- and beta-emitting radionuclides. Figure B3.4 summarizes the radiological analytical data for borings. All gross alpha and gross beta activity results are listed as well as individual radionuclides that significantly contribute to the total activity. Results for the reference samples are provided for comparison.

The highest gross beta activity in soils at SIOU is reported for samples collected from boring SB189 located near the western perimeter of Impoundment 3524. The reported gross beta activity in the 4- to 4.3-ft sample collected from this boring was 791 Bq/g, the fifth highest gross beta activity measured in Waste Area Grouping 1 soils. Individual isotopes reported at significantly elevated levels for this sample include ^{63}Ni (1258 Bq/g), ^{147}Pm (25 Bq/g), ^{55}Fe (1.5 Bq/g), and ^{45}Ca (0.73 Bq/g). Nickel-63 has not been previously reported associated with the sediments present in the impoundments and is not reported in any other boring. Gross beta activity and the activity of ^{63}Ni increases with depth in boring SB189, suggesting that the source of the activity may indicate an underground release, possibly from a waste transfer line, unrelated to the operation of the impoundments.

After SB189, the highest gross beta activity is reported for samples from SB105 (25 Bq/g for sample interval 4 to 4.6 ft), SB104 (18.3 Bq/g for sample interval 2 to 4 ft) and SB103 (12.5 Bq/g for sample interval 0 to 2 ft). For SB103 and SB104, gross beta activity decreases with depth and ^{137}Cs is identified as the primary beta-emitting radionuclide. Boring SB-105 is located near SB189 and the sample interval reported for SB105 is comparable to that reported for the most contaminated sample from SB189. No individual radionuclide is reported for SB105 that accounts for the gross beta activity.

Limited alpha contamination was reported for the soil borings in the vicinity of the impoundments. Soil boring SB102, located immediately south of Impoundment 3513, has the highest gross alpha activity (11 Bq/g for the sample interval 6–7.5 ft) reported for samples in the vicinity of the impoundments. (The highest gross alpha activity reported for Waste Area



BORING SB104	Sample Interval (ft)	
ANALYSIS	2–4	6–7
GROSS BETA	18.7	1.30
Cs-137	12.5	0.06
TOTAL STRONTIUM	0.02	0.26
K-40	0.66	0.31
Pm-147	25.0	--
Fe-55	0.23	--
GROSS ALPHA	1.29	1.33
U-238	0.98	0.16

BORING SB209	Sample Interval (ft)	
ANALYSIS	0–8	8–8.8
GROSS BETA	1.8	4.8
Cs-137	0.004	0.03
TOTAL STRONTIUM	0.03	1.3
K-40	0.36	1.00
GROSS ALPHA	1.36	1.07
U-234	0.04	0.00

Constituent	Background median	UCL
Cs-137	0.05	0.12
K-40	0.56	0.60
Sr-90		0.16*
Th-228	0.046	0.064
Pu-239,240	0.001	0.003
U-234	0.037	0.045
U-238	0.030	0.044

Activities Reported in Bq/g

*See 1993a recommended that the detection limit used as background level

Detection exceeds reference level

BORING SB189	Sample Interval (ft)	
ANALYSIS	2–4	4–4.3
GROSS BETA	345	791
Cs-137	0.1	1.0
TOTAL STRONTIUM	1.3	2.6
K-40	0.34	0.05
Co-45	1.96	0.73
Fe-55	3.7	1.5
Pm-147	19.1	25.0
Ni-63	533	1258
GROSS ALPHA	0.0	2.7
U-238	2.8	0.00

BORING SB112	Sample Interval (ft)
ANALYSIS	0–0.3
GROSS BETA	--
Cs-137	--
TOTAL STRONTIUM	--
K-40	--
GROSS ALPHA	4.4
Pu-239/240	1.06

BORING SB105	Sample Interval (ft)
ANALYSIS	4–4.8
GROSS BETA	25
Cs-137	0.03
TOTAL STRONTIUM	0.025
K-40	0.71
GROSS ALPHA	1.43
U-238	0.44

BORING SB113	Sample Interval (ft)
ANALYSIS	2–4
GROSS BETA	5.6
Cs-137	1.35
TOTAL STRONTIUM	1.10
K-40	0.40
GROSS ALPHA	0.07
Th-228	0.00

BORING SB103	Sample Interval (ft)		
ANALYSIS	0–2	4–6	8–8.9
GROSS BETA	12.5	1.34	1.00
Cs-137	12.4	0.13	0.11
TOTAL STRONTIUM	0.02	0.30	0.03
K-40	0.40	0.34	0.75
GROSS ALPHA	1.05	0.90	0.75
U-238	0.50	0.00	0.04

BORING SB102	Sample Interval (ft)	
ANALYSIS	4–6	6–7.5
GROSS BETA	1.6	9.0
Cs-137	0.03	0.008
TOTAL STRONTIUM	0.017	0.002
K-40	0.39	0.30
GROSS ALPHA	1.29	11.0
U-238	0.034	0.3

BORING SB100	Sample Interval (ft)		
ANALYSIS	0–2	10–12	12–13.3
GROSS BETA	1.3	1.0	0.0
Cs-137	0.05	0.003	0.002
TOTAL STRONTIUM	0.34	0.013	0.016
K-40	0.02	0.34	0.31
GROSS ALPHA	0.17	0.99	0.90
Th-228	0.0	0.04	0.04

Source: DOE 1992.

Radiological contaminants detected in soil borings in the vicinity of the Surface Impoundments Operable Unit

Oak Ridge National Laboratory
Oak Ridge, Tennessee

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Fig B3.4.

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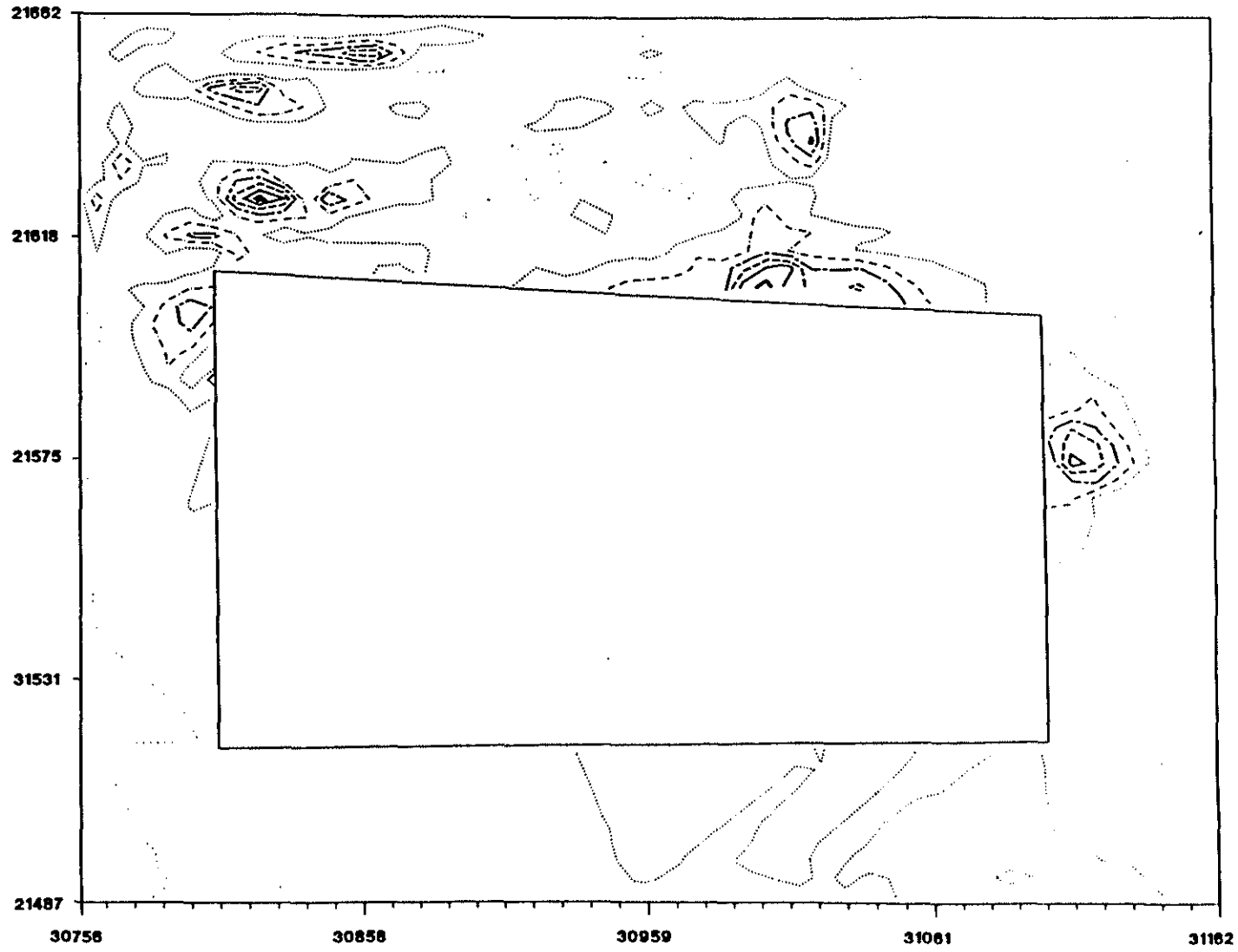
Grouping 1 is 115 Bq/g at a location near Building 3019.) The gross alpha activity for soil boring SB102, as well as SB189, is attributed primarily to ^{238}U. Gross alpha activity reported for soil boring SB112 is attributed primarily to $^{239,240}Pu$. Soil boring SB112 is located southeast of Impoundment 3524 near sample location EB-2 (Fig. B3.3), where Uziel et al. (1989) reported elevated gross alpha activity, and south of the sample location EB-1, where elevated gross alpha activity was also reported and subsequent analysis indicated 5.2 Bq/g ^{239}Pu.

As part of the Site Characterization Summary Report Investigation of Waste Area Grouping 1, a surface radiation survey was conducted (DOE 1992c). Using the ultrasonic ranging and data system, two radiation detection systems were used concurrently to measure radiation fields. A NaI (Tl) detection system was used to measure near-surface gamma radiation fields while an ionization chamber set at approximately 1 m above ground measured direct exposure rates of the gamma radiation field.

After validation, the digital data were gridded into intervals of 2 ft by 2 ft to allow efficient processing. Contour maps were generated from the data for Waste Area Grouping 1. Thirteen areas in Waste Area Grouping 1 were identified that exhibit exposure rates greater than or equal to 100 μR/hour. The highest rate measured as greater than 2,500 μR/hour was reported in the South Tank Farm, part of the Gunite and Associated Tanks Operable Unit, located north of SIOU. A contour map of exposure rates in the vicinity of Impoundment 3524 is shown in Figure B3.5. The exposure rates shown in Figure B3.5 range from less than 25.5 μR/hour to greater than 404 μR/hour. A contour map of exposure rates in the vicinity of Impoundment 3513 is shown in Figure B3.6. The exposure rates shown in Figure B3.6 range from less than 31 μR/hour to greater than 472 μR/hour.

The ultrasonic ranging and data system data in general cannot be interpreted as a direct measure of the extent of radioactive contamination in soils. Measurements made by both radiation detection systems are omnidirectional and do not differentiate beta/gamma radiation emitted by radionuclide contaminants in soils from radiation emitted by surrounding structures (e.g., radiologically contaminated piping, tanks, building). Radiation from such sources which may include above-ground structures, is referred to as "shine." The Site Characterization Summary Report investigation evaluated the data at the thirteen areas with elevated exposure rates to determine is the exposure rates were due to contaminated soil or shine. The result of the evaluation indicated that the exposure rates in the vicinity of the impoundments are due primarily to contamination present in the soil and sediment.

Francis and Stansfield (1986a) and Francis and Hyder (1987) reported on an investigation to collect cores of bedrock from beneath Impoundment 3513. The objective of the investigation



LEGEND

- 404.58 µR/h
- 341.38 µR/h
- 278.21 µR/h
- 215.04 µR/h
- 151.86 µR/h
- 88.69 µR/h
- 25.51 µR/h

Source: DOE 1992.

USRADS radiological contour map of Impoundment 3524 area

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Fig B3.5.

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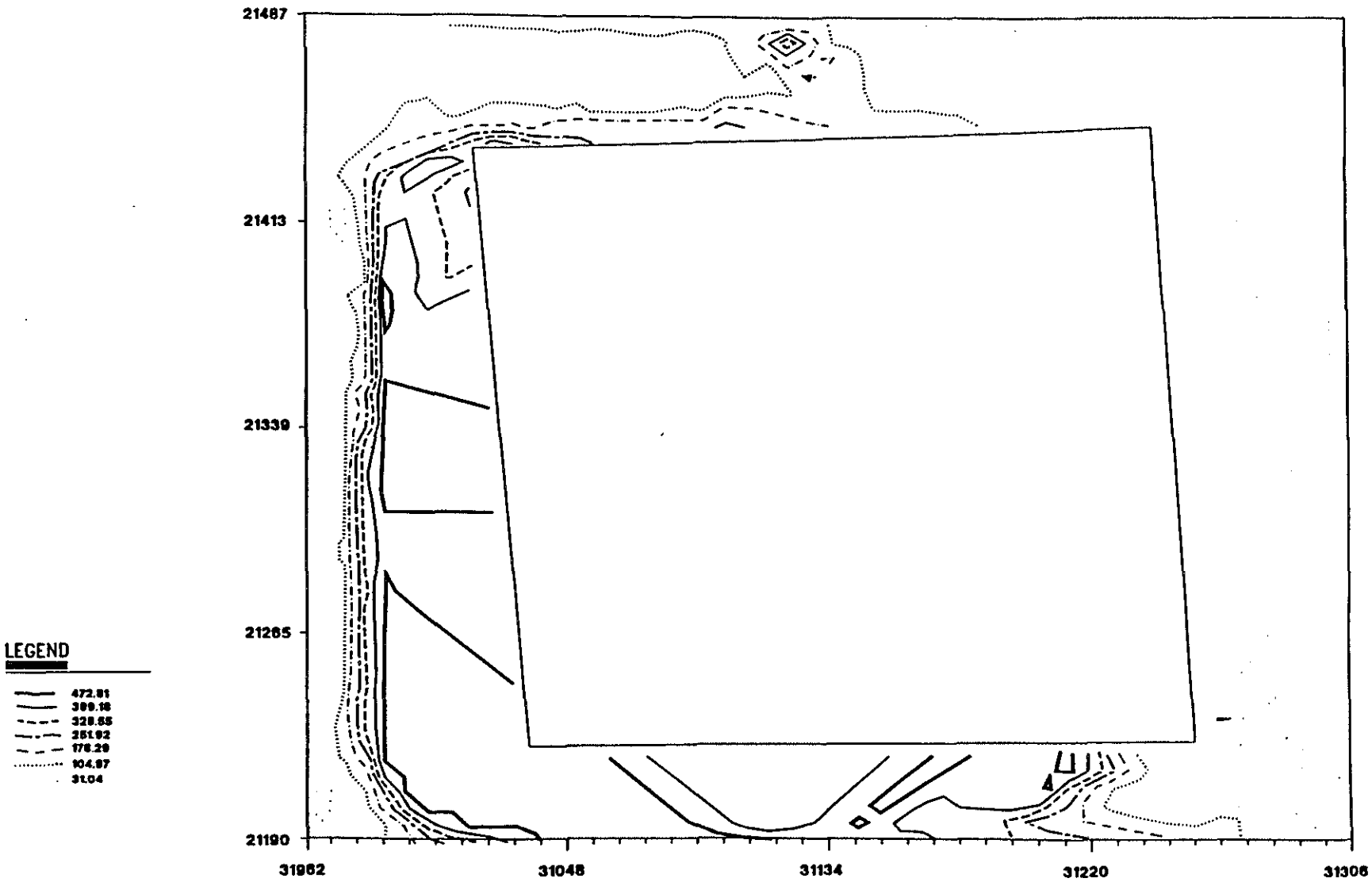

Source: DOE 1992.

USRADS radiological contour map of impoundment 3513 area

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Fig B3.6.

A2020/15NOV94/1.2

was to evaluate the potential for contaminant migration into the bedrock from the impoundment. Two boreholes were drilled at an angle under the impoundment. One borehole identified as C-1 was drilled nearly perpendicular to geologic strike, and the second borehole identified as C-2 was drilled nearly parallel to geologic strike. Two-inch diameter cores, approximately 100 ft long, were recovered from each borehole.

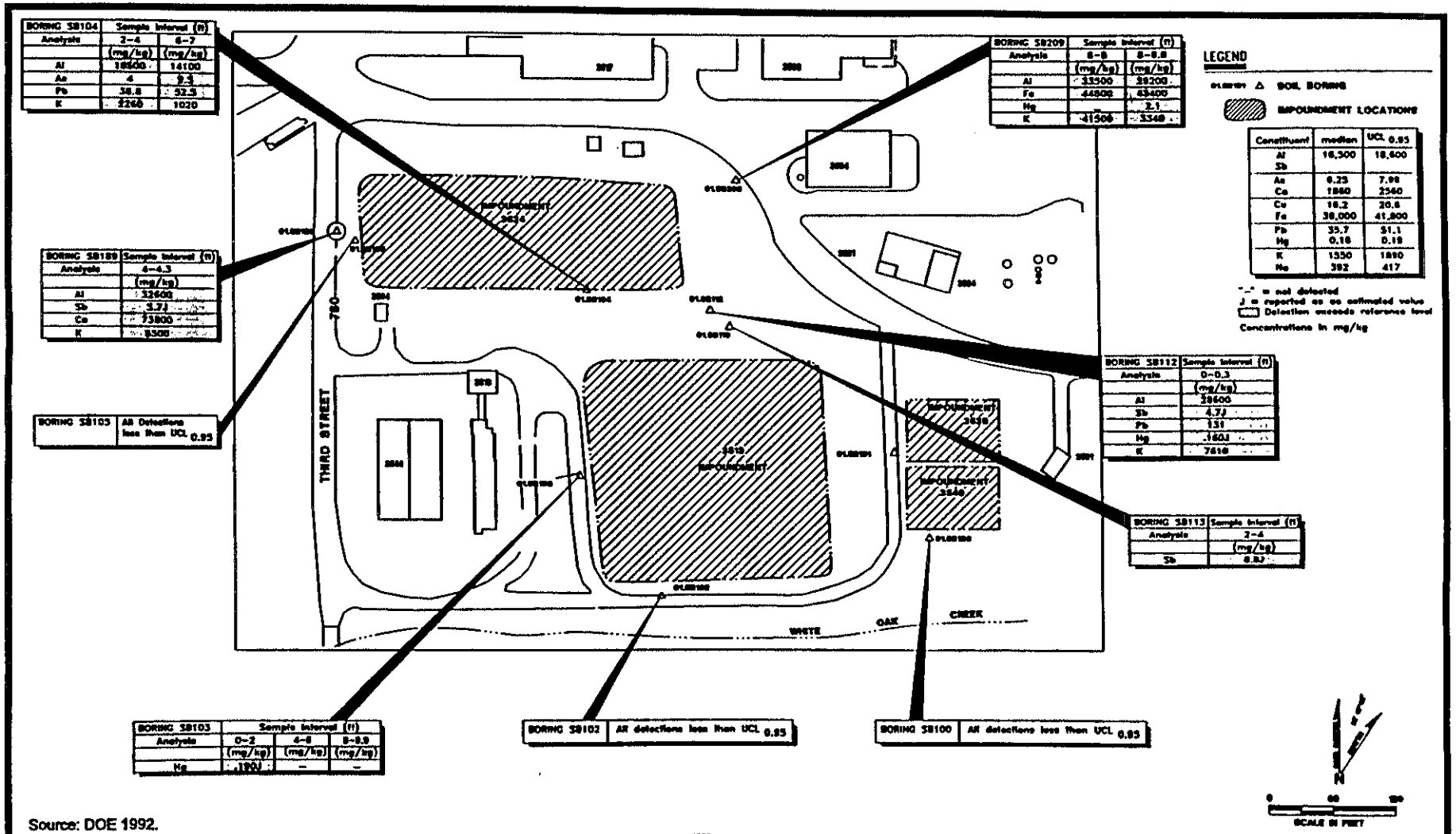
To evaluate if the bedrock was contaminated, fine-grained material from fracture surfaces and voids was collected from intervals along the length of the cores. Samples were analyzed for gross alpha and gross beta activity. Selected samples were also analyzed for ^{90}Sr, gamma-emitting radionuclides, and mercury.

Reported results for gross alpha activity did not indicate contamination of the bedrock by alpha-emitting radionuclides. Gross beta measurements indicated detectable activity; however, with the exception of one sample from core C1, reported results were statistically not significantly different than that reported for the control sample. Gross beta activity in the sample from the 38.5- to 43.5-ft interval in core C1 was statistically, significantly higher than the control sample. Analysis of this sample for ^{90}Sr identified detectable activity (0.04 ± 0.03 Bq/g). No other samples had detectable levels of ^{90}Sr or detectable levels of any gamma-emitting radionuclides. These data will, therefore, not be reproduced in this report.

3.2.2 Metal Contamination

The only samples analyzed for metals in soils at SIOU were collected in 1992 as part of the Waste Area Grouping 1 RI. Samples were collected from nine soil borings in the vicinity of SIOU; detections of most metals varied widely, even among samples from the same boring. Because metals are naturally present in soils, analytical results have been compared to the median and UCL_{95} detected in soils derived from the same geologic unit in Bethel Valley (DOE 1993a,b,c). This approach provides a means to screen out metals within the range of naturally occurring metals for this type of soil and focus only on those metals present in higher concentrations. The metals detected in exceedence of maximum reference levels, however, may still represent natural conditions as a result of variability within soil types or may potentially be the result of contamination. Analytical results from sediment/sludge samples collected in 1994 from the impoundments are also compared to results from SB100 and SB102-SB105 to determine possible sources of contamination.

Figure B3.7 shows the distribution of metals detected in soil borings in the vicinity of SIOU. The following paragraphs discuss only those metals detected above the maximum reference levels. Metals detected of greatest concern were Sb, As, Pb, and Hg. Al, Ca, Fe and K also were detected above reference levels in surface soils (0–2 ft depth) and subsurface soils



Source: DOE 1992.

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Metals detected in soil borings in the vicinity of the Surface Impoundments Operable Unit

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Oak Ridge, Tennessee

Fig B3.7.

(> 2 ft depth); however, these metals are naturally present in soils in varying quantities, and do not pose a health risk. They will not be discussed in detail.

3.2.2.1 Impoundment 3524

Two soil borings (SB104 and SB105) were drilled south and west of Impoundment 3524 to determine if nearby soils have been impacted (Fig. B3.7). Only subsurface soils were sampled and analyzed. Arsenic was detected in SB104 at concentrations of 5.0 and 9.5 mg/kg with the highest detection at 6–7 ft, above the UCL_{95} of 8.0 mg/kg. Concentrations of arsenic detected in sediment/sludge samples collected from the impoundment ranged from 3.7 to 16.4 mg/kg, which suggests that impoundment 3524 is the probable source. Arsenic was not detected in SB105 at the western border of the impoundment.

Lead also was detected in subsurface soils from SB104. Concentrations detected were 38.8 and 52.5 mg/kg, with concentration increasing with depth. Lead detected in sediment/sludge samples from the impoundment ranged from 215 to 5,180 mg/kg; therefore, it is likely that the impoundment is the source of the lead contamination in this soil boring. Lead was not detected in SB105 to the west.

3.2.2.2 Other borings near Impoundment 3524

Four other borings (SB189, SB112, SB113, and SB209) in the vicinity of Impoundment 3524 were drilled to investigate suspect contamination not related to operation of the impoundments. Soil boring SB189, which was installed to investigate a known leak in a waste transfer pipeline, contained antimony (5.7J mg/kg) and arsenic (5.2J mg/kg) in subsurface soils at 8–9 ft depth, the only interval sampled (Fig. B3.7). Antimony was not detected in reference samples; however, the UCL_{95} for arsenic is 8.0 mg/kg. Concentrations of Al, Ca, and K also were detected above the UCL_{95}s. Soils in this boring indicate they have been impacted by contamination; the source is most likely the buried pipeline.

The radiological survey conducted by Uziel et al, (1989) indicated an area of potential contamination based on survey results. Within this area is the distribution box that serves as a sump for process waters from the main plant and evenly distributes these waters via several pipelines to Impoundment 3513. Two soil borings (SB112 and SB113) were drilled in this area to determine if contamination was present in the soils. Samples were collected from 0–0.3 ft in SB112 and 2–4 ft in SB 113. Antimony, which was not detected in reference samples, was present in surface and subsurface soils at concentrations ranging from 4.7J to 6.8J mg/kg in borings SB112 and SB113, respectively (Fig. B3.7). Data were insufficient to determine vertical distribution trends. No other metals were detected in SB113 above maximum reference levels. Lead (131 mg/kg), UCL_{95}, as well as Al and K, were detected in surface soils from SB112 above

UCL_{95}. Arsenic (6.4 mg/kg) and mercury (160J mg/kg) were detected but at concentrations below their UCL_{95}. These soils appear to be impacted by the activities associated with the process water distribution box.

Contamination of subsurface soils was suspected northeast of Impoundment 3524 based on the radiological survey conducted by Uziel et al. (1989) and the presence of a buried waste transfer pipeline in the area. Soil boring SB209 was drilled to investigate the possibility of subsurface soil contamination; samples were collected from 6–8 ft and 8–9 ft intervals. Mercury was detected only in the lower interval at 2.1 mg/kg exceeding the UCL_{95} of 0.19 mg/kg. Al, Fe, and K from both intervals also exceeded reference levels. The presence of mercury only at the lower interval suggests the source is a leak in the buried waste transfer pipeline.

3.2.2.3 Impoundment 3513

Soil samples were collected from borings SB102 and SB103 located south and west of Impoundment 3513, respectively. All metals detected in SB102 were below maximum reference levels. Mercury was detected in SB103 at 0.19J mg/kg in the surface soil sample, but was not detected in subsurface soils. Mercury has a UCL_{95} of 0.19 mg/kg. This is the only metal detected at or above reference level in soils downgradient of Impoundment 3513. Concentrations of mercury detected in sediment/sludge samples from this impoundment ranged from 22.6 to 65.5 mg/kg; therefore, it is possible that the source of the mercury detected in surface soils at SB103 is Impoundment 3513 or that the contamination is the result of a surface spill.

As indicated in Section 3.2.2, selected samples collected from two cores of bedrock obtained from below Impoundment 3513 were analyzed for mercury (Francis and Hyder 1987). Concentrations of mercury ranged from 0.012 to 0.063 mg/kg. Although individual results are above the value reported for the control sample, the elevated values are considered to represent the natural variation in mercury concentration and not an indication of contamination. All values are within the background levels for soils (i.e., 0.19 mg/kg) reported by DOE (1993a,b,c). However, because the cores are not the same media, this is not strictly an appropriate comparison.

3.2.2.4 Impoundment 3539 and 3540

Two soil borings (SB100 and SB101) are located south and west of Impoundments 3539 and 3540; however, only SB100 was sampled and analyzed. Intervals sampled were 0–2 ft, 10–12 ft, and 12–13.3 ft. All reported concentrations were below their respective UCL_{95}.

3.2.3 Organic Contamination

3.2.3.1 Impoundment 3524

Two borings (SB104 and SB105) shown in Figure B3.8 were drilled south and west of Impoundment 3524; soil samples were collected only from the subsurface (> 2 ft depth). Methylene chloride was the only parameter detected (39 μg/kg) in SB105 at a depth of 4–4.6 ft. Methylene chloride was also detected (43 μg/kg) in SB104 at a depth of 6–7 ft, but was not detected in the more shallow intervals sampled. Methylene chloride was also not detected in sediment/sludge samples from Impoundment 3524, indicating the possibility of a different source.

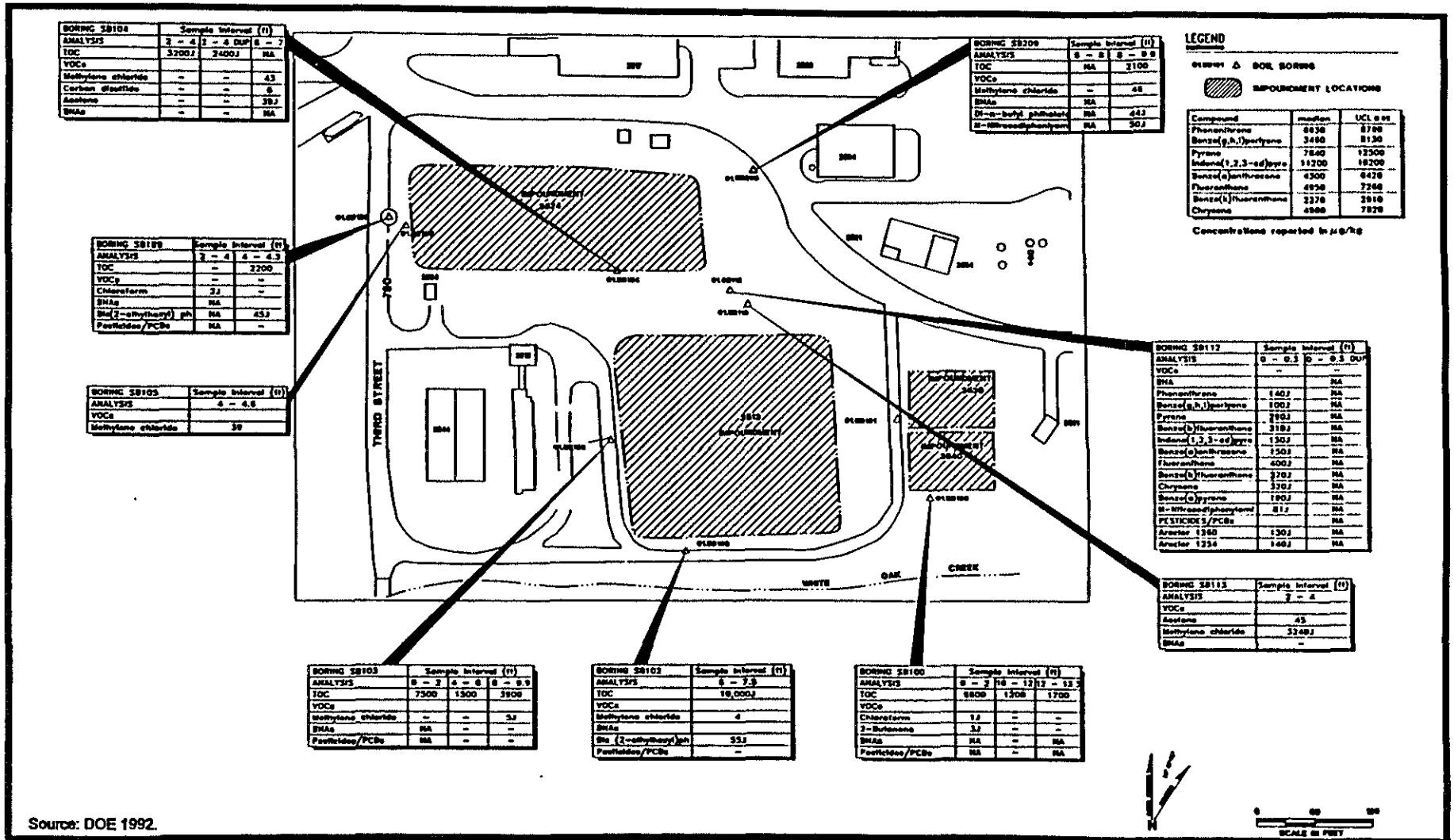
Soil boring SB104 also contained 6 μg/kg carbon disulfide and 39 μg/kg acetone in the 6–7 ft interval; however, neither was detected in the shallow intervals. Carbon disulfide was not detected in impoundment sediments, but acetone was detected ranging from 300 to 1,100 μg/kg, indicating the possibility of contamination from Impoundment 3524. TOC detected in SB104 decreased with depth with the highest concentration in the 2–4-ft interval at 3,200J μg/kg. Sediments from the impoundment ranged from 1,300 to 33,000 μg/kg TOC. No base-neutral/ acid (BNAs) extractables, pesticides, or PCBs were detected in SB104

3.2.3.2 Other borings near Impoundment 3524

As previously discussed, four borings (SB189, SB112, SB113, and SB209) were drilled in the vicinity of Impoundment 3524 to investigate suspect contamination not related to operation of the impoundments. Soil boring SB189 was installed to investigate a known leak in a waste transfer pipeline. Chloroform was detected at 2J μg/kg at 2–4 ft in this boring, but was not detected at 4–4.3 ft. Bis(2-ethylhexyl)phthalate was detected at 45J μg/kg at 4–4.3 ft, but was not detected at 2–4 ft. TOC also was reported at 2,200 μg/kg in the lower interval.

Two soil borings (SB112 and SB113) drilled near the process water distribution box were sampled at 0–0.3 ft in SB112 and 2–4 ft in SB113. VOCs were the only organics detected in SB113; BNAs and pesticides/PCBs were the only organics detected in SB112 (Fig B3.8). The levels of contamination in the shallow soils indicate possible spills, leaks, or overflows from the distribution box. The reconcentration for the BNA compounds were below their respective UCL_{95}s where data were available.

Soil boring SB209 was drilled northeast of Impoundment 3524 to investigate the possibility of subsurface soil contamination from a buried waste transfer pipeline; samples were collected at 6–8 ft and 8–9 ft intervals. No organics were detected in the 6–8 ft interval. TOC (2,100 μg/kg), methylene chloride (46 μg/kg), Di-n-butylphthalate (44J μg/kg), and



BORING SB104	Sample Interval (ft)		
ANALYSIS	2 – 4	2 – 4 DUP	6 – 7
TOC	3200J	2400J	NA
VOCs			
Methylene chloride	–	–	43
Carbon disulfide	–	–	6
Acetone	–	–	39J
BNAs	–	–	NA

BORING SB109	Sample Interval (ft)	
ANALYSIS	2 – 4	4 – 4.3
TOC	–	2200
VOCs	–	–
Chloroform	3J	–
BNAs	NA	
Bis(2-ethylhexyl) ph	NA	45J
Pesticides/PCBs	NA	–

BORING SB105	Sample Interval (ft)
ANALYSIS	4 – 4.6
VOCs	
Methylene chloride	39

BORING SB103	Sample Interval (ft)		
ANALYSIS	0 – 2	4 – 6	8 – 9.5
TOC	7500	1300	3900
VOCs			
Methylene chloride	–	–	3J
BNAs	NA	–	–
Pesticides/PCBs	NA	–	–

BORING SB102	Sample Interval (ft)
ANALYSIS	6 – 7.5
TOC	10,000J
VOCs	
Methylene chloride	4
BNAs	
Bis (2-ethylhexyl)ph	55J
Pesticides/PCBs	–

BORING SB100	Sample Interval (ft)		
ANALYSIS	0 – 2	10 – 12	12 – 13.5
TOC	6800	1300	1700
VOCs			
Chloroform	1J	–	–
2-Butanone	3J	–	–
BNAs	NA	–	NA
Pesticides/PCBs	NA	–	NA

BORING SB209	Sample Interval (ft)	
ANALYSIS	0 – 2	8 – 9.5
TOC	NA	2100
VOCs		
Methylene chloride	–	46
BNAs	NA	
Di-n-butyl phthalate	NA	44J
N-Nitrosodiphenylam	NA	50J

Compound	median	UCL 0.95
Phenanthrene	6830	8700
Benzo(g,h,i)perylene	3400	8130
Pyrene	7840	12300
Indeno(1,2,3-cd)pyre	11200	18200
Benzo(a)anthracene	4300	6470
Fluoranthene	4950	7260
Benzo(k)fluoranthene	2370	3910
Chrysene	4900	7870

BORING SB112	Sample Interval (ft)	
ANALYSIS	0 – 0.5	0 – 0.5 DUP
VOCs	–	–
BNA		NA
Phenanthrene	140J	NA
Benzo(g,h,i)perylene	100J	NA
Pyrene	290J	NA
Benzo(b)fluoranthene	310J	NA
Indeno(1,2,3-cd)pyre	130J	NA
Benzo(a)anthracene	150J	NA
Fluoranthene	400J	NA
Benzo(k)fluoranthene	270J	NA
Chrysene	370J	NA
Benzo(a)pyrene	190J	NA
N-Nitrosodiphenylamine	81J	NA
PESTICIDES/PCBs		NA
Aroclor 1260	130J	NA
Aroclor 1254	140J	NA

BORING SB113	Sample Interval (ft)
ANALYSIS	2 – 4
VOCs	
Acetone	45
Methylene chloride	3240J
BNAs	–

Source: DOE 1992.

Organic chemicals detected in soil borings in the vicinity of the Surface Impoundments Operable Unit

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Oak Ridge, Tennessee

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Fig B3.8.

JP1018/10NOV95/0000

N-nitrosodiphenylamine (50J μg/kg) were detected at 8-9 ft. These data suggest a possible leak in the transfer pipeline.

3.2.3.3 Impoundment 3513

Two soil borings (SB102 and SB103) were drilled south and west of Impoundment 3513. One interval (6-7 ft) was sampled and analyzed in SB102 and three intervals (0-2 ft, 4-6 ft, and 8-9 ft) in SB103. In SB102 methylene chloride was detected at 4 μg/kg, bis(2-ethylhexyl)phthalate at 55J μg/kg, and TOC at 10,000J μg/kg. Of these parameters, only bis(2-ethylhexyl)phthalate was reported in sediment/sludge samples from the impoundment ranging from 7,000BJ to 380,000BD μg/kg. Methylene chloride was detected in SB103 only in the deepest interval at 5J μg/kg; TOC ranged from 1,500 to 7,500 μg/kg with the highest detection in surface soils. BNAs were not detected in SB103; pesticides/PCBs were not detected in samples from either boring. Based on the low concentrations detected, apparently Impoundment 3513 is not significantly impacting surrounding soils.

3.2.3.4 Impoundments 3539 and 3540

Soil samples were collected from only one boring located south of Impoundments 3539 and 3540 (SB100) from depths of 0-2 ft, 10-12 ft, and 12-13 ft. TOC concentrations ranged from 1,200 to 6,600 μg/kg with the highest concentration in surface soils. Chloroform (1J μg/kg) and 2-Butanone (3J) were detected in surface soils but not in subsurface soils. BNAs and pesticides/PCBs were analyzed for in the sample collected at 10-12 ft, but were not detected. Chloroform was not detected in sediment/sludge samples from these impoundments; however, 2-Butanone was detected at 47 and 71 μg/kg. These data indicate that Impoundments 3539 and 3540 have little, if any, impact on surrounding soils.

3.3 GROUNDWATER

A separate groundwater operable unit has been defined to address groundwater remediation in Waste Area Grouping 1, and additional characterization activities will be conducted as part of the Waste Area Grouping 1 Groundwater Operable Unit. Evaluation of the nature and extent of groundwater contamination at SIOU is based on the results of previous investigations. Additional sampling and analyses were not conducted. The need to address the nature and extent of contamination of the groundwater for SIOU is limited to supporting a risk assessment to evaluate the groundwater as a potential pathway for contaminant migration. Data from previous investigations are presented as reported except for conversion to consistent units of concentration. With the exception of anions, all groundwater constituents are reported as μg/L; anions are reported as mg/L. Analytical uncertainty in the data are not included and the referenced report should be reviewed for a discussion of this issue.

Discussion of the nature and extent of groundwater contamination includes consideration of radiological, inorganic, and organic constituents. The interpretation at SIOU is complicated by several factors that can influence the variability and range of concentration for different constituents. Contaminant concentrations can vary with contaminant release mechanisms, contaminant migration properties, seasonal variability in groundwater level and groundwater flow. Many potential contaminants are also natural constituents of groundwater and the natural variability of these constituents can also depend upon seasonal variations in groundwater level and groundwater flow. In addition, the measurement of the concentration may depend upon well construction, amount of suspended and dissolved solids present, sample collection and preservation techniques, and analytical techniques.

All of the factors described above potentially influence interpretation of the data at SIOU. Previous reported investigations have collected groundwater samples from 1985 to 1991. The investigations conducted during this interval utilized different approaches and techniques to address potential groundwater contamination. In addition, Impoundments 3524, 3539 and 3540 received process waste until 1989 and other potential sources of groundwater contamination are known to be in the area.

To support an evaluation of the potential impact of the impoundments on groundwater concentrations of potential contaminants at SIOU can be compared to established regulatory criteria and to background levels. Regulatory criteria consider risk and technology considerations and are typically established for drinking water supplies (e.g. maximum contaminant levels). The groundwater at SIOU is not a current source of drinking water and evaluation of the potential threat to human health or the environment is considered in the risk assessment. The evaluation conducted in this section focuses on comparison against background levels.

Two approaches are typically considered when comparing data from a facility against background levels and both approaches are utilized. In the first approach, concentrations from monitoring wells around the impoundments are compared to natural background levels determined in other areas with the same geologic unit but unaffected by operations in the same manner used for soils in Section 3.2. The concentrations of groundwater constituents obtained as part of the reference sampling program conducted to support the preparation of the Site Characterization Summary Report for Waste Area Grouping 1 (DOE 1992a) are considered natural background levels. The concentrations reported by individual investigations are compared directly against background levels.

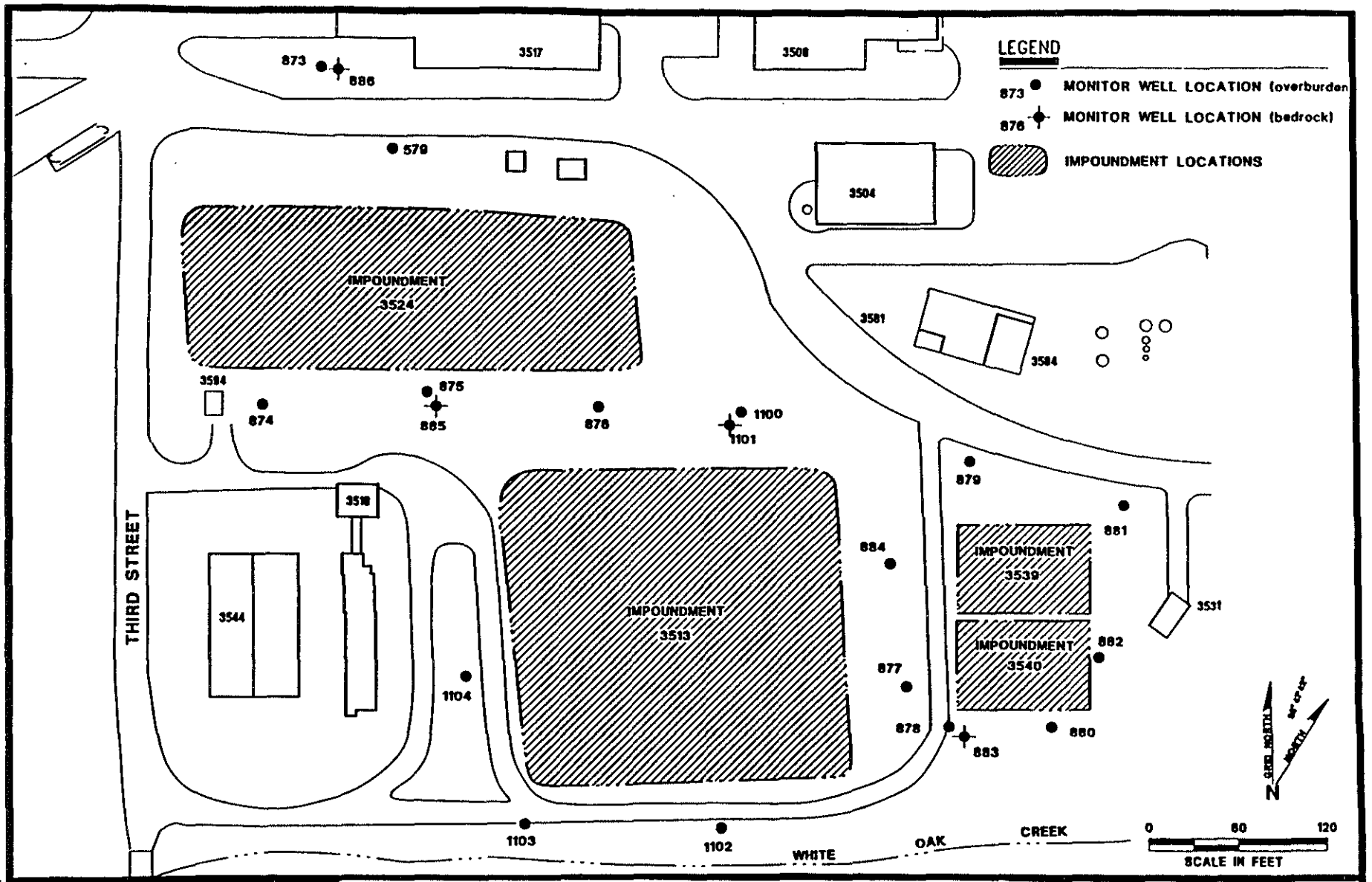
The second approach is to statistically compare data from monitoring wells that are immediately downgradient from an impoundment with monitoring wells that are upgradient. This

approach is routinely used for groundwater monitoring at sites regulated under RCRA. The first reported investigations conducted at SIOU performed such a statistical evaluation (Montford et al. 1986; Francis and Stansfield 1986b) and several statistical approaches are available. An advantage of this approach is that the specific impact of a facility can be evaluated where other sources of groundwater contamination are present at upgradient locations. A limitation of this approach is that sufficient data must be available to meet the specific requirements of the test. The statistical evaluation utilizing all available data at SIOU is presented in Section 3.3.5

3.3.1 Previous Investigations

Twenty monitoring wells shown in Figure B3.9 are located sufficiently close to SIOU to provide information on the nature and extent of groundwater contamination. Before 1985, MW-579, located north and upgradient of the impoundments, was the only well in the immediate area. Monitoring of the groundwater at the four impoundments that are included in SIOU was initiated with the installation of 19 monitoring wells (MW-873 to MW-886 and MW-1100 to MW-1104) around the individual impoundments in 1985. These monitoring wells were initially installed to evaluate more thoroughly the environmental impact of the impoundments in response to provisions promulgated for RCRA facilities, although the impoundments have not been, and are not, RCRA-regulated facilities. These wells have been periodically sampled since installation, and the data from individual sampling events have been summarized in several reports. These data will, therefore, not be reproduced in this report.

In accordance with RCRA requirements, groundwater samples were collected quarterly for one year from the wells around the impoundments. Samples were analyzed for parameters defined by NIPDWS. Samples were also analyzed for groundwater quality parameters and indicator parameters. Additional parameters were included depending upon the site and the scope of the investigation. Details of the sampling and analytical methodology conducted during the first year investigations are described in Francis and Stansfield (1986b) and are not presented here. For Impoundments 3524, 3539, and 3540 the results for the initial year of sampling are summarized in Montford et al. (1986). For Impoundment 3513, results for the initial year of sampling are reported in Francis and Stansfield (1986b). Groundwater samplings at Impoundment 3513 were also conducted in February and June 1987 and reported in Francis and Sealand (1987b). The objective of the samplings was to further evaluate possible contamination of groundwater at Impoundment 3513 by certain metals, primarily lead and chromium. More comprehensive groundwater sampling at Impoundment 3513 was conducted in 1988 and reported in Solomon et al. (1989). The 1988 sampling expanded the list of parameters considered to include specific hazardous organic compounds.



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Groundwater monitoring well locations in the vicinity of the Surface Impoundments Operable Unit

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Oak Ridge, Tennessee

Fig B3.9.

The most comprehensive and recent investigation of groundwater was conducted to support the preparation of the Site Characterization Summary Report for Waste Area Grouping 1 (DOE 1992a). As previously discussed, the Site Characterization Summary Report investigation is part of the Waste Area Grouping 1 Phase I RI. With regard to groundwater at Waste Area Grouping 1, the Site Characterization Summary Report work was planned as a broad scope investigation "...primarily to provide an initial focus for data discussion; it is not intended to represent final interpretation regarding the nature and extent of groundwater contamination in Waste Area Grouping 1" (DOE 1992b, 1992c, 1992d, 1992e, 1992f). The Waste Area Grouping 1 Phase I RI identified issues that required additional work and, as a result, individual operable units were defined, including the Waste Area Grouping 1 Groundwater Operable Unit. Additional work is planned to further characterize the groundwater in Waste Area Grouping 1. Further characterization of the groundwater may be required to implement remediation activities at SIOU; however, the available information is considered adequate for the purpose and scope of this RI/FS.

Samples were collected from 109 monitoring wells and piezometers in Waste Area Grouping 1 during the Site Characterization Summary Report investigation. Nineteen of the twenty wells (monitoring well 883 was not sampled) mentioned previously were sampled. Groundwater sampling typically involved collection of both unfiltered and filtered samples for radiological and chemical analysis. Specific analytes at the contract laboratory varied, but the majority of groundwater samples were analyzed for TCL organics, TAL metals, and radionuclides. Selected samples were also analyzed for Appendix IX constituents, general water quality constituents, and major ions. The Site Characterization Summary Report described details of the sampling and analytical methodology, and are not presented here.

Several separate sampling events were conducted, but not all wells and piezometers were sampled during each event. Initially, three extensive sampling events were planned. The first sampling event occurred in 1990 during the driest months of the year, September and October, under normal low base groundwater flow (LBF) conditions. A total of 77 wells and piezometers were sampled during the LBF event. The second sampling event (referred to as STORM) occurred during a two-day storm on February 22 and 23, 1991, under the resulting high base groundwater conditions. A total of 18 wells and piezometers were sampled during the STORM event. The third sampling event occurred in March and April 1991 at the end of the normal period of highest precipitation; it is referred to as normal (i.e., nonstorm) high base groundwater flow (HBF) conditions. A total of 82 wells and piezometers were sampled during the HBF event. Two additional sampling events were added to the Site Characterization Summary Report investigation to address specific issues. None of the monitoring wells at SIOU were sampled during these events.

Table B3.33 provides a summary of the monitoring wells in the vicinity of SIOU sampled under the Site Characterization Summary Report Investigation in each sampling event and the analyses performed for TAL metals, TCL organics, and radiological analyses. (Additional analyses may have been performed, and reference should be made to the Site Characterization Summary Report for the complete list.) All wells except MW-883 were sampled during the LBF and HBF events. Only MW-579 and MW-873 were sampled during the storm event. Certain chemical and radiological constituents may occur naturally in environmental media, and it is useful to compare results for these constituents against background levels. A reference groundwater sampling program was established in the Site Characterization Summary Report investigation, and the information is used in this report to assist in interpretation of the data.

3.3.2 Groundwater Contaminant Flux

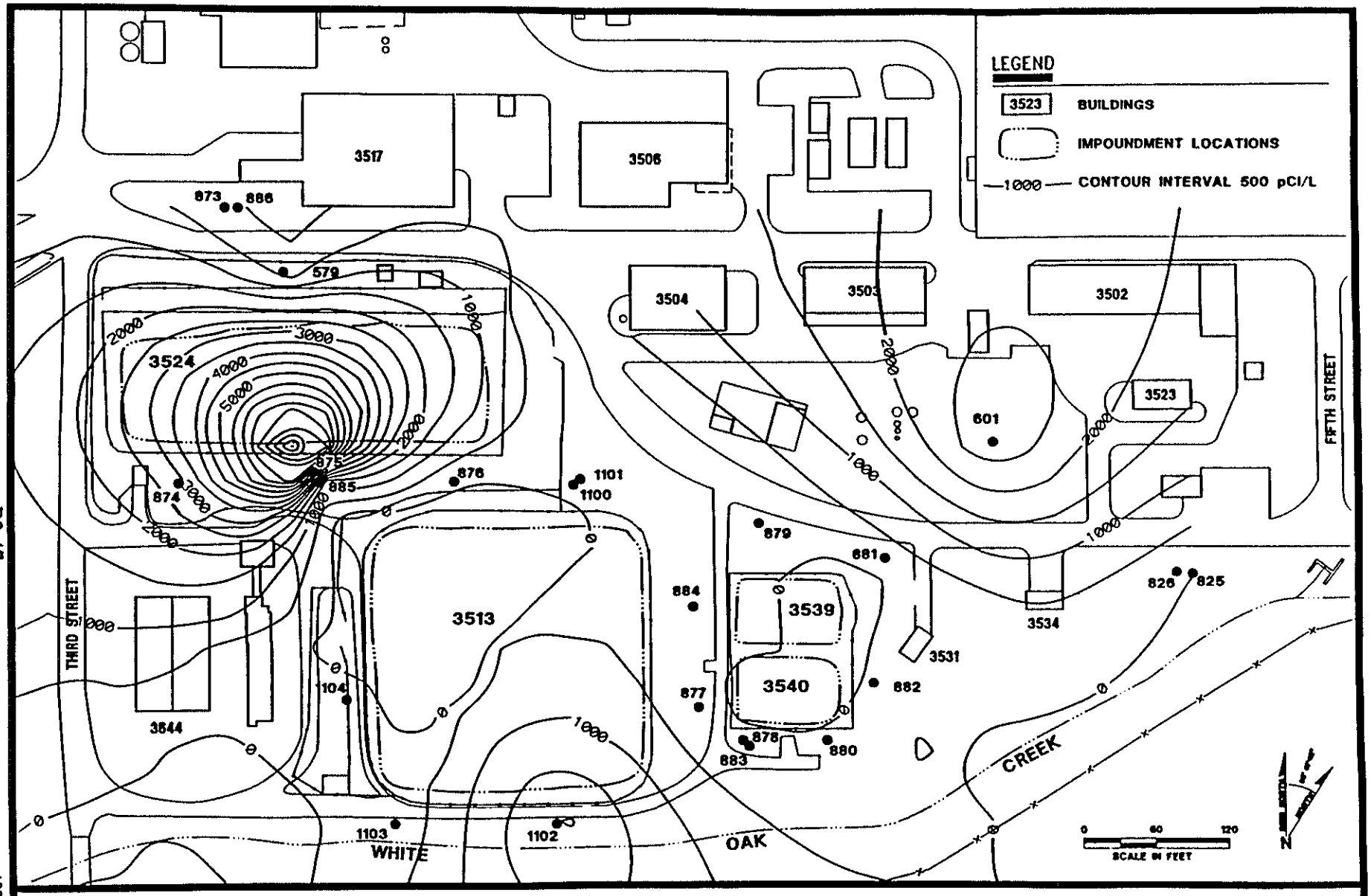
Figures B3.10 through B3.15 display concentration maps for various radiological contaminants in the groundwater. Information is presented on gross alpha, gross beta, and total ^{90}Sr levels (from both filtered and unfiltered analyses for each parameter). The concentration values from which this information was derived represent the highest analyzed values taken from several episodes of sampling conducted from 1990 to 1993. As can be seen in the figures, a consistent pattern of upgradient contamination is apparent. Some contaminants are evident in the upgradient wells to the north (wells 873, 886, and 579) and to the east (well 601). The figures also indicate a significant impact to the groundwater, apparently from Impoundment 3524. Well 875 displays elevated levels of all three radiological parameters. This suggests that Impoundment 3524 is leaching contaminants to the groundwater. Because Impoundment 3524 is an unlined impoundment in direct communication with groundwater during high stands of groundwater, this is a reasonable interpretation.

The wells around Impoundments 3539 and 3540 do not indicate elevated levels, based on the figures. This is consistent with the belief that, because these two impoundments have compacted clay liners, they are not leaching contaminants into the groundwater.

3.3.3 Statistical Evaluation of Potential Groundwater Contamination

Comparison of site-specific groundwater data against background levels provides an approach that can quickly identify potential site contamination. Two disadvantages of the approach are (1) the background levels may not be fully representative because of limited background sampling, and (2) other sources of contamination are present in the vicinity. Both of these issues need to be considered at SIOU.

DOE (1992a) noted that the Waste Area Grouping 1 reference groundwater network may not be adequate to fully characterize the variability in natural groundwater quality. The reference



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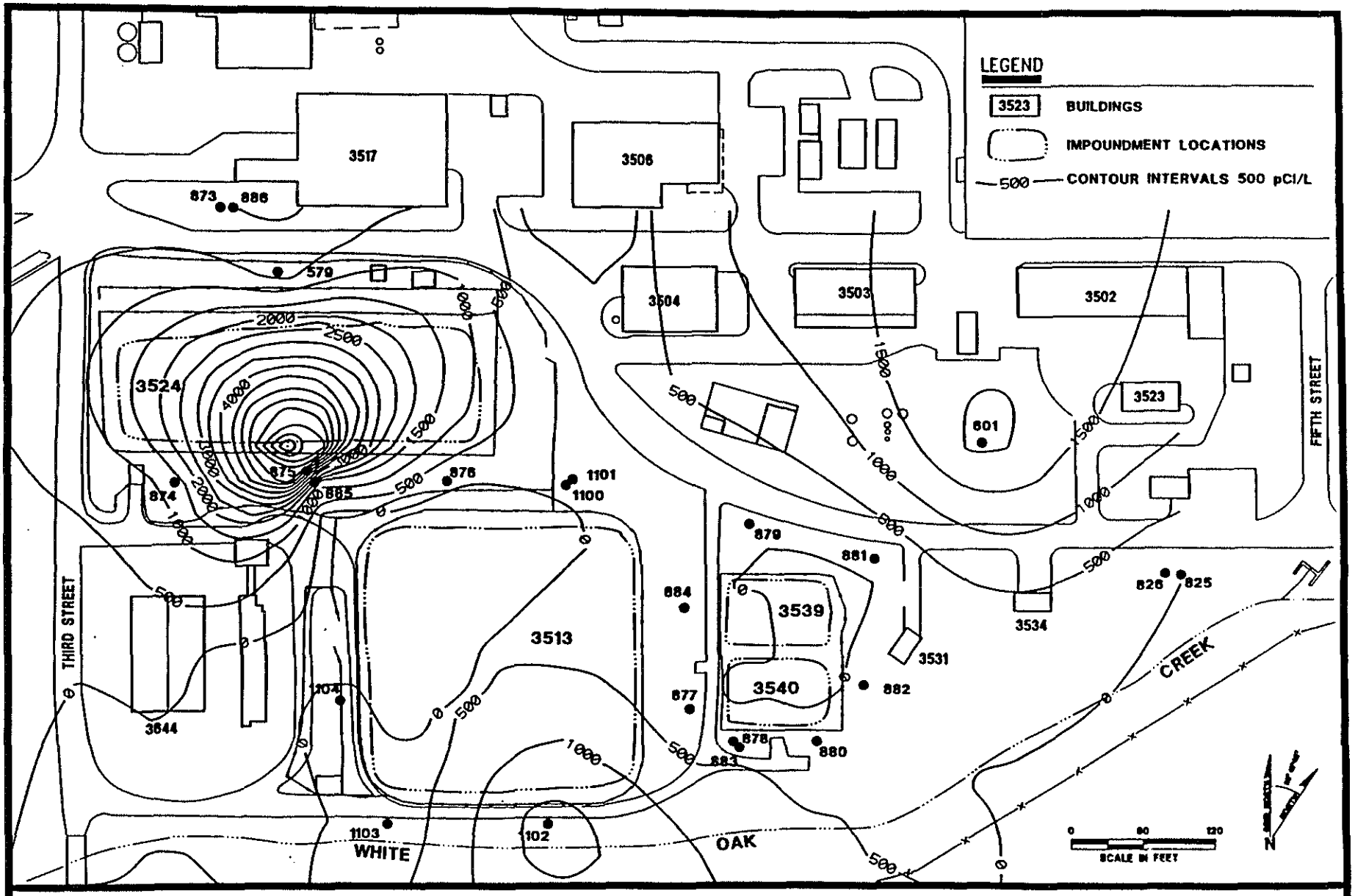
Gross beta (unfiltered) concentrations in groundwater

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Fig B3.10.

A2022/14NOV94/118



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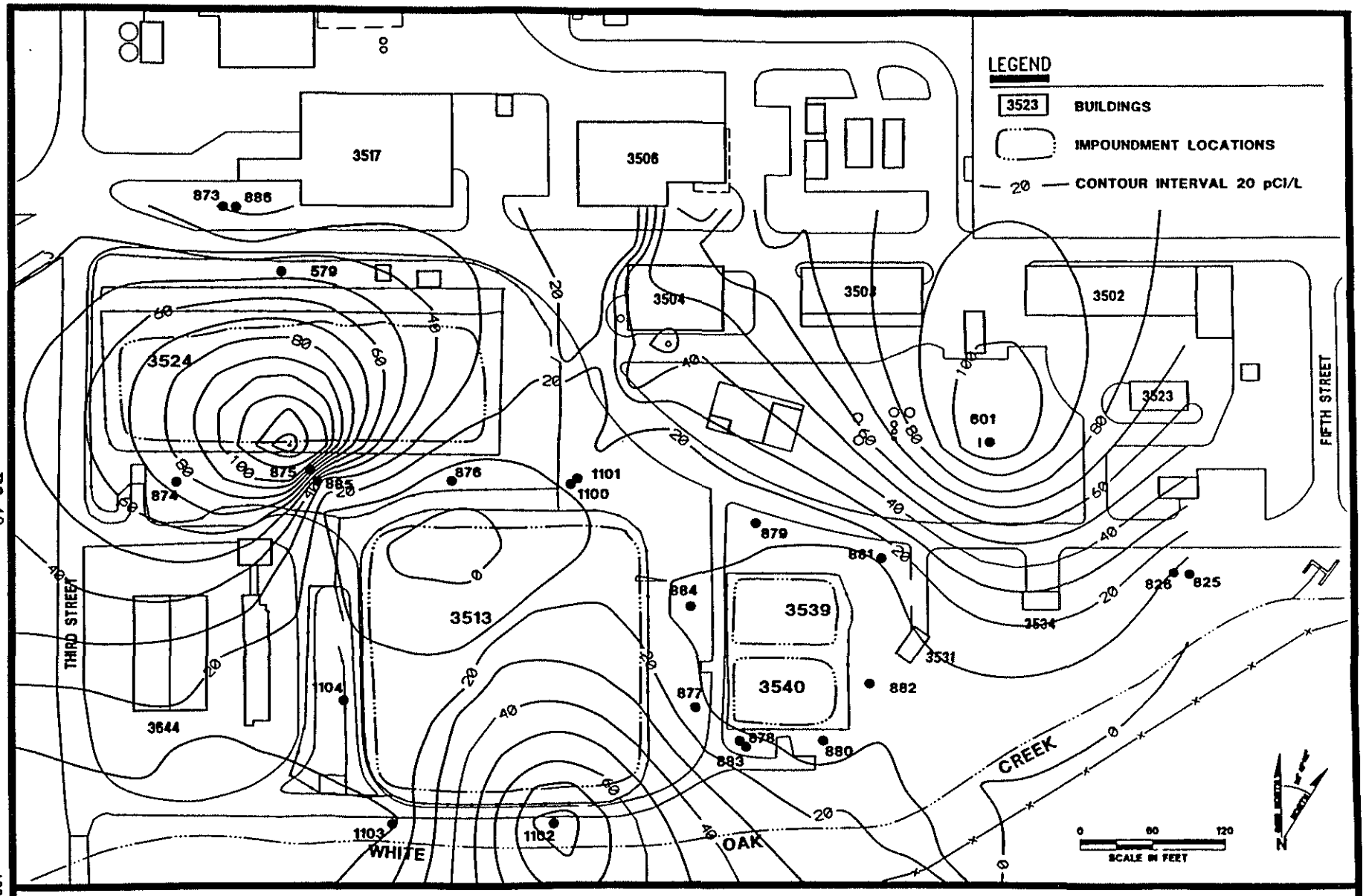
Gross beta (filtered) concentrations in groundwater

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Fig B3.11.

A2023/14NOV94/118



Gross alpha (unfiltered) concentrations in groundwater

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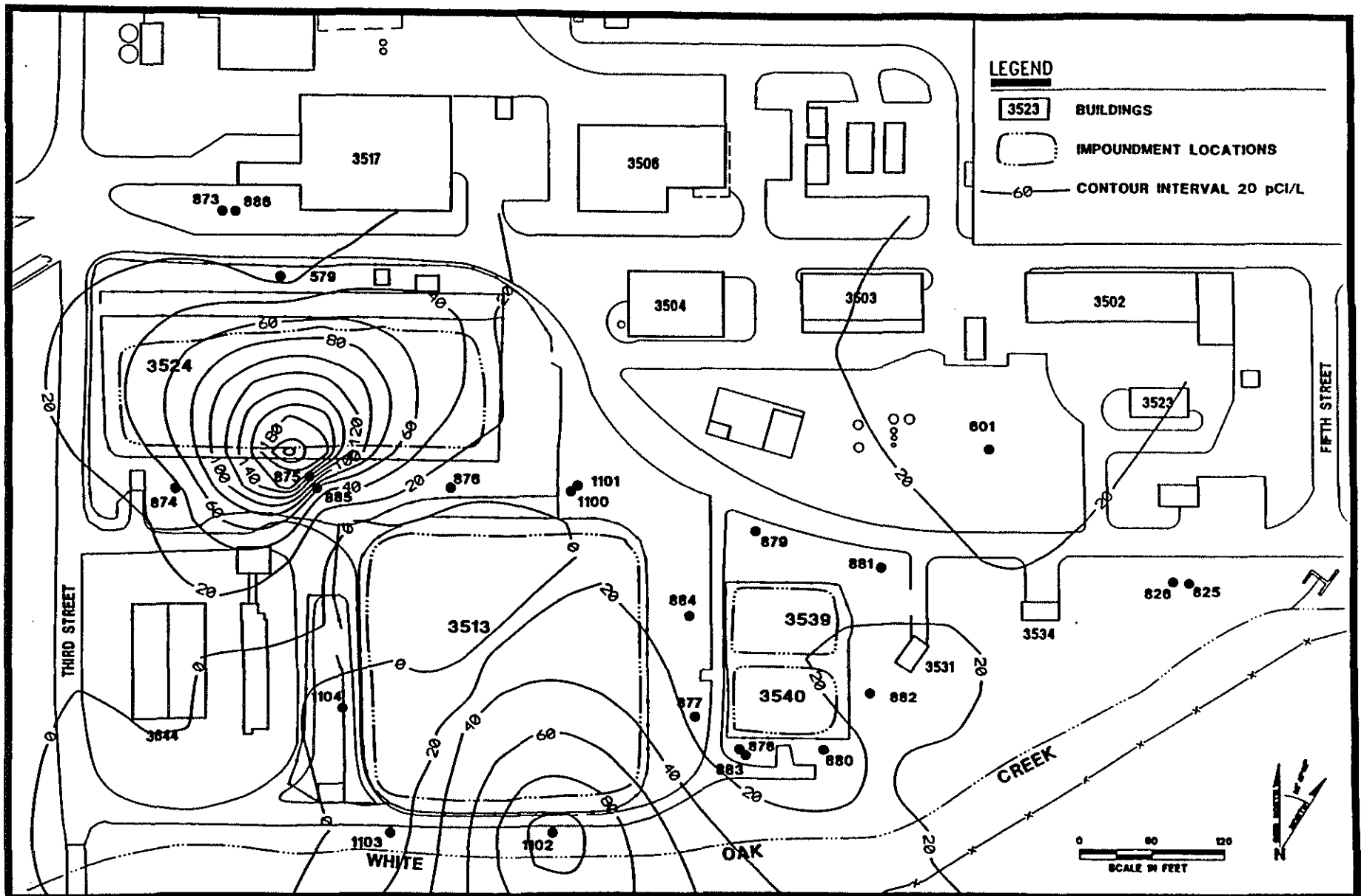
Fig B3.12.

A2039/14NOV94/118



Gross alpha (filtered) concentrations in groundwater

Oak Ridge National Laboratory
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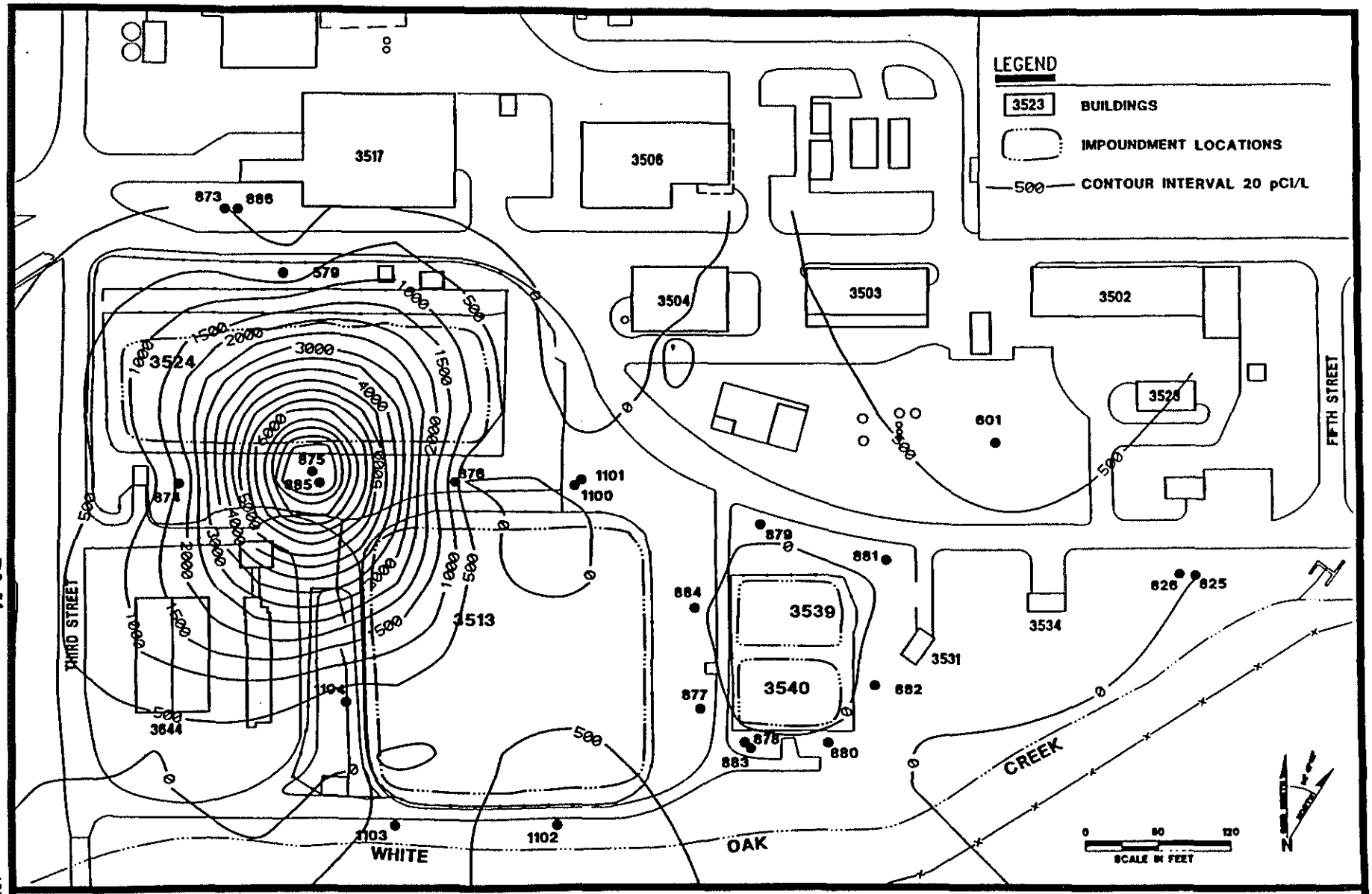
Fig B3.13.

A2025/14NOV94/118



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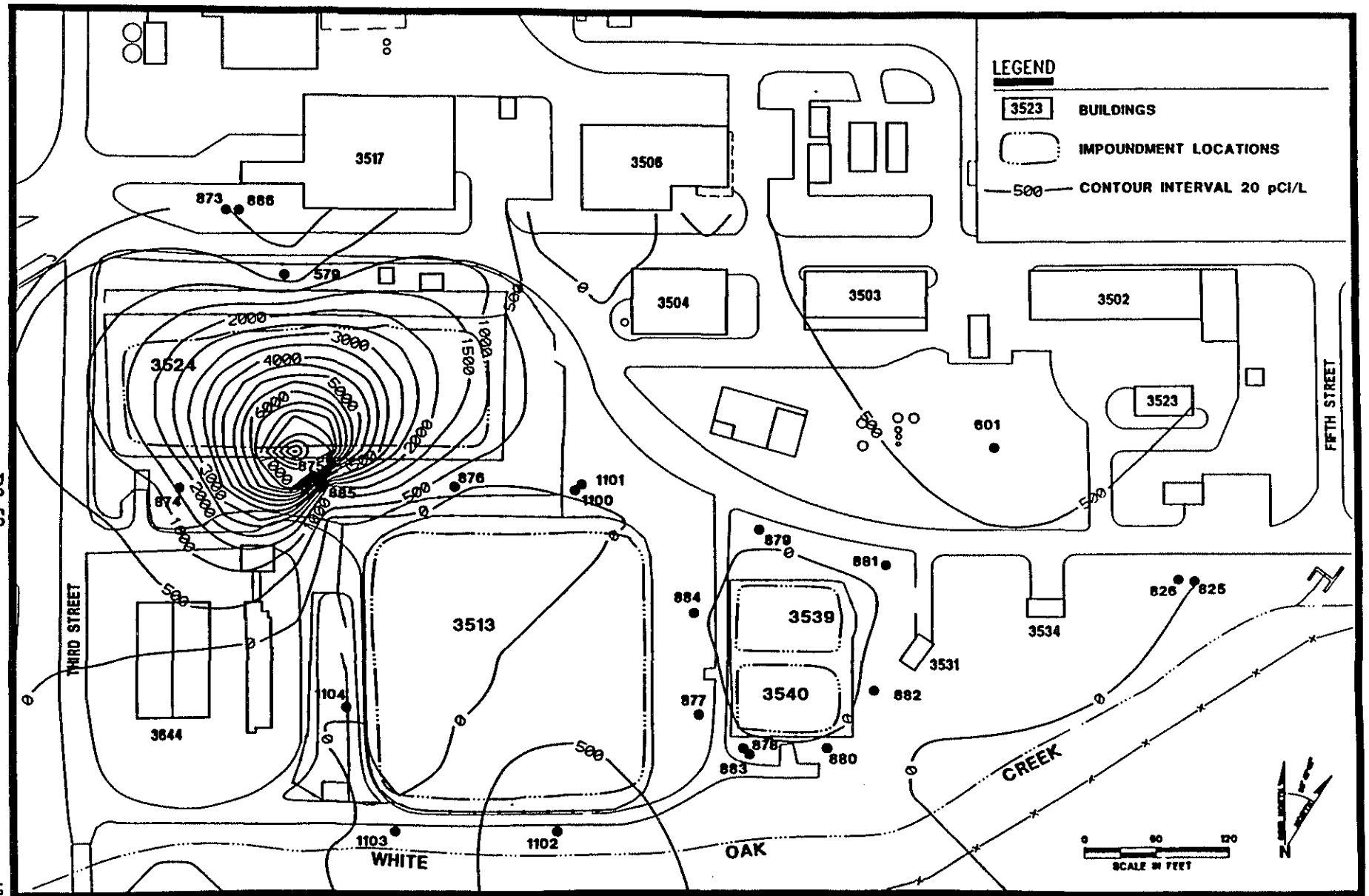
Strontium-90 (unfiltered) concentrations in groundwater

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Fig B3.14.

A2026/14NOV94/11B



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Strontium-90 (filtered) concentrations in groundwater

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Fig B3.15.

A20027/14NOV94/118

groundwater network for Waste Area Grouping 1 consists of two locations where two rounds of sampling were conducted and reported, and three locations at which one round of sampling was conducted and reported. Concentrations of certain naturally occurring inorganic constituents (e.g., aluminum, iron, potassium) vary widely in samples collected from within Waste Area Grouping 1 but vary only within a very narrow range in the reference samples.

The reports identified in Section 3.3.1 were used to describe the nature and extent of groundwater contamination and indicate that several other potential sources of contamination exist within the immediate vicinity of SIOU, as well as upgradient of SIOU. In addition, because of the close proximity of the individual impoundments and the complicated groundwater flow pattern in the area, contamination from one impoundment may impact groundwater monitoring wells at other impoundments.

The alternate approach described previously in the introduction is to compare data from monitoring wells that are immediately upgradient from a facility with monitoring wells that are immediately downgradient. The upgradient monitoring wells are used to determine local background levels for comparison against data from downgradient monitoring wells for evaluating the impact of the facility on groundwater. An advantage of this approach is that the specific impact of a facility can be evaluated where other sources of groundwater contamination are present at upgradient locations. A statistical evaluation also avoids subjective evaluation of the data. A limitation of this approach is that sufficient data of an appropriate quality must be available to meet the specific requirements of the selected statistical test.

The statistical evaluation is routinely used for groundwater monitoring at sites regulated under RCRA and the first reported investigations conducted at SIOU (Montford et al. 1986, Francis and Stansfield 1986b) performed such statistical evaluations for the limited data set collected. Several statistical approaches that have been standardized under the RCRA program (EPA 1989, EPA 1992a) are available as a personal computer program released as *A Groundwater Information Tracking System with Statistical Analysis Capability, GRITS/STAT v. 4.2* (EPA 1992b).

The complete groundwater data base available for monitoring wells at SIOU was considered in the statistical evaluation except for data reported by Montford et al. (1986). Montford et al. present annual average results for individual parameters instead of the individual quarterly results. These data have already been statistically manipulated and cannot be considered in the statistical routines.

The approach used in evaluating the data is summarized in the following four steps. The first step was to select parameters for statistical analysis. As previously indicated, a limitation of the statistical approach is that sufficient data of an appropriate quality must be available to meet the specific requirements of the selected statistical test. Data were initially screened based on: (1) compounds with high mobility, high risk, and/or known source impact characteristics; (2) the total number of analyses (N), and (3) percent nondetects (%ND).

The first screening requirements were selected to force the statistical evaluation for certain compounds considered potential COCs even where subjective evaluation of the available information indicates the data available may not be adequate. This step also permits elimination of certain compounds that are not considered a site-specific problem. In practice, the VOCs tetrachloroethene, trichloroethene, 1,2-dichloroethene, and vinyl chloride were always considered, but all BNAs (and selected major cations and anions) were excluded from detailed evaluation. The second and third screening requirements are limitations imposed by the statistical tests.

The second step was to group the data according to specific site and by upgradient and downgradient wells. Where necessary to meet the requirements of the statistical tests, data from upgradient monitoring wells were pooled. For Impoundment 3524 monitoring wells MW-579, MW-873, and MW-886 are considered upgradient and MW-874, MW-875, MW-876, and MW-885 are considered downgradient. For Impoundment 3513, monitoring wells MW-876, MW-1100, and MW-1101 are considered upgradient and monitoring wells MW-1102, MW-1103, and MW-1104 are considered downgradient. For Impoundments 3539 and 3540 monitoring wells MW-879 and MW-881 are considered upgradient and monitoring wells MW-877, MW-878, MW-880, MW-882, MW-883, and MW-884 are considered downgradient. In addition to evaluating the data available for the individual impoundments (3524, 3513, and 3539/3540), an evaluation of the combined impoundments was also made. In considering the impact of SIOU as a single facility, monitoring wells WM-579, MW-873, MW-879, MW-881, MW-886, MW-1100, and MW-1101 are considered upgradient and monitoring wells MW-874, MW-875, MW-878, MW-880, MW-882, MW-883, MW-885, MW-1102, MW-1103, and MW-1104 are considered downgradient.

The third step before conducting the statistical evaluation was to remove individual data where a reported detection limit for nondetects was greater than the maximum detected concentration reported for another investigation. This step is needed to minimize statistical bias and primarily affects data from earlier investigations where the analytical method and/or interferences resulted in a result reported not detected but with a high detection limit [e.g., lead concentrations reported by Francis and Sealand (1987b) as less than 200 μg/L for the June 1987 sampling event].

In the fourth step, four selected statistical tests evaluated the potential impact of SIOU sites on the groundwater. In order of their approximate statistical power the tests are (1) Parametric Tolerance Interval Test, (2) Parametric ANOVA Test, (3) Nonparametric ANOVA Test, and (4) Wilcoxon Rank Sum Test. In addition to the indicated statistical tests, the two parametric tests require that the data are normally or log normally distributed. To test the distribution, the Shapiro-Wilk test or Shapiro-Francia test were used on the data set. All tests except the Wilcoxon Rank Sum test were conducted using the program GRITS/STAT (EPA 1992b). The Wilcoxon Rank Sum test was conducted using the commercial program SYSTAT (SYSTAT 1992). The capabilities and requirements (criteria) of the individual tests are summarized here. The criteria follow the RCRA guidance as described in EPA (1992a) and Horsey et al. (1993).

Parametric Tolerance Interval Test. This test constructs a one-sided tolerance interval on pooled upgradient well data using 95 percent coverage and 95 percent tolerance coefficient. Downgradient well concentrations that exceed the upper tolerance limit are considered evidence of impact for that well.

Criteria:

- total number of analyses (N) $\geq$ 8 for pooled upgradient wells.
- percentage of nondetects (%ND) for upgradient wells $\leq$ 15 percent (nondetects replaced with one-half the detection limit).
- upgradient observations are normally or log normally distributed; Shapiro-Wilk test ($n \leq 50$) or Shapiro-Francia test ($n > 50$).

Parametric ANOVA Test. This test conducts a one-way analysis of variance at the 5 percent level of significance to determine whether any of the downgradient well means are significantly different than the upgradient well means. Downgradient well means that are significantly higher than upgradient well means are considered evidence of impact for that well.

Criteria:

- $N-p \geq 5$ (N = total number of analyses; p = total number of wells.
- %ND for both upgradient or downgradient wells $\leq$ 15 (nondetects replaced with one-half the detection limit).

- pooled residuals are normally or log normally distributed; Shapiro-Wilk test ($n \leq 50$) or Shapiro-Francia test ($n > 50$).

- homogeneity of variance (using Levene's test).

Nonparametric ANOVA Test. Also known as the Kruskal-Wallace test. Similar to the parametric ANOVA except that upgradient and downgradient well medians are tested. Downgradient well medians that are significantly higher than upgradient well medians are considered evidence of impact for that well.

Criteria:

- %ND $\leq$ 50 percent (nondetects replaced with one-half the detection limit).

- analyses (N) $\geq$ 4 per well group and $\geq$ well groups (upgradient analyses pooled into one group; downgradient wells treated as individual groups).

Wilcoxon Rank Sum Tests. A variation of the Kruskal-Wallace test; also known as the Mann-Whitney U test. Conducts a nonparametric test of whether pooled upgradient and pooled downgradient data are derived from identical distributions. Evidence of impact for downgradient wells (as a pooled group) exists when the downgradient well distribution is significantly different (higher values) than the upgradient well distribution at the 5 percent level of significance.

Criteria:

- analyses (N) $\geq$ 4 per group (upgradient wells and downgradient wells pooled into two groups).

- %ND $\leq$ 50 percent (nondetects replaced with one-half the detection limit).

For each parameter, the most powerful test (parametric tolerance interval) was used, provided that all criteria for the test were met. If any criteria for that particular test were not met, then the next most powerful test was conducted. In cases where the criteria for the least powerful test used (Wilcoxon Rank Sum) were not met, comments are provided regarding data needs for further statistical analysis. Although less powerful techniques than the Wilcoxon Rank sum test are possible (e.g., adjustments for censored data), these techniques have tenuous ability for discerning actual impacts, and were therefore not considered.

Results of the statistical test applied to SIOU as a single facility and to Impoundments 3524, 3513, and 3539/3540 are presented in Tables B3.18 to B3.21, respectively. For parameters meeting the parametric tolerance interval criteria, impacted downgradient wells are listed along with the sampling event date. The confidence level (CL) of either 5 percent or 1 percent at which the pooled upgradient data are normally or log normally distributed (pass the Shapiro-Wilk Test) are also provided. If all criteria for the tolerance interval tests were met and the data were normal or log normal at the 5 percent level, then no additional tests were required. If the upgradient data met all criteria but were normal or log normal at only the 1 percent level, then the next most powerful test was also conducted for evaluation of impact. For any of the tests that did not meet testing criteria, the reason for not conducting the test is indicated under the "failed criteria" heading.

For the nonparametric ANOVA test, typically some downgradient well groups contained a sufficient number of analyses while others did not. In these cases, results correspond only to those wells with $N \geq 4$, and the Wilcoxon Rank Sum test was also conducted to test evaluate impact for the pooled downgradient wells. For Wilcoxon test results in Tables B3.18 to B3.21 the probability (p value) is provided to enable evaluation of the relative degree with which the pooled upgradient and downgradient well distributions differ (p values, which range between 0.001 and 1, decrease as the two distributions become more dissimilar). A p value of 0.05 (5 percent level of significance) was used as the cut-off for determination of impact.

The results of the statistical evaluation summarized in Tables B3.18 through B3.21 provide statistical support to some of the previous observations made earlier on the impact of the impoundments on the groundwater. SIOU is apparently contributing beta-emitting radionuclides. The primary beta emitter is probably ^{90}Sr, although the available data were sufficient only for the nonparametric Wilcoxon Rank Sum test. Tritium, which as previously discussed is a weak beat emitter that is not efficiently detected by the gross beta analysis, is also a groundwater contaminant derived from the impoundments. Nonradiological contaminants apparently impacting the groundwater include both barium and sodium.

The results of the statistical evaluation for individual impoundments provide additional information on potential groundwater contaminants. The evaluation provides statistical support for the observation that Impoundment 3524 is a source of tritium, as well as gross beta activity. No other beta-emitting radionuclides or other constituents are identified at Impoundment 3524. Impoundment 3513 appears to be a source of ^{90}Sr, Na, Zn, Cl, as well as TOC, although no specific organic compounds are identified. The potential contribution of Zn from Impoundment 3513 is possible due to the presence of Zn in the impoundment sediments as discussed in Section 3.3. However, the potential Zn impact reported is based on the results of the nonparametric

Table B3.18. Results of statistical tests for SIOU

Parameter	Parametric tolerance interval				Parametric ANOVA		Nonparametric ANOVA		Wilcoxon rank sum			Comments
	CL	Well	Date	Criteria failed	Well	Criteria failed	Well	Criteria failed	Impact	Criteria failed	p-value	
Radiological constituents												
Gross alpha	—	—	—	%ND > 15	—	%ND > 15	None	N < 4	No	—	0.097	No impact
Gross beta	—	—	—	%ND > 15	—	%ND > 15	1102	N < 4	Yes	—	0.001	Impact
Cesium-137	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Radium-226	—	—	—	N < 8	—	%ND > 15	—	N < 4	No	—	0.439	No impact
Radium-228	—	—	—	N < 8	—	N-p < 5	—	N < 4	*b*	*b*	*b*	*b*
Strontium-90	—	—	—	N < 8	—	%ND > 15	1102	N < 4	Yes	—	0.002	Impact
							1104					Impact
Tritium	1%	874	—	—	—	Lavene's	874					Impact
		875					875					Impact
		885					885					Impact
		1102					1102					Impact
		1103					1103					Impact
		1104					1104					Impact
Uranium-234	—	—	—	N < 8	—	N-p < 5	—	%ND > 50	—	%ND > 50	—	No impact[a]
Inorganic constituents-TAL metals												
Silver	—	—	—	%N > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Arsenic	—	—	—	%N > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Barium	5%	1102	4/85	—	—	—	—	—	—	—	—	Impact
		1102	1/86									Impact
		1102	8/88									Impact
		1103	4/85									Impact
		1103	1/86									Impact
		1104	1/86									Impact
Calcium	5%	None	—	—	—	—	—	—	—	—	—	No impact
Cobalt	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Chromium	—	—	—	%ND > 15	—	%ND > 15	None	N < 4	No	—	0.196	No impact
Iron	5%	None	—	—	—	—	—	—	—	—	—	No impact
Potassium	5%	None	—	—	—	—	—	—	—	—	—	No impact

Table B3.18 (continued)

Parameter	Parametric tolerance interval				Parametric ANOVA		Nonparametric ANOVA		Wilcoxon rank sum			Comments
	CL	Well	Date	Criteria failed	Well	Criteria failed	Well	Criteria failed	Impact	Criteria failed	p-value	
Magnesium	5%	None	—	—	—	—	—	—	—	—	—	No impact
Manganese	5%	None	—	—	—	—	—	—	—	—	—	No impact
Sodium	5%	1102	2/85	—	—	—	—	—	—	—	—	Impact
		1102	4/85									Impact
		1102	1/86									Impact
		1102	8/88									Impact
Nickel	—	—	—	%ND > 15	—	%ND > 15	None	N < 4	No	—	0.586	No impact
Lead	—	—	—	%ND > 15	—	%ND > 15	None	N < 4	No	—	0.439	No impact
Strontium	—	—	—	N < 8	—	N-p < 5	—	N < 4	*b*	*b*	*b*	*b*
Vanadium	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Zinc	—	—	—	%ND > 15	—	%ND > 15	—	N < 4	No	—	0.637	No impact
Inorganic constituents—anions												
Chlorine	5%	None	—	—	—	—	—	—	—	—	—	No impact
Sulfide	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Organic constituents												
Tetrachloroethene	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Trichloroethene	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
1,2-Dichloroethene	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Vinyl chloride	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]

Source: CDM Federal Programs Corporation 1994.

[a]Need lower detection limit.
[b]Test not conducted for insufficient data.

Table B3.19. Results of statistical tests for Impoundment 3524

Parameter	Parametric tolerance interval				Parametric ANOVA		Nonparametric ANOVA		Wilcoxon rank sum			Comments
	CL	Well	Date	Criteria failed	Well	Criteria failed	Well	Criteria failed	Impact	Criteria failed	p-value	
Radiological constituents												
Gross alpha	—	—	—	%N > 15	—	%ND > 15	—	N < 4	—	%ND > 50	—	No impact[a]
Gross beta	5%	875	10/95	—	—	—	—	—	—	—	—	Impact
Uranium-234	—	—	—	N < 8	—	N-p < 5	—	N < 4	—	N < 4	—	Need data
Tritium	5%	874	—	—	—	—	—	—	—	—	—	Impact
	5%	874										Impact
	5%	875										Impact
	5%	875										Impact
	5%	876										Impact
	5%	885										Impact
	5%	885										Impact
Inorganic constituents-TAL metals												
Silver	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Arsenic	—	—	—	N < 8	—	N-p < 5	—	%ND > 50	—	%ND > 50	—	No impact[a]
Barium	—	—	—	N < 8	None	—	—	—	—	—	—	No impact
Calcium	—	—	—	N < 8	None	—	—	—	—	—	—	No impact
Cobalt	—	—	—	N < 8	—	%ND > 15	—	N < 4	—	%ND > 50	—	No impact[a]
Chromium	—	—	—	N < 8	—	%ND > 15	—	N < 4	No	—	0.078	No impact[b]
Iron	—	—	—	N < 8	—	Normality	—	N < 4	No	—	0.006	No impact[b]
Potassium	—	—	—	N < 8	None	—	—	—	—	—	—	No impact
Magnesium	—	—	—	N < 8	—	Levene's	—	N < 4	No	—	0.337	No impact[b]
Manganese	—	—	—	N < 8	—	Normality	—	N < 4	No	—	0.749	No impact[b]
Sodium	—	—	—	N < 8	None	—	—	—	—	—	—	No impact
Nickel	—	—	—	N < 8	—	%ND > 15	—	N < 4	—	%ND > 50	—	No impact[a]
Lead	—	—	—	N < 8	—	%ND > 15	—	N < 4	No	—	0.229	No impact[b]
Strontium	—	—	—	N < 8	—	N-p < 5	—	N < 4	*			
Vanadium	—	—	—	N < 8	—	%ND > 15	—	N < 4	—	%ND > 50	—	No impact[a]
Zinc	—	—	—	N < 8	—	%ND > 15	—	N < 4	No	—	0.229	No impact[b]

Table B3.19 (continued)

Parameter	Parametric tolerance interval				Parametric ANOVA		Nonparametric ANOVA		Wilcoxon rank sum			Comments
	CL	Well	Date	Criteria failed	Well	Criteria failed	Well	Criteria failed	Impact	Criteria failed	p-value	
Inorganic constituents-anions												
Chloride	—	—	—	N < 8	None	—	—	—	—	—	—	No impact
Sulfide	—	—	—	N < 8	—	%ND > 15	—	N < 4	—	%ND > 50	—	No impact[a]
Organic constituents												
Tetrachloroethene	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Trichloroethene	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
1,2-dichloroethene	—	—	—	N < 8	—	%ND > 15	—	N < 4	N < 4	—	0.602	No impact

Source: CDM Federal Programs Corporation 1994.

[a]Need lower detection limit.
[b]Upgradient concentration higher.

Table B3.20. Results of statistical tests for Impoundment 3513

Parameter	Parametric tolerance interval				Parametric ANOVA		Nonparametric ANOVA		Wilcoxon rank sum			Comments
	CL	Well	Date	Criteria Failed	Well	Criteria Failed	Well	Criteria Failed	Impact	Criteria Failed	p-value	
Radiological constituents												
Gross alpha	—	—	—	%ND > 15	—	%ND > 15	None	—	—	—	—	No impact
Gross beta	5%	None	—	—	—	—	—	—	—	—	—	No impact
Cesium-137	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > %	—	No impact[a]
Radium-226	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > %	—	No impact[a]
Strontium-90	1%	None	—	—	1102	—	—	—	—	—	—	Impact
Tritium	5%	None	—	—	—	—	—	—	—	—	—	No impact
Inorganic constituents-TAL metals												
Silver	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Arsenic	—	—	—	%ND > 15	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Barium	—	—	—	%ND > 15	—	%ND > 15	None	—	—	—	—	No impact
Chromium	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Iron	5%	None	—	—	—	—	—	—	—	—	—	No impact
Manganese	5%	None	—	—	—	—	—	—	—	—	—	No impact
Sodium	1%	None	—	—	—	Normality	1102	—	—	—	—	Impact
Nickel	—	—	—	N < 8	—	%ND > 15	—	N < 4	—	%ND > 50	—	No impact[a]
Lead	—	—	—	%ND > 15	—	%ND > 15	None	—	—	—	—	No impact
Zinc	—	—	—	N < 8	—	%ND > 15	—	N < 4	Yes	—	0.03	Impact
Inorganic constituents-anions												
Chlorine	5%	1102	2/85	—	—	—	—	—	—	—	—	Impact
	5%	1102	4/85									Impact
	5%	1102	9/85									Impact
	5%	1102	1/86									Impact
	5%	1103	4/85									Impact
	5%	1103	9/85									Impact
	5%	1103	1/86									Impact

Table B3.20 (continued)

Parameter	Parametric tolerance interval				Parametric ANOVA		Nonparametric ANOVA		Wilcoxon rank sum			Comments
	CL	Well	Date	Criteria Failed	Well	Criteria Failed	Well	Criteria Failed	Impact	Criteria Failed	p-value	
	5%	1103	8/88									Impact
Sulfate (SO_4)	5%	None	—	—	—	—	—	—	—	—	—	No impact
Organic constituents												
TOC	5%	1103	1/86	—	—	—	—	—	—	—	—	Impact
		1104	1/86									Impact
TOX	5%	None	—	—	—	—	—	—	—	—	—	No impact
1,2-Dichloroethene	—	—	—	N < 8	—	N-p < 5	—	N < 4	—	N < 4	—	Need data

Source: CDM Federal Programs Corporation 1994.

[a]Need lower detection limit.
[b]Upgradient concentration higher.

Table B3.21. Results of statistical test for Impoundments 3539/3540

Parameter	Parametric tolerance interval				Parametric ANOVA		Nonparametric ANOVA		Wilcoxon rank sum			Comments
	CL	Well	Date	Criteria failed	Well	Criteria failed	Well	Criteria failed	Impact	Criteria failed	p-value	
Radiological constituents												
Gross alpha	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Gross beta	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50		No impact[a]
Cesium-137	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50		No impact[a]
Tritium	—	—	—	N < 8	—	Normality	—	N < 4	No	—	0.396	No impact
Inorganic constituents-TAL metals												
Silver	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Arsenic	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Barium	—	—	—	N < 8	—	Normality	—	N < 4	No	—	0.671	No impact
Calcium	—	—	—	N < 8	—	Levene's	—	N < 4	No	—	0.723	No impact
Cobalt	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Chromium	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Iron	—	—	—	N < 8	—	Levene's	—	N < 4	No	—	0.258	No impact
Potassium	—	—	—	N < 8	—	Levene's	—	N < 4	No	—	0.777	No impact
Magnesium	—	—	—	N < 8	—	None	—	—	—	—	—	No impact
Manganese	—	—	—	N < 8	—	Levene's	—	N < 4	No	—	0.066	No impact
Sodium	—	—	—	N < 8	—	Levene's	—	N < 4	No	—	0.005	No impact[b]
Lead	—	—	—	N < 8	—	%ND > 15	—	N < 4	No	—	0.225	No impact
Zinc	—	—	—	N < 8	—	%ND > 15	—	N < 4	No	—	0.888	No impact
Vanadium	—	—	—	N < 8	—	%ND > 15	—	%ND > 50	—	%ND > 50	—	No impact[a]
Inorganic constituents-anions												
Chloride	—	—	—	N < 8	—	Normality	—	N < 4	No	—	0.571	No impact
Sulfide	—	—	—	N < 8	—	%ND > 15	—	N < 4	No	—	0.827	No impact
Organic constituents												
None												

Source: CDM Federal Programs Corporation 1994.

[a]Need lower detection limit.
[b]Upgradient concentration higher.

Wilcoxon Rank Sum test, the least powerful of the statistical tests used. Impoundments 3529 and 3540 appear statistically to have no significant contribution to groundwater contamination.

Comparison of the statistical results with the previous observations made from evaluation of the distribution of the data as presented in historical data and reports suggest several apparent inconsistencies. Most of these apparent inconsistencies are due to the limits on the available data necessary to meet the specific requirements for the individual statistical tests. This is probably best illustrated by the data available for the chlorinated solvents, tetrachloroethene, trichloroethene, 1,2-dichloroethene, and vinyl chloride. Evaluation of the historical data and reports suggest certain patterns are present. However, because of the percent of nondetection results reported, the data do not generally meet the requirements for any of the statistical tests used and the result is the assumption that there is no impact.

Another source of the apparent inconsistencies because of the limited data is the use of pooled data. To meet the criteria for the statistical tests for individual impoundments and constituents, data from more than one well were combined. Pooled data for upgradient wells were used for the Parametric Tolerance Interval Test, Parametric ANOVA test, and the Nonparametric ANOVA test. Pooled data from upgradient and downgradient wells were used for the Wilcoxon Rank Sum test. Using pooled data assumes that the data represent a single population. However, from the evaluation of past investigations, there appears to be differences for certain constituents between upgradient wells because of potential presences of upgradient sources of contamination. There also appear to be potential differences for certain constituents between wells completed in different hydrologic units. Pooling the upgradient data may yield a different median value and large standard deviation for the upgradient population. Because the statistical tests compare upgradient data to the downgradient data on the basis of median value and standard deviation, using the pooled data that do not represent a single population may obscure some differences, resulting in the determination of no impact when there is an impact. This is a particular problem with the evaluation of SIOU as a whole, but may also influence interpretation of the individual impoundments.

4. FIELD INVESTIGATION EFFORTS

After review and evaluation of the available information from historical investigations, it was established that certain additional data were required to support completion of the human health risk assessment, the ecological risk assessment, and the FS. Additional data were needed on the organic chemical content of the impoundment sediments to address both risk assessment issues and requirements of the FS. Section 4.1 summarizes the results of additional sediment sampling conducted in Impoundments 3524, 3513, 3539, and 3540.

To support the ecological assessment, an analysis was required of fish tissue from Impoundment 3513 for contaminants of potential concern; Section 4.2 summarizes these results.

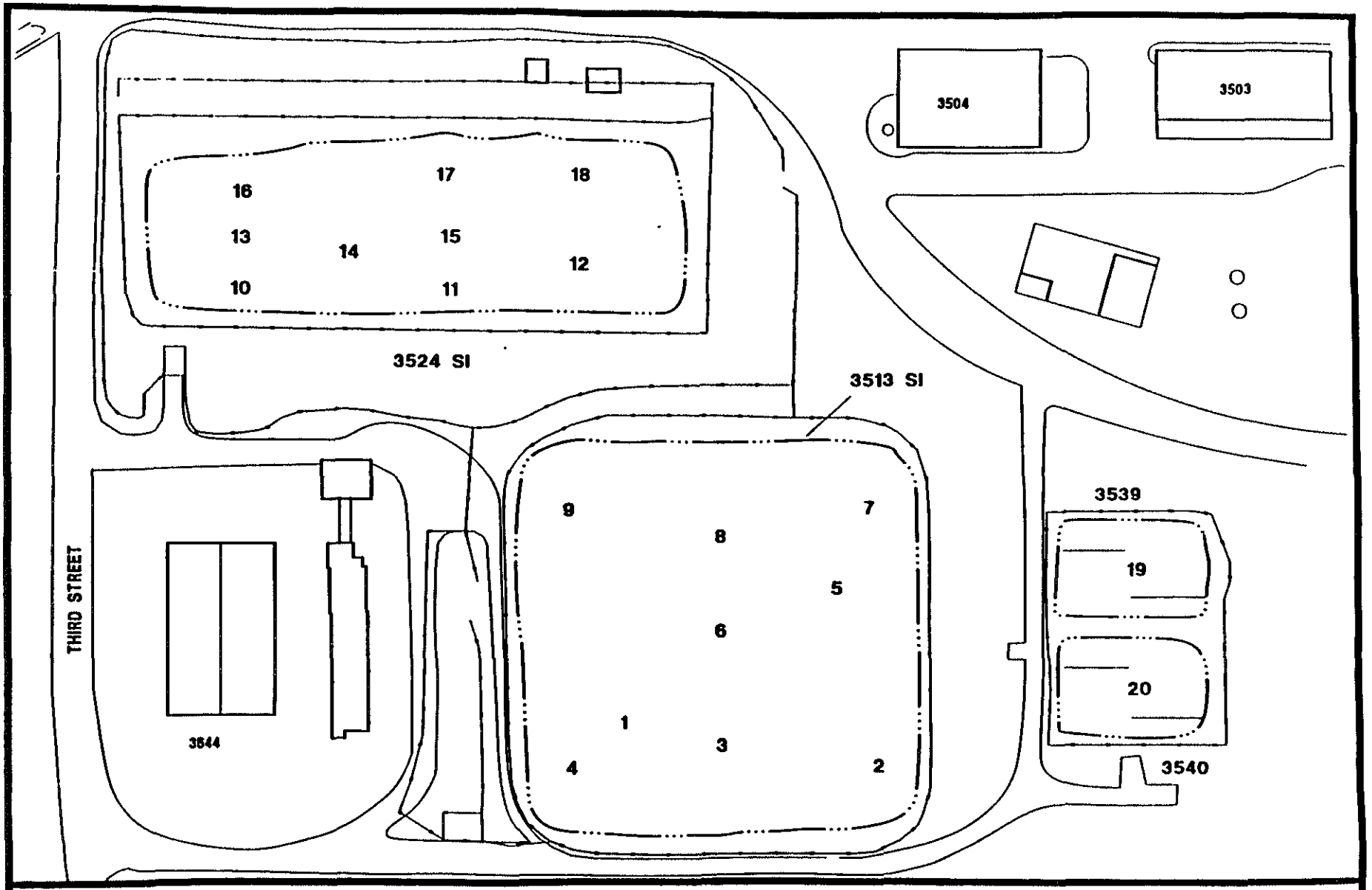
Although the surface water in White Oak Creek is included as part of Waste Area Grouping 2, contaminated groundwater from SIOU appears to be discharging to the creek. To support the human health risk assessment, data were needed on the contamination present in the surface water of White Oak Creek. Sampling of White Oak Creek has been conducted under the Waste Area Grouping 2 RI to address current sources of contamination to the creek. Section 4.3 summarizes selected data from the Waste Area Grouping 2 RI seeps and tributary sampling effort.

4.1 SEDIMENT SAMPLING

The primary objective of conducting additional sampling of sediments in the impoundments was to characterize the type and concentrations of organic compounds present. Sediment samples from each impoundment were analyzed for TCL organic compounds, but were also analyzed for inorganic constituents (TAL metals and selected inorganic anions) and radionuclides. It was also possible to collect samples of interstitial water from Impoundments 3524 and 3513. Interstitial water samples were analyzed using gross alpha, gross beta, and gamma spectroscopy methodologies.

The approach for sampling Impoundments 3524 and 3513 differed from the approach for Impoundments 3539 and 3540 due to the surface water maintained in these impoundments. Nine cores were collected from each impoundment. The location of the cores in Impoundments 3524 and 3413 are shown in Figure B4.1. The core locations were selected to sample the areas anticipated to have the highest radioactivity levels based on previously reported results.

For sampling the sediment, a modified pontoon boat was placed in the impoundment and used as a work platform. The boat was moved manually and held in place by aluminum rods.



CDM FEDERAL PROGRAMS CORPORATION
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Sediment sampling points for the Surface Impoundments Operable Unit Remedial Investigation

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Fig B4.1.

A20172A/14NOV94/00

After the boat was positioned at a sample location, an 8-ft-long stainless-steel casing was driven into the clay bottom of the impoundments. Due to the larger sample volume required for inorganic and organic chemical analyses, compared to analysis of radiological constituents conducted for similar historical investigations, an 8-in.-diameter casing was used. It was originally intended to remove complete cores. However, possibly due to the larger diameter of the sampling casing, it proved impossible to remove intact cores.

As an alternative method for collecting the sediment sample, sediment was pumped from within the casing. The success of this method is an indication of the high moisture content and lack of cohesion of the sediment. The surface water was pumped from the casing until all residual water was removed. After the surface water was removed, samples were collected in the following order:

- interstitial water
- VOCs
- radiological constituents
- BNA organics, pesticides/PCBs
- inorganics (metals and selected anions)

Interstitial water was collected by allowing gravity to displace fluids from the sediment and using a peristaltic pump to extract the sample. The sample was then placed in a labeled sample container, and the remaining water above the sediment was removed and returned to the impoundment. The samples for VOCs were collected using a small, stainless-steel dipper with the sample transferred to an appropriately labeled container. All remaining samples (i.e., radiological, BNA organics, pesticides/PCBs and metals) were collected using the peristaltic pump. To obtain a composited sample, the sampling tube from the pump was moved from the top to the bottom of the sediment column during the collection of each sample.

Tables B4.1–B4.3 present the results for Impoundment 3524 sediment samples for radionuclides, inorganics, and TCL organics. Tables B4.4–B4.6 present results for Impoundment 3513 sediment samples for radionuclides, inorganic, and TCL organics. Table B4.7 presents the results for interstitial water from Impoundment 3524 for selected radionuclides and Table B4.8 presents the results for Impoundment 3513. Table B4.9 lists areas of elevated soil contamination.

Due to small their size and shallow water depth in Impoundments 3539 and 3540, a more conventional method of sampling was used to collect sediment samples. A stainless-steel dipper was used to extract samples from six locations in each impoundment. The individual samples were mixed in a stainless-steel pan to prepare a single, composited sample for each impoundment

Table B4.1. Radionuclide activities in sediment samples from Impoundment 3524

Analyte	Units	ID 24-10	ID 24-11	ID 24-12	ID 24-13	ID 24-14	ID 24-15	ID 24-16	ID 24-17	ID 24-18	ID 24-19
Plutonium-238	Bq/g	3.85	51.35	23.86	17.87	110.54	16.80	5.70	131.99	13.95	15.87
Plutonium-239,240	Bq/g	13.24	725.86	266.3	166.85	1,763.23	302.92	13.32	2,660.38	81.80	145.69
Thorium-228	Bq/g	0.88	0.09	8.36	14.33	15.27	9.04	3.66	36.66	5.36	6.05
Thorium-230	Bq/g	0.07	0.92	0.77	0.26	1.26	2.22	0.50	3.05	0.95	1.35
Thorium-232	Bq/g	0.09	4.65	2.34	0.40	8.25	6.58	1.17	23.64	1.51	3.36
Uranium	μg/g	24.00	388.00	176.00	86.00	744.00	259.00	64.00	1,585.00	108.00	125.00
Uranium-234	Bq/g	0.33	5.36	2.44	1.19	10.32	5.40	0.89	21.98	3.00	2.60
Uranium-235	Bq/g	0.01	0.22	0.09	0.03	0.39	0.14	0.03	0.87	0.06	0.07
Uranium-238	Bq/g	0.30	4.77	2.18	1.06	9.17	3.20	0.79	19.57	1.33	1.54

Source: CDM Federal Programs Corporation 1994.

Table B4.2. Inorganic constituent concentrations in sediment samples from Impoundment 3524

Analyte	Units	ID 24-10	ID 24-12	ID 24-13	ID 24-13	ID 24-14	ID 24-15	ID 24-26	ID 24-17	ID 24-18
Organics										
Aluminum[a]	mg/kg	8,090	18,600	9,020	9,580	19,800	14,600	12,600	11,300	11,900
Antimony[a]	mg/kg	NR	NR	NR	NR	NR	NR	NR	3.5(BN)-	NR
Arsenic[b]	mg/kg	NR	10.3(S)-	6.4	3.7(B)-	6.6	16.4	3.9(B)-	9.7(S)	5.6
Barium[a]	mg/kg	193	1,440	616	329	1,010	1,040	359	890	497
Cadmium[a]	mg/kg	2.2	41.7	19.5	3.4	38.3	23.2	2.6	1,080	10.6
Chromium[a]	mg/kg	3.6	28.8	13.7	6.6	29.1	15.1	8.1	16	19.3
Cobalt[a]	mg/kg	149	1,810	787	227	1,730	784	368	914	1,330
Copper[a]	mg/kg	9.5(B)-	13	12.7	10.2	15.2	14.6	10.7	13.3	14.3
Iron[a]	mg/kg	414	1,070	1,020	1,910	1,360	926	1,230	643	911
Lead[a]	mg/kg	18,700	33,400	53,200	25,300	31,800	73,300	31,700	66,900	24,600
Magnesium[a]	mg/kg	215	5,180	1,290	376	3,550	2,030	364	2,710	1,160
Manganese[a]	mg/kg	9,360	12,900	27,200	27,800	9,190	31,600	20,100	34,100	8,110
Mercury[c]	mg/kg	482	521	711	452	608	749	545	641	754
Nickel[a]	mg/kg	42.7	916	247	77	530	480	85.4	750	436
Potassium[a]	mg/kg	944(B)-	1,470	752(B)-	1,000	1,540	1,130	1,310	708(B)	1,140
Selenium[a]	mg/kg	NR	NR	NR	NR	1.6(BN)-	NR	NR	1.8(BN)-	1.1(BN)-
Silver[a]	mg/kg	27	264	129	43.7	269	180	59.6	196	151
Sodium[a]	mg/kg	1,620	1,730	928(B)-	5,450	431(B)-	2,670	5,250	3,000	343(B)-
Thallium[a]	mg/kg	NR	1.5(B)-	1.8(B)-	NR	1.8(B)	NR	NR	NR	2.1(B)-
Vanadium[a]	mg/kg	10.7	26.5	17.3	13.2	27.7	25.8	17.8	27.5	17.7
Zinc[a]	mg/kg	762	2,450	8,030	1,950	3,120	5,900	2,090	3,760	4,310
Inorganics										
Cyanide[d]	mg/kg	1.4(B)-	7.1	97.7	1.6(B)-	9.1	3.9(B)-	2.3(B)-	8.8	7
Sulfate[e]	mg/kg	15	23	19	15	27	17	18	15	35
p-Phosphate[e]	mg/kg	66	170	53	110	88	110	93	100	62

Table B4.2 (continued)

Analyte	Units	ID 24-10	ID 24-12	ID 24-13	ID 24-13	ID 24-14	ID 24-15	ID 24-26	ID 24-17	ID 24-18
Carbonate[f]	mg/L	870	910	320	1,700	320	660	NR	780	220

Source: CDM Federal Programs Corporation 1994.

[a]Test method was ICPLPS.
[b]Test method was EPA 206.2/CLPs_AS.
[c]Test method was EPA 245.5/CLPS_HG.
[d]Test method was CN_UG.
[e]Method/test was SW 846, 9056/IC-ER.
[f]Method/test was IC-C03.

Table B4.3. Organic constituent concentrations in sediment samples from Impoundment 3524

Analyte	Units	ID 24-10	ID 24-12	ID 24-13	ID 24-13	ID 24-14	ID 24-15	ID 24-26	ID 24-17	ID 24-18
Total organic carbon[a]	µg/g	4,700	33,000	26,000	21,000	30,000	2,700	15,000	2,300	13,000
Volatiles[b]										
Acetone	µg/kg	560	560	400	680	530	920	820	720	1,300
2-Butanone	µg/kg	150	190	110	170	73(J)-	220	240	160	320
Chlorobenzene	µg/kg	nr	70	nr	nr	nr	73	nr	1,600(D)-	nr
Toluene	µg/kg	nr	nr	nr	83	nr	nr	nr	160	nr
Xylene (meta + para)	µg/kg	nr	47	31(J)-	nr	nr	nr	120	150	nr
Xylene (ortho)	µg/kg	nr	nr	nr	nr	nr	nr	51(J)-	nr	
Base neutral/acids[c]										
Anthracene	µg/kg	440(J)	nr	nr	nr	nr	nr	80(J)	2,900(J)	nr
Benzo(a)anthracene	µg/kg	260(J)	1,200(J)	200(J)	110(J)	nr	nr	120(J)	870(J)	130(J)
Benzo(a)pyrene	µg/kg	220(J)	1,300(J)	nr	120(J)	nr	nr	120(J)	780(J)	90(J)
Benzo(b)fluoranthene	µg/kg	230(J)	1,600(J)	nr	180(J)	nr	nr	270(J)	nr	100(J)
Benzo(k)fluoranthene	µg/kg	nr	1,400(J)	nr	100(J)	nr	nr	nr	nr	nr
Benzo(g,h,i)perylene	µg/kg	nr	nr	nr	nr	nr	nr	nr	nr	170(J)
bis(2-Ethylhexyl)phthalate	µg/kg	nr	130,000(BD)	nr	nr	nr	nr	nr	nr	nr
Butyl benzyl phthalate	µg/kg	nr	nr	nr	130)J)	nr	nr	nr	nr	nr
Carbazole	µg/kg	210(J)	nr	nr	nr	nr	nr	90(J)	nr	nr
4-Chloro-3-methylphenol	µg/kg	nr	nr	140(J)	nr	nr	nr	nr	400(J)	100(J)
Chrysene	µg/kg	290(J)	1,500(J)	250(J)	190(J)	nr	nr	150(J)	1,100(J)	280(J)
Di-n-butylphthalate	µg/kg	330(BJ)	7,800(BJ)	nr	nr	nr	nr	nr	nr	1,200
3,3'-Dichlorobenzidine	µg/kg	nr	1,300(J)	nr	nr	nr	nr	nr	nr	nr
2,4-Dinitrotoluene	µg/kg	nr	1,200(J)	nr	nr	nr	nr	nr	nr	nr
2,6-Dinitrotoluene	µg/kg	nr	nr	nr	150(J)	nr	nr	120(J)	nr	nr
Di-n-octylphthalate	µg/kg	nr	1,000(BJ)	nr	860(BJ)	nr	nr	nr	nr	170(J)
Fluoranthene	µg/kg	490(J)	1,700(J)	350(J)(J)	310(J)	850(J)	nr	240(J)	2,100(J)	410(J)
Indeno(1,2,3-cd)pyrene	µg/kg	160(J)	nr	nr	nr	nr	nr	nr	470(J)	240(J)
2-Methylnaphthalene	µg/kg	nr	1,200(J)	nr	nr	nr	nr	nr	nr	nr
4-Methylphenol	µg/kg	nr	nr	nr	4,400	nr	nr	540(J)	nr	nr
Naphthalene	µg/kg	nr	nr	nr	nr	nr	nr	230(J)	nr	nr
2-Nitrophenol	µg/kg	nr	1,100(J)	nr	nr	nr	nr	nr	570(J)	nr

Table B4.3 (continued)

Analyte	Units	ID 24-10	ID 24-12	ID 24-13	ID 24-13	ID 24-14	ID 24-15	ID 24-26	ID 24-17	ID 24-18
N-Nitrosodi-n-propylamine	µg/kg	nr	nr	nr	nr	23,000	nr	nr	nr	nr
N-Nitrosodiphenylamine	µg/kg	nr	1,000(J)	nr	nr	nr	nr	nr	nr	180(J)
Phenanthrene	µg/kg	210(J)	980(J)	140(J)	180(J)	nr	nr	160(J)	640(J)	160(J)
Phenol	µg/kg	nr	nr	nr	880(J)	nr	nr	310(J)	2,100(J)	nr
Pyrene	µg/kg	360(J)	600(J)	310(J)	280(J)	nr	nr	260(J)	1,600(J)	270(J)
1,2,4-Trichlorobenzene	µg/kg	nr	nr	nr	180(J)	nr	nr	nr	nr	nr
Pesticides/PCBs										
Endosulfan I[d]	µg/kg	nr	11,000(DP)-	2,700(DP)-	nr	3,600(DJP)-	3,300(D)-	1,900(D)-	8,600((DP)-	4,300(D)-
Endrin aldehyde[d]	µg/kg	94(JPBD)-	nr	nr	nr	nr	nr	nr	nr	nr
Aroclor-1254[e]	µg/kg	10,000(D)	140,000(D)-	50,000(D)-	31,000(D)-	96,000(DP)-	47,000(D)-	26,000(D)-	140,000(D)-	75,000(D)-
Aroclor-1260[e]	µg/kg	nr	nr	nr	nr	nr	nr	nr	nr	nr

Source: CDM Federal Programs Corporation 1994.

[a]Test method was TOC_UG.
[b]Test method was CLP 624/VOACLP.
[c]Test method was CL_ 625/BNACLP.
[d]Test method was CLP/CLPESS.
[e]Test method was CLP/PCBS.

Table B4.4. Radionuclide activities in sediment samples from Impoundment 3513

Radionuclide	Units	ID 13-01	ID 13-02	ID 13-03	ID 13-04	Dup 13-04	ID 13-05	ID 13-06	ID 13-07	ID 13-08	ID 13-09
Plutonium-238	Bq/g	18.3	< 1.26	< 0.85	1.22	26.67	< 1.70	22.12	2.15	< 1.26	5.96
Plutonium-239,240	Bq/g	239.99	194.82	84.57	207.25	56.79	153.68	334.67	135.48	186.20	236.96
Thorium-228	Bq/g	11.10	12.31	2.5	10.78	73.33	6.92	8.92	7.60	5.48	7.11
Thorium-230	Bq/g	1.68	2.22	0.43	1.10	3.59	1.22	1.35	1.16	1.05	1.26
Thorium-232	Bq/g	8.97	9.74	2.17	5.86	20.53	5.17	11.62	6.33	5.77	9.06
Uranium	μg/g	363.00	525.00	2,675.00	271.00	960.00	2,778.00	964.00	242.00	2,016.00	1,252.00
Uranium-234	Bq/g	5.03	6.07	30.93	3.77	13.54	32.11	8.92	3.36	29.97	17.35
Uranium-235	Bq/g	0.20	0.30	1.52	0.15	0.54	1.58	0.54	0.14	1.14	0.71
Uranium-238	Bq/g	4.48	6.47	33.04	3.35	12.02	34.30	11.91	2.99	24.90	15.46

Source: CDM Federal Programs Corporation 1994.

Table B4.5. Inorganic constituent concentrations in sediment samples from Impoundment 3513

Analyte	Units	ID 13-01	ID 13-02	ID 13-03	ID 13-04	ID 13-05	ID 13-06	ID 13-07	ID 13-08	ID 13-09
					Organics					
Aluminum[a]	mg/kg	11,800	19,000	20,100	9,430	19,600	24,400	12,600	12,400	16,400
Arsenic[b]	mg/kg	2.9(J)	nd	nd	1.6(B)	2.4(J)	nd	nd	1.8(B)	2.6(J)
Barium[a]	mg/kg	247	311	209	178	286	345	201	227	280
Beryllium[a]	mg/kg	43.4(J)	37.7(J)	11.4(J)	20.2(J)	35.6(J)	37.2(J)	31.1(J)	37.4(J)	45.8(J)
Cadmium[a]	mg/kg	15.3	18.9	5	10.7	12.9	15.8	10.6	10.5	13.9
Calcium[a]	mg/kg	162,000	185,000	86,100	197,000	146,000	161,000	174,000	166,000	185,000
Chromium[a]	mg/kg	848	971	420	635	829	1,240	584	676	919
Cobalt[a]	mg/kg	6.4(B)	8.2(B)	9.9(B)	7(B)	8.1(B)	9.8(B)	7(B)	6.4(B)	7.6(B)
Copper[a]	mg/kg	771	676	211	743	531	497	696	902	1,200
Iron[a]	mg/kg	11,700	13,600	19.400	11,200	15,700	18,200	12,700	10,400	12,900
Lead[a]	mg/kg	2,340	3,470	1,130	1,240	2,630	5,140	1,720	1,960	3,010
Magnesium[a]	mg/kg	7,430	9,880	5,100	10.700	8,850	10.700	9,460	8,490	10,200
Manganese[a]	mg/kg	898	823	1,080	631	1,060	1,010	575	574	781
Mercury[c]	mg/kg	398	443	105	257	300	382	327	339	472
Nickel[a]	mg/kg	53	65.3	36	52.6	54.4	60.9	59.1	56.2	61.4
Potassium[a]	mg/kg	1,570	2,690	2,180(J)	1,450(J)	2,390(J)	2,030(J)	1,870(J)	1,770(J)	1,900(J)
Selenium[a]	mg/kg	2.2(B)	2.4(B)	nr	2(B)	2.4(B)	1.4(B)	2.6(B)	2(B)	2.9(B)
Silver[a]	mg/kg	61.9	65.1	22.8	56.1	54.3	71.6	65.4	55.6(J)	67.9
Sodium[a]	mg/kg	258	520(B)	324(B)	376(B)	458(B)	615(B)	351(B)	440(B)	512(B)
Vanadium[a]	mg/kg	40.3	63.1	38.6	36.3	47.3	40.2	46.3	57.2	60.7
Zinc[a]	mg/kg	579	826	257	491	579	794	534	499	619

Table B4.5 (continued)

Analyte	Units	ID 13-01	ID 13-02	ID 13-03	ID 13-04	ID 13-05	ID 13-06	ID 13-07	ID 13-08	ID 13-09
Inorganics										
Sulfate[d]	mg/kg	42	17	21	26	36	48	29	29	48
p-Phosphate[d]	mg/kg	43	21	290	53	200	430	95	140	430
Carbonate[e]	mg/L	220	340	300	270	400	nr	510	430	470

Source: CDM Federal Programs Corporation 1994.

[a]Test method was ICPLPS.
[b]Test method was EPA 206.2/CLPs_AS.
[c]Test method was EPA 245.5/CLPS_HG.
[d]Method/test was SW 846, 9056/IC-ER.
[e]Method/test was IC-C03.

Table B4.6. Organic constituent concentrations in sediment samples from Impoundment 3513

Analyte	Units	ID 13-01	ID 13-02	ID 13-03	ID 13-04	ID 13-05	ID 13-06	ID 13-07	ID 13-08	ID 13-09
Total organic carbon[a]	µg/g	8,800	13,100	3,100	12,400	26,400	901	34,000	23,100	28,000
Volatiles[b]										
Acetone	µg/kg	310	200-(J)	nr	110	nr	210	170	nr	nr
2-Butanone	µg/kg	nr	nr	nr	nr	nr	nr	80(BJ)(BJ)	nr	nr
Base neutral/acids[c]										
Acenaphthene	µg/kg	nr	nr	170(J)-	nr	nr	nr	nr	nr	130(J)-
Anthracene	µg/kg	nr	nr	110(J)-	nr	nr	nr	170(J)-	240(J)-	400(J)-
Benzo(a)anthracene	µg/kg	680(J)-	350(J)-	220(J)-	240(J)-	480(J)-	nr	nr	260(J)-	700(J)-
Benzo(a)pyrene	µg/kg	780(J)-	nr	120(J)-	120(J)-	200(J)-	nr	200(J)-	200(J)-	nr
Benzo(b)fluoranthene	µg/kg	1,400(J)-	570(J)-	160(J)-	290(J)-	1,000(J)-	nr	650(J)-	390(J)-	nr
Benzo(k)fluoranthene	µg/kg	nr	nr	100(J)-	nr	nr	nr	nr	280(J)-	nr
Benzo(g,h,i)perylene	µg/kg	nr	nr	nr	nr	nr	nr	nr	220(J)-	nr
bis(2-Ethylhexyl)phthalate	µg/kg	8,200(B)-	130,000(BDX)	10,000(B)-	98,000(BDX)-	14,000(B)-	240,000(BDX)-	44,000(BDX)-	20,000(BDX)-	48,000(BDX)-
Butyl benzyl phthalate	µg/kg	nr	nr	nr	nr	210(BJ)-	nr	nr	nr	nr
4-Chloro-3-methylphenol	µg/kg	200(J)-	140(J)-	80(J)-	80(J)-	nr	nr	nr	160(J)-	390(J)-
2-Chlorophenol	µg/kg	nr	120(J)-	nr	nr	nr	nr	nr	120(J)-	nr
Chrysene	µg/kg	520(J)-	130)J)-	100(J)-	70(J)-	310(J)-	nr	410(J)-	420(J)-	300(J)-
Dibenzofuran	µg/kg	nr	nr	nr	nr	nr	nr	nr	100(J)-	nr
Di-n-butylphthalate	µg/kg	940(J)-	470(J)-	260(BJ)-	220(BJ)-	nr	nr	650(BJ)-	550(BJ)-	480(J)-
Dibenz(a,h)anthracene	µg/kg	nr	nr	nr	nr	nr	nr	180(J)-	130(J)-	nr
3,3'-Dichlorobenzidine	µg/kg	nr	nr	120(J)-	nr	nr	nr	nr	550(J)-	nr
2,6-Dinitrotoluene	µg/kg	nr	nr	nr	200(J)-	nr	nr	nr	nr	nr
Di-n-octylphthalate	µg/kg	520(BJ)-	440(BJ)-	260(BJ)-	550(BJ)-	33,000(BDX)-	nr	370(BJ)-	850(BJ)-	2,100(B)-
Fluoranthene	µg/kg	1,100(J)-	710(J)-	1,200(J)-	280(J)-	1,300(J)-	nr	1,200(J)-	1,200(J)-	1,900
Fluorene	µg/kg	nr	nr	220(J)-	nr	70(J)-	nr	200(J)-	270(J)-	210(J)-
Indeno(1,2,3-cd)pyrene	µg/kg	nr	nr	nr	90(J)-	nr	nr	400(J)-	320(J)-	nr
Isophorene	µg/kg	nr	nr	nr	nr	nr	nr	nr	120(J)-	nr
2-Methyl-4,6-dinitrophenol	µg/kg	nr	nr	nr	nr	140(J)-	nr	nr	nr	160(J)-
2-Methylnaphthalene	µg/kg	nr	nr	nr	nr	140(J)-	nr	nr	140(J)-	300(J)-
4-Methylphenol	µg/kg	nr	nr	nr	nr	nr	nr	nr	100(J)-	nr
Naphthalene	µg/kg	nr	nr	nr	nr	nr	nr	nr	nr	160(J)-
2-Nitrophenol	µg/kg	740(J)-	nr	310(J)-	90(J)-	1,300	3,400(J)	nr	900(J)-	nr
4-Nitrophenol	µg/kg	760(J)-	650(J)-	280(J)-	210(J)-	1,900(J)-	4,400(J)	nr	nr	2,000(J)-
N-Nitrosodi-n-propylamine	µg/kg	14,000	34,000(DX)-	3,600	nr	nr	nr	11,000	28,000(DX)-	nr
N-Nitrosodiphenylamine	µg/kg	nr	nr	nr	nr	160(J)-	nr	nr	200(J)-	nr

Table B4.6 (continued)

Analyte	Units	ID 13-01	ID 13-02	ID 13-03	ID 13-04	ID 13-05	ID 13-06	ID 13-07	ID 13-08	ID 13-09
Pentachlorophenol	µg/kg	440(J)-	110(J)-	nr	nr	nr	nr	nr	nr	240(J)-
Phenanthrene	µg/kg	440(J)-	230(J)-	1,100(J)-	90(J)-	560(J)-	nr	460(J)-	490(J)-	1,000(J)-
Pyrene	µg/kg	830(J)-	580(J)-	850(J)-	140(J)-	nr	nr	nr	650(J)-	900(J)-
1,2,4-Trichlorobenzene	µg/kg	nr	nr	nr	nr	nr	nr	nr	90(J)-	90(J)-
2,4,6-Trichlorophenol	µg/kg	nr	nr	nr	nr	nr	nr	140(J)-	nr	nr
Pesticides/PCBs										
Endosulfan I[d]	µg/kg	1,700(DP)(J)	1,200(DP)(J)	570(DP)(J)	650(DP)(J)	nr	6,600(DP)	nr	nr	nr
Endrin aldehyde[d]	µg/kg	nr	nr	nr	nr	4,500(D)(J)	nr	nr	nr	nr
Aroclor-1254[e]	µg/kg	65,000(DP)(J)	36,000(DP)(J)	20,000(DP)(J)	17,000(DP)(J)	52,000(DP)(J)	99,000(DP)(J)	45,000(DP)(J)	48,000(DP)(J)	56,000(DP)(J)
Aroclor-1260[e]	µg/kg	nr	nr	nr	nr	21,000(P)(J)	38,000(D)	nr	nr	22,000(DP)(J)

Source: CDM Federal Programs Corporation 1994.

[a]Test method was TOC_UG.
[b]Test method was CLP 624/VOACLP.
[c]Test method was CL_ 625/BNACLP.
[d]Test method was CLP/CLPESS.
[e]Test method was CLP/PCBS.

Table B4.7. Radionuclide activities in interstitial waters from core samples from Impoundment 3524

(Bq/L)

Analyte	ID 24-10	ID 24-11	ID 24-12	ID 24-13	ID 24-14	ID 24-15	ID 24-16	ID 24-17	ID 24-18	Dup 24-18
Gross alpha	26.6	52.0	23.4	61.1	18.5	24.0	25.0	31.1	22.4	19.3
Gross beta	1417.1	2763.1	848.5	696.0	528.2	1430.0	721.8	323.1	1092.7	111.73
Cerium-144	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cesium-134	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1
Cesium-137	1.11	321.9	68.4	39.6	13.0	144.6	160.2	41.1	88.4	102.8
Chromium-51	28.0	ND	1.6	1.3	0.9	ND	0.7	ND	1.6	0.5
Cobalt-57	0.5	0.3	0.03	0.4	0.4	0.2	0.4	0.7	3.2	1.9
Cobalt-58	0.4	0.3	ND	ND	0.1	0.3	ND	0.4	ND	ND
Cobalt-60	11.1	8.0	4.7	2.4	2.0	6.2	3.1	27.8	4.1	3.7
Iron-59	ND	ND	ND	ND	ND	ND	ND	ND	1.9	0.6
Manganese-54	0.3	0.1	0.1	ND	0.1	0.1	ND	0.1	ND	0.6
Niobium-95	ND	ND	ND	ND	ND	ND	ND	ND	2.5	0.2
Potassium-40	4.6	ND	1.6	ND	ND	0.1	1.3	ND	0.8	ND
Ruthenium-106	0.7	ND	0.5	ND	1.9	ND	0.1	0.6	0.1	ND
Sodium-22	0.1	ND	0.3	0.3	0.2	ND	ND	0.5	ND	0.6
Strontium	850.9	1035.9	321.9	362.6	192.4	355.2	3700.0	111.0	444.0	628.9
Strontium-89	148.0	554.9	125.8	74.0	136.9	55.5	ND	18.5	196.1	55.5
Antimony-125	ND	ND	ND	3.8	ND	0.5	3.8	ND	0.5	ND
Thallium-208	ND	ND	ND	ND	ND	1.5	ND	ND	1.5	0.9
Zinc-65	1.0	ND	0.2	ND	ND	ND	ND	ND	ND	2.0
Zirconium-95	ND	ND	ND	ND	ND	7.3	ND	ND	7.3	0.4
Bismuth-212	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lead-212	ND	ND	0.9	ND	0.2	0.2	ND	0.2	0.9	0.5
Uranium-235	ND	ND	ND	ND	ND	ND	ND	ND	148.0	0.7

Source: CDM Federal Programs Corporation 1994.

Table B4.8. Radionuclide activities in interstitial waters from core samples from Impoundment 3513

(Bq/L)

Analyte	ID 13-01	ID 13-02	ID 13-03	ID 13-04	Dup 13-04	ID 13-05	ID 13-06	ID 13-07	ID 13-08	Dup 13-09
Gross alpha	38.5	23.0	18.4	11.0	29.9	12.48	22.0	33.3	13.76	13.04
Gross beta	1024	1370	668	579	1,040	596	959	838	822	876
Cesium-137	340	266	57.7	61.4	55.5	459	181	477	255	265
Chromium-51	ND	ND	0.459	ND	ND	0.651	1.87	2.35	ND	ND
Cobalt-57	0.150	0.540	0.077	0.237	0.177	0.910	0.149	0.141	0.426	0.0907
Cobalt-58	0.0907	ND	0.013	ND	ND	ND	ND	0.291	ND	0.168
Cobalt-60	1.38	1.07	0.303	0.611	0.555	4.51	1.10	1.81	1.31	3.06
Lead-212	ND	ND	ND	0.266	0.095	ND	0.0714	ND	ND	0.178
Manganese-54	ND	0.529	0.016	ND	0.128	ND	0.0052	ND	ND	ND
Potassium-40	0.168	1.92	ND	ND	ND	2.42	3.10	0.773	ND	3.37
Ruthenium-106	0.607	ND	1.04	0.448	0.625	4.88	0.088	5.59	300	3.38
Sodium-22	0.0503	0.047	0.0925	0.128	ND	0.765	ND	0.262	59.2	0.129
Strontium	444	407	277	233	322	74	292	344	ND	407
Strontium-89	70.3	77.7	51.8	48.1	30.0	88.8	159	48.1	ND	77.7
Thallium-208	ND	ND	ND	ND	0.251	ND	0.37	ND	ND	ND
Zinc-65	0.0648	ND	0.133	ND	0.243	ND	ND	ND	ND	ND

Source: CDM Federal Programs Corporation 1994.

Table B4.9. Areas of elevated soil contamination within Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Area of elevated contamination	Source	Area m^2 (ft^2)	Depth
East of Impoundment 3524[a]	Unknown; possible sump overflow	Minimum 114.3 (1,230)	Ranges from < 0.6–1.2 m (2–4 ft)[a,b]
North of Impoundment 3524[a]	Unknown; possible sump overflow	34.4 (370)	Unknown
North of Impoundment 3524[a]	Possible sump overflow	32.5 (350)	Unknown
Between Impoundment 3513 and 3524[a]	Unknown	4.6 (50)	Unknown
Between Impoundment 3513 and 3524[a]	Unknown, but area surrounds a stormwater grate and may be the result of accumulation of contaminants from spills in the area	6.5 (70)	Unknown
Between Impoundment 3513 and 3524[a]	Unknown subsurface source	2.3 (25)	> 46 cm (1.5 ft)[a]
Around perimeter of Impoundment 3513[c]	Unknown	919.7 (9,900)	> 2.4 m (7.9 ft)[b]
West of Impoundment 3513[c]	Unknown	418.0 (4,500)	> 3 m (9.9 ft)[b]

[a]Uziel, Williams, and Tiner 1989
[b]DOE 1992a
[c]Huang et al. 1984

cm = centimeter
DOE = U.S. Department of Energy
ft = feet
m = meter
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

from which aliquots were taken for analysis. Tables B4.10–B4.12 present the analysis results of Impoundments 3539 and 3540 sediment samples for selected radionuclides, inorganic constituents, and TCL organics. No surface water or interstitial water samples were collected from Impoundments 3539 or 3540.

All sampling equipment was extensively decontaminated before initiating the sampling event and before proceeding to the next sampling location. A laboratory-grade detergent was used to wash each piece of equipment. The equipment was then rinsed with deionized water, methanol, and a second rinse of deionized water. Samples for equipment rinses were collected from approximately 10 percent of the sampling locations at all four impoundments.

4.2 IMPOUNDMENT 3513 FISH SAMPLING

Fish samples in Impoundment 3513 were collected to support the ecological risk assessment. Although several species of fish are present in the impoundment, only samples of *Gambusia Affinis*, commonly named the mosquito fish, were collected. *Gambusia Affinis* is a small fish, typically less than 3.5 cm in length. Analyses were conducted on whole fish as filleting is impractical. In addition, a large number of fish were required to obtain adequate material for analyses. Fish were collected on two consecutive days, using a net from the bank of the impoundment. All fish collected on the first day were prepared as a single composite sample. It was determined that aliquots of a single composite would not provide adequate information to support statistical evaluation. The impoundment was resampled the following day, and the fish were sorted by size into five groups that were individually composited. Samples prepared from the second day sampling were identified numerically as fish Samples 1–5. The first day sample was identified as Sample 6. The individually composited fish samples (Samples 1–5) were analyzed for gross alpha activity, gross beta activity, ^{137}Cs, ^{90}Sr, TAL metals, BNA organic compounds, and pesticide/PCBs. Sample 6 was analyzed only for gross alpha activity, gross beta activity, ^{137}Cs, and ^{90}Sr. Table B4.13 presents the analytical results for radiological parameters and TAL metals. Table B4.14 presents analytical results for BNA organic compounds, while Table B4.15 presents results for pesticide/PCBs.

4.3 WHITE OAK CREEK SURFACE WATER AND SEEP SAMPLING

Contaminated groundwater from SIOU appears to be discharging to the White Oak Creek located south of and adjacent to the operable unit. Data were needed on contamination present in the surface water of White Oak Creek to support the human health risk assessment. Contamination in White Oak Creek is being addressed under Waste Area Grouping 2. Sampling of White Oak Creek has been conducted under Waste Area Grouping 2 to address current sources

Table B4.10. Radionuclide activities in sediment samples from Impoundments 3539 and 3540

Radionuclide	Activity (Bq/g)	Impoundment 3539	Impoundment 3540
Plutonium-238	Bq/q	ND	20.0
Plutonium-239,240	Bq/q	162.0	25.0
Thorium-228	Bq/q	70.0	73.9
Thorium-230	Bq/q	11.1	9.3
Thorium-232	Bq/q	85.7	86.1
Uranium	μg/g	168.0	153.0
Uranium-234	Bq/q	199.0	105.0
Uranium-235	Bq/q	4.2	3.9
Uranium-238	Bq/q	55.8	50.8

Source: CDM Federal Programs Corporation 1994.

Table B4.11. Inorganic constituent concentrations in sediment samples from Impoundments 3539 and 3540

Analyte	Units	Impoundment 3539 ID 39-19	Impoundment 3540 ID 40-20
Aluminum[a]	mg/kg	15,000	16,200
Barium[a]	mg/kg	380	413
Beryllium[a]	mg/kg	7.6	10.8
Cadmium[a]	mg/kg	24.1	29.4
Calcium[a]	mg/kg	10,300	4,230
Chromium[a]	mg/kg	1,300	1,790
Cobalt[a]	mg/kg	18.3	13.5
Copper[a]	mg/kg	2,640	3,300
Iron[a]	mg/kg	28,100	27,700
Lead[a]	mg/kg	2,960	4,190
Magnesium[a]	mg/kg	1,950	1,260
Manganese[a]	mg/kg	162	100
Mercury[c]	mg/kg	795	732
Nickel[a]	mg/kg	306	303
Potassium[a]	mg/kg	873	1,220
Selenium[a]	mg/kg	0.74	7.2
Silver[a]	mg/kg	283	303
Sodium[a]	mg/kg	106	69.5
Thallium[a]	mg/kg	1.1	3.5
Vanadium[a]	mg/kg	27.5	31.8
Zinc[a]	mg/kg	1,220	1,120
Cyanide[d]	mg/kg	46.1	37.7
Carbonate[e]	mg/L	80	NR
Sulfate[f]	mg/kg	210	150
o-Phosphate[f]	mg/kg	60	170

Source: CDM Federal Programs Corporation 1994.

[a]Test method was ICPCLPC.
[b]Test method was EPA 206.2/CLPS As.
[c]Test method was EPA 245.5/CLPS Hg.
[d]Test method was Cn μg.
[e]Method/test was SW-846, 9056/IC-ER.
[f]Method/test was IC-CO3.

Table B4.12. Organic concentration in sediment samples from Impoundments 3539 and 3540

Analyte	Units	ID 39-19	ID 40-20
Total organic carbon[a]	µg/g	19,000	14,000
Volatiles[b]			
Acetone	µg/kg	260	150
2-Butanone	µg/kg	71	60
Toluene	µg/kg	54	100
Base neutral/acids[c]			
Acenaphthene	µg/kg	180(J)	nd
Anthracene	µg/kg	410(J)	170
Benzo(a)anthracene	µg/kg	5,400	830
Benzo(a)pyrene	µg/kg	4,500	nd
Benzo(b)fluoranthene	µg/kg	8,900	nd
Benzo(k)fluoranthene	µg/kg	1,300(J)	nd
Benzo(g,h,i)perylene	µg/kg	2,900	nd
Butyl benzyl phthalate	µg/kg	469(J)	nd
Carbazole	µg/kg	130(J)	nd
Chrysene	µg/kg	7,900	1,700(J)
Di-n-butylphthalate	µg/kg	92,000(BDX)	110,000(BDX)
Dibenz(a,h)anthracene	µg/kg	2,100(J)	nd
Diethylphthalate	µg/kg	120(J)	1,400
2,6-Dinitrotoluene	µg/kg	240(J)	nd
Fluoranthene	µg/kg	3,800(J)	2,100(J)
Fluorene	µg/kg	160(J)	1409J)
Indeno(1,2,3-cd)pyrene	µg/kg	2,600	nd
2-Methylnaphthalene	µg/kg	120(J)	nd
4-Methylphenol	µg/kg	400(J)	nd
Naphthalene	µg/kg	200(J)	120(J)
2-Nitrophenol	µg/kg	120(J)	nd
4-Nitrobenzenamine	µg/kg	nd	150(J)
N-Nitrosodi-n-propylamine	µg/kg	3,400	nd
N-Nitrosodiphenylamine	µg/kg	120(J)	nd
Phenanthrene	µg/kg	1,000(J)	570(J)
Pyrene	µg/kg	4,000	1,600(J)
Pesticides/PCBs			
Endosulfan I[d]	µg/kg	8,100(DP)-	4,900(DJP)-
Aroclor-1254[e]	µg/kg	150,000(D)-	180,000(D)-
Aroclor-1260[e]	µg/kg	nd	120,000(D)-

Source: CDM Federal Programs Corporation 1994.

[a]Test method was TOC_UG.
[b]Test method was CLP 624/VOACLP.
[c]Test method was CL_ 625/BNACLP.
[d]Test method was CLP/CLPESS.
[e]Test method was CLP/PCBS.

Table B4.13. Radiological and TAL metal results for fish samples from Impoundment 3513

Analyte	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6
			Radionuclides (Bq/kg)			
Alpha activity	12	4	40	−57	−44	80
Beta activity	130,000	120,000	120,000	140,000	100,000	110,000
Cesium-137	35,000	32,000	40,000	3,800	29,000	37,000
Strontium	36,000	43,000	41,000	58,000	36,000	34,000
			Radionuclides (Bq/kg)			
Aluminum	0.3026 UJ	0.1247 UJ	0.434 UJ	0.0987 UJ	0.2532 UJ	na
Antimony	0.0239 J	0.0224 J	0.0245 J	0.0268 J	0.0376 J	na
Arsenic	0.0013 UJ	0.013 UJ	0.0348 J	−0.0052 UJ	0.0046 UJ	na
Barium	0.2428 UJ	0.187 UJ	0.2985 UJ	0.1768 UJ	0.2539 UJ	na
Cadmium	0.0035 J	0.033 J	0.0037 J	0.0055 J	0.0073 J	na
Calcium	709.4 J	584.9 J	751.1 J	206.5 UJ	683 J	na
Chromium	0.008 J	0.001 UJ	0.0053 J	0.0069 J	0.0035 J	na
Cobalt	0.0041 J	0.0024 J	0.0039 J	0.0042 J	0.0029 J	na
Copper	0.1758 J	0.1195 J	0.1469 J	0.0606 J	0.1193 J	na
Iron	1.127 UJ	0.8795 UJ	1.133 UJ	0.6878 UJ	1.028 UJ	na
Lead	0.0011 UJ	−0.0041 UJ	0.0084 UJ	−0.0072 UJ	−0.0054 UJ	na
Magnesium	26.75 J	24.06 J	25.48 J	16.66 J	23.82 J	na
Manganese	0.5108 J	0.3292 J	0.4398 J	0.291 J	0.3497 J	na
Mercury	0.54 J	0.57 J	0.9 J	0.67 J	0.61 J	na
Nickel	0.0052 UJ	0.0002 UJ	0.0037 UJ	−0.0037 UJ	−0.0036 UJ	na
Potassium	240.2 J	229 J	206.7 J	131.3 J	190.3 J	na
Selenium	0.0131 UJ	0.0423 UJ	0.0245 UJ	0.0315 UJ	0.0376 UJ	na
Silver	−0.0137 UJ	−0.0107 UJ	−0.0094 UJ	−0.0056 UJ	−0.0064 UJ	na
Sodium	69.89 UJ	70.22 UJ	74.55 UJ	53.27 UJ	51.95 UJ	na
Thallium	−0.0278 UJ	−0.019 UJ	−0.0307 UJ	−0.0134 UJ	−0.0171 UJ	na
Vanadium	0.0046 UJ	0.04 UJ	0.0057 UJ	0.0037 UJ	0.0049 UJ	na
Zinc	3.271 UJ	3.124 UJ	3.628 UJ	2.308 UJ	3.323 UJ	na

Source: CDM Federal Programs Corporation 1994.

Table B4.14. Organic constituent concentrations in sediment samples from Impoundment 3524

Analyte	ID 24-10	ID 24-12	ID 24-13	ID 24-13	ID 24-14
Base neutral/acids					
1,2,4-Trichlorobenzene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
1,2-Dichlorobenzene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
1,3-Dichlorobenzene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
1,4-Dichlorobenzene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
2,4,5-Trichlorophenol	70,000 U	60,000 U	47,000 U	75,000 U	74,000 U
2,4,6-Trichlorophenol	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
2,4-Dichlorophenol	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
2,4-Dimethylphenol	28,000 U	24,000 U	1,9000 U	30,000 U	30,000 U
2,4-Dinitrophenol	70,000 UJ	60,000 UJ	47,000 UJ	75,000 UJ	74,000 UJ
2,4-Dinitrotoluene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
2,6-Dinitrotoluene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
2-Chloronaphthalene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
2-Chlorophenol	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
2-Methylnaphthalene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
2-Methylphenol	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
2-Nitroaniline	70,000 U	60,000 U	47,000 U	75,000 U	74,000 U
2-Nitrophenol	28,000 U	24,000 U	19,000 U	30,000 UJ	30,000 U
3,3'-Dichlorobenzidine	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
3-Nitroaniline	70,000 U	60,000 U	47,000 U	75,000 U	74,000 U
4,6-Dinitro-2-methylphenol	70,000 U	60,000 U	47,000 U	75,000 U	74,000 U
4-Bromophenyl phenyl ether	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
4-Chloro-3-methylphenol	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
4-Chloroaniline	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
4-Chlorophenylphenyl ether	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
4-Methylphenol	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
4-Nitroaniline	70,000 U	60,000 U	47,000 U	75,000 U	74,000 U
4-Nitrophenol	70,000 U	60,000 U	47,000 U	75,000 U	74,000 UJ
Acenaphthene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Acenaphthylene	28,000 U	24,000 U	19,000 UJ	30,000 U	30,000 U
Anthracene	28,000 UJ	24,000 UJ	19,000 U	30,000 UJ	30,000 UJ
Benzo(a)anthracene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Benzo(a)pyrene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Benzo(b)fluoranthene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Benzo(g,h,i)perylene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Benzo(k)fluoranthene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Benzyl alcohol	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U

Table B4.14 (continued)

Analyte	ID 24-10	ID 24-12	ID 24-13	ID 24-13	ID 24-14
bis(2-Chloroethoxy)methane	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
bis(2-Chloroethyl)ether	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
bis(2-Chloroisopropyl)ether	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
bis(2-Chlorohexyl)phthalate	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
bis(2-Ethylhexyl)phthalate	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Butyl benzyl phthalate	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Carbazole	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Chrysene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Di-n-butylphthalate	28,000 UJ	24,000 UJ	19,000 UJ	30,000 UJ	30,000 UJ
Di-n-octylphthalate	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Dibenz(a,h)anthracene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Dibenzofuran	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Diethylphthalate	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Dimethylphthalate	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Fluoranthene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Fluorene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Hexachlorobenzene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Hexachlorobutadiene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Hexachlorocyclopentadiene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Hexachloroethane	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Indeno(1,2,3-cd)pyrene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Isophorone	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
N-Nitroso-di-n-propylamine	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
N-Nitrosodiphenylamine[a]	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Naphthalene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Nitrobenzene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Pentachlorophenol	70,000 U	60,000 U	47,00 U	75,000 U	74,000 U
Phenanthrene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Phenol	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U
Pyrene	28,000 U	24,000 U	19,000 U	30,000 U	30,000 U

Source: CDM Federal Programs Corporation 1994.

Table B4.15. Analytical results for pesticides/PCBs in fish samples from Impoundment 3513

Analyte	ID 1	ID 2	ID 3	ID 4	ID 5
	Pesticides/PCBs (μg/kg)				
4,4'-Dichlorodiphenyldichloroethane	674 U	537 U	706 U	515 U	656 U
4,4'-Dichlorodiphenyldichloroethylene	674 U	537 U	706 U	515 U	656 U
4,4'-Dichlorodiphenyltrichloroethane	674 U	537 U	706 U	515 U	656 U
Aldrin	347 U	277 U	364 U	265 U	338 U
alpha-Benzene hexachloride	347 U	277 U	364 U	265 U	338 U
alpha-Chlorodane	347 U	277 U	364 U	265 U	338 U
beta-Benzene hexachloride	347 U	277 U	364 U	265 U	338 U
delta-Benzene hexachloride	347 U	277 U	364 U	265 U	338 U
Dieldrin	674 U	537 U	706 U	515 U	656 U
Endosulfan I	347 U	277 U	364 U	265 U	338 U
Endosulfan II	647 U	537 U	706 U	515 U	656 U
Endosulfan sulfate	647 U	537 U	706 U	515 U	656 U
Endrin	647 U	537 U	706 U	515 U	656 U
Endrin aldehyde	647 U	537 U	706 U	515 U	656 U
Endrin ketone	647 U	537 U	706 U	515 U	656 U
gamma-Chlorodane	347 U	277 U	364 U	265 U	338 U
Heptachlor	347 U	277 U	364 U	265 U	338 U
Heptachlor epoxide	347 U	277 U	364 U	265 U	338 U
Lindane	347 U	277 U	364 U	265 U	338 U
Methoxychlor	3,474 U	2,766 U	3,638 U	2,653 U	3,377 U
Aroclor-1016	6,744 U	5,369 U	7,061 U	5,151 U	6,556 U
Aroclor-1221	13,692 U	10,900 U	14,337 U	10,458 U	13,311 U
Aroclor-1232	6,744 U	5,369 U	7,061 U	5,151 U	6,556 U
Aroclor-1242	6,744 U	5,369 U	7,061 U	5,151 U	6,556 U
Aroclor-1248	6,744 U	5,369 U	7,061 U	5,151 U	6,556 U
Aroclor-1254	14,904 D	19,489 D	25,901 D	21,984 D	12,457 D
Aroclor-1260	2,630 D	3,436 D	5,861 D	5,163 D	2,688 D
Toxaphene	34,741 U	27,657 U	36,376 U	26,535 U	33,775 U

Source: CDM Federal Programs Corporation 1994.

of contamination to the creek. This appendix presents selected data available from the Waste Area Grouping 2 database for samples collected upstream and downstream of SIOU.

Sampling of seeps and tributaries to White Oak Creek was conducted in June 1994 to characterize sources of contamination to the creek. Five sample locations are in the vicinity of SIOU. Sample location WC-24 is located in the creek, upstream of SIOU, and is considered a background location for evaluating the impact of SIOU on surface water. Sample locations WC-22 and WC-22A are located in the creek, downstream of SIOU. Sample location SW1-1 represents a seep located on the northern embankment of White Oak Creek, and sample location OF-304 is a designated outfall to the creek.

Samples of surface water are grab samples collected directly in appropriate containers following standard operation procedures developed for Waste Area Grouping 2 investigations (*Standard Operating Procedures for Waste Area Grouping 2 Project at ORNL Manual; Collection and Processing of Water and Particulate Samples from Seeps, Tributaries, and Streams*, ER/WAG2-SOP-3202, Rev. 1). Samples are also collected directly from the center of the creek, or from the seeps and outfalls. Samples collected for location WC-24 were analyzed for radionuclides, inorganic constituents (TAL metals and cyanide), and VOCs. Samples from the downstream locations WC-22 and WC-22A, the seep SW1-1, and the outfall OF-304 were only analyzed for gross alpha and gross beta activity. Table B4.16 presents analytical results for radionuclides, inorganic constituents. Table B4.17 presents analytical results for organic constituents.

Table B4.16. Analytical results for radiological and inorganic constituents in surface water samples from White Oak Creek

Analyte	WC-24 ID 4299	WC-24 DUP ID 4307	OF-304 ID 4302	WC-22A ID 4303	SW1-1 ID 4304	WC-22 ID 4305
Radionuclides (Bq/L)						
Alpha activity	0.03 R	na	0.70	−0.3	1.78	−0.2
Americium-241	0.002 R	0.002 R	na	na	na	na
Beta activity	0.5 R	na	48.1	1.78	81.40	3.55
Cesium-137	−0.02 R	0.07 R	na	na	na	na
Cobalt-60	0.02 R	0.01 R	na	na	na	na
Curium-244	−0.002 R	0.0003 R	na	na	na	na
Europium-152	0.63 R	0.4 R	na	na	na	na
Europium-154	0.42 R	0.55 R	na	na	na	na
Europium-155	-0.01 R	−0.01 R	na	na	na	na
Plutonium-238	−0.001 R	−0.003 R	na	na	na	na
Plutonium-239	−0.001 R	−0.001 R	na	na	na	na
Strontium-90	0.20 J	na	na	na	na	na
TAL metals (μg/L)						
Arsenic	0.59 U	0.93 U	na	na	na	na
Cadmium	1.1 U	1.5 U	na	na	na	na
Chromium	1.1 U	0.1 U	na	na	na	na
Lead	0.66 U	0.90 U	na	na	na	na
Mercury	0.08 B	0.06 B	na	na	na	na
Nickel	1.9 U	−2.3 U	na	na	na	na
Cyanide	10 U	10 U	na	na	na	na
Chromium, hexavalent	0.01 U	0.01 U	na	na	na	na

Source: CDM Federal Programs Corporation 1994.

Table B4.17. Analytical results for organic constituents in surface water samples from White Oak Creek

Analyte	WC-24 ID 4299	WC-24 DUP ID 4307
	Volatiles (μg/L)	
1,1,1-Trichloroethane	5 U	5 U
1,1,2,2-Tetrachloroethane	5 U	5 U
1,1,2-Trichloroethane	5 U	5 U
1,1-Dichloroethane	5 U	5 U
1,1-Dichloroethene	5 U	5 U
1,2-Dichlorobenzene	5 U	5 U
1,2-Dichloroethane	5 U	5 U
1,2-Dichloropropane	5 U	5 U
1,3-Dichlorobenzene	5 U	5 U
1,4-Dichlorobenzene	5 U	5 U
2-Butanone	10 U	10 U
2-Hexanone	10 UJ	10 UJ
4-Methyl-2-pentanone	10 U	10 U
Acetone	10 U	10 U
Benzene	5 U	5 U
Bromodichloromethane	5 U	5 U
Bromoform	5 U	5 U
Bromomethane	10 U	10 U
Carbon disulfide	5 U	5 U
Carbon tetrachloride	5 U	5 U
Chlorobenzene	5 U	5 U
Chloroethane	10 U	10 U
Chloroform	5.1	5.1
Chloromethane	10 U	10 U
cis-1,2-Dichloroethene	5 U	5 U
cis-1,3-Dichloropropene	5 U	5 U
Dibromochloromethane	5 U	5 U
Ethylbenzene	5 U	5 U
Methylene chloride	5 U	1.5 U
Styrene	5 U	5 U
Tetrachloroethene	5 U	5 U
Toluene	5 U	5 U
trans-1,2-Dichloroethene	5 U	5 U
trans-1,3-Dichloropropene	5 U	5 U
Trichloroethene	5 U	5 U
Vinyl acetate	10 U	10 U
Vinyl chloride	10 U	10 U
Xylene (Meta + Para)	5 U	5 U
Xylene, Ortho	5 U	5 U

Source: CDM Federal Programs Corporation 1994.

5. STATISTICAL ANALYSES OF SEDIMENT CONCENTRATIONS IN THE IMPOUNDMENTS

Preliminary risk assessments performed for SIOU using values derived from historical investigations revealed that radioactivity in the sediments within the impoundments would dominate the human health risk assessments. The radiological concentrations used for the risk assessment calculations must be carefully examined to refine these key input parameters. The data from the historic investigations, discussed in Chapter 3, and the 1994 RI sampling event, discussed in Chapter 4, for each impoundment will be used to derive the best estimates of average, maximum, and UCL_{95} concentrations for use in subsequent risk assessments.

5.1 IMPOUNDMENT 3513

Tamura et al. (1977) conducted the earliest investigation at Impoundment 3513. Intact cores were extracted from 15 uniformly distributed locations, frozen for transport, and partially thawed for extraction at the laboratory. Tamura et al. (1977) identified up to five distinct sediment horizons in each core, based on visual appearance, and then analyzed these horizons individually for gross weight, volume of water removed after centrifuging at 3,000 rpm for 20 min, and oven dry weights. Dried samples were analyzed for ^{90}Sr, ^{137}Cs, and gross alpha, reported as $^{239,240}Pu$.

Huang et al. (1984) conducted a second investigation. Intact cores were obtained from five random locations by hammering a plastic tube into the impoundment bottom until refusal, draining the water above the sediment by cutting a slit in the side of the tube, and compositing each core. Wet-weight concentrations were reported for ^{137}Cs, ^{90}Sr, ^{238}Pu, ^{239}Pu, ^{60}Co, ^{154}Eu, ^{241}Am, and ^{244}Cm.

Francis and Sealand (1987a) conducted a third investigation. Samples were collected from eight random locations using a 3-L (0.8-gal) stainless-steel dipper on a 3.7-m (12-ft pole). Aliquots of equal weights from each sample were composited into a single sample which was analyzed for ^{137}Cs, ^{90}Sr, ^{238}Pu, ^{239}Pu, ^{60}Co, ^{154}Eu, and ^{241}Am.

Energy Systems conducted an RI in 1994 during which composite samples from nine cores were obtained and analyzed for isotopic plutonium, total and isotopic uranium, and isotopic thorium. Due to difficulties in extracting intact cores, an alternate approach of removing sediments from the interior of the cores using a peristaltic pump was employed. Descriptions of the process indicated the overlying water column of each core was pumped off, and sample

collection began when the water appeared cloudy; the entire column was removed to the extent that the pump could remove the solids.

Comparisons of the data collected by the three historical and the 1994 investigations were complicated by the use of different sampling and analysis techniques. The Tamura et al. (1977) report contained the most complete data regarding physical characteristics of the sediment, but the use of gross alpha analyses for determining plutonium concentrations introduced additional uncertainties in these results. Huang et al. (1984) presented the most complete list of analytes, but did so on a wet-weight basis. Also, it was unclear whether the bottom clay layer was included in the samples analyzed, or whether any or all of the topmost, lightweight sediment layer described by Tamura et al. (1977) was lost when the water was drained. Francis and Sealand (1987a) provided more recent analyses, and thus probably the most reliable of the historical data sets from a sample QA/QC perspective. However, the correlation between collecting samples using a dipper instead of using intact cores was uncertain. The 1994 RI sampling event did not record the depths of sampling, nor did they indicate sediment appearance. As a result, the representativeness of these samples was uncertain. The top layer was probably obtained, but it was uncertain how well the pump could move the deeper sediments (i.e., the fact that the sampling team experienced difficulty in obtaining intact cores due to the clay layer not forming a tight plug in the cores indicated that the clays may have been fluid enough to be brought up by the pump). Finally, all three historical reports only interpreted the data for average concentrations and did not report a UCL_{95}. Therefore, the following data analyses were conducted to resolve these issues and present final, best estimates of average, maximum, and UCL_{95} radionuclide concentrations.

5.1.1 Data Interpretations

The following sections present analyses conducted on the data from each investigation conducted at Impoundment 3513.

5.1.1.1 Tamura et al. (1977)

As mentioned earlier, the Tamura et al. (1977) report contained the most complete data set for sediment weights, as well as the most detailed breakdown of concentrations by apparent change in physical properties. Therefore, it was decided to use this report to understand the effects on the final reported concentrations of subsequent sampling efforts using different sampling approaches that may not include a layer.

One problem arose immediately when it was recognized that the Tamura et al. (1977) sample identification codes did not necessarily correspond to the sediment horizon number. However, a review of the report text revealed that the top layer was always sediment horizon 1,

described as a "very loose, lightweight" material. Also, the bottom sediment horizon, described as a "dense compact" material, existed for all cores except 2-3. The middle three horizons were all described as a dark organic material, with the only difference between them being the amount of whitish-gray strata intermixed (from none for horizon 2 to more predominant in horizon 4). The text also revealed that sample 1-3-3 apparently was mislabeled, and in reality was the bottom sample, and samples 2-5-1 was inadvertently combined with 2-5-2 (for convenience, the identifier 2-5-1&2 will be used for this combined sample). Finally, gross weights were not reported for samples 1-3-2 and 2-5-1&2, so values were interpolated using the average ratio of gross weights to centrifuged volumes plus dried weights from samples in the same interval(s) in cores with identical numbers of samples.

Making these adjustments to the data set, weight ratios were constructed for dry weights divided by gross weights, centrifuged weights divided by gross weights, and dry weights divided by centrifuged weights (i.e., gross weights minus the weight of centrifuged water volumes, assuming a density of 1.0 g/cc for the water removed). The average ratio for each core was then determined, and the average, UCL_{95}, and lower confidence limit of the mean ratio (LCL_{05}) were determined from these values for four possible scenarios: all layers included, the top layer excluded, the bottom layer excluded, and both the top and bottom layers excluded (i.e., only middle layers). For the purpose of determining confidence limits, *W* tests were performed to ascertain whether normal or lognormal distributions were better assumptions for the data sets; lognormal distributions were assumed unless the *W* value for a normal distribution was greater than that for lognormal distributions and greater than $W_{0.05}$. Table B5.1 presents the results. These ratios were later used to explore possible wet-weight to dry-weight concentration conversions for the Huang et al. (1984) data.

Values of the total activity, in picocuries, were then determined for each sample using the dry weights times dpm/g divided by a conversion factor of 2.22 pCi/dpm. Next, since it was possible to identify samples belonging to the top and bottom horizons for each core, the data were grouped into three sets: the top horizon, the middle three horizons, and the bottom horizon. Though ideally it would be desirable to maintain the five groupings noted by Tamura et al. (1977) for data analysis, it was felt that the overall power of the analysis would not be significantly impacted since the three middle horizons had the common element of containing the dark organic material. Therefore, it was deemed that the uncertainties that would have occurred in an attempt to assign the middle samples to individual sediment horizons would not have been justified.

Weighted average and UCL_{95} concentrations for each data set were determined. The total weights, weight percents, and activity percents by layer were also calculated. Finally, the overall average and UCL_{95} concentrations were decay-corrected to 1994 activities. These results are

Table B5.1. Estimated weight ratios using data presented in Tamura et al. (1977), Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

	UCL_{95}	Average	LCL_{05}	W_{normal}	$W_{lognormal}$
Dry weight/gross weight ratios					
Including all layers	0.3357	0.2976	0.2595	**0.948**	0.855
Excluding top layer	0.4046	0.3557	0.3069	**0.953**	0.868
Excluding bottom layer	0.2195	0.1849	0.1608	0.941	**0.989**
Excluding top and bottom layers	0.2650	0.2073	0.1735	0.963	**0.974**
Centrifuged weight/gross weight ratios					
Including all layers	0.5549	0.5075	0.4601	**0.967**	0.949
Excluding top layer	0.6318	0.5753	0.5187	**0.933**	0.912
Excluding bottom layer	0.4374	0.3963	0.3632	0.937	**0.972**
Excluding top and bottom layers	0.4845	0.4356	0.3968	0.918	**0.949**
Dry weight/centrifuged weight ratios					
Including all layers	0.5639	0.5279	0.4919	**0.951**	0.916
Excluding top layer	0.6168	0.5658	0.5240	0.981	**0.981**
Excluding bottom layer	0.4909	0.4532	0.4155	**0.947**	0.919
Excluding top and bottom layers	0.5254	0.4694	0.4135	**0.947**	0.884

Note: $W_{0.05}$ = 0.881; the distribution assumed for confidence limits is indicated by bold numbers.

LCL_{05} = 5th percentile lower confidence limit of the mean
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean

all presented in Table B5.2. The UCL_{95} concentrations in all cases were less than the maximum detected concentrations, eliminating the need to report these additional values. As a final note, it should be noted that gross alpha analyses are generally useful only as a qualitative screening tool and are limited in their usefulness for quantitative assessments.

5.1.1.2 Francis and Sealand (1987a)

The only question remaining for this data set before using it in comparative analyses concerned the representativeness of the 3-L (0.8-gal) dipper used by Francis and Sealand (1987a) in obtaining sediments from all layers. For this determination ^{137}Cs and ^{90}Sr concentrations for each of the four possible variances determined previously (Tamura et al. 1977) (i.e., using all layers, excluding the top layer, excluding the bottom layer, and excluding both the top and bottom layers) were decay-corrected and compared to Francis and Sealand (1987a) concentrations. The dry-mass weighted averages shown for Tamura et al. (1977) under each scenario were calculated by including only those samples occurring in the layers of interest. The results of these comparisons are shown in Table B5.3. To make the predicted concentrations

Table B5.2. Statistical summaries of the Tamura et al. (1977) data, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(pCi/g)

Layer	Weight		Gross alpha			Cesium-137			Strontium-90		
	(g)	(%)	Average	UCL_{95}	Activity (%)	Average	UCL_{95}	Activity (%)	Average	UCL_{95}	Activity (%)
All	4,057	100	4,653	21,353	100	199,204	1,204,119	100	32,253	132,959	100
Top	485	12	14,742	31,448	38	611,699	1,720,886	37	83,439	119,747	31
Middle	1,254	31	8,837	16,026	59	385,339	951,848	60	68,717	145,128	66
Bottom	2,318	57	278	905	3	12,213	91,715	4	1,821	11,316	3
1994 activities			**4,651**	**21,342**		**134,859**	**815,176**		**21,455**	**88,446**	

g = gram
ORNL = Oak Ridge National Laboratory
% = percent
pCi = picocurie
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean

most closely match, the best hypothesis was to assume that all layers were representatively sampled.

5.1.1.3 Huang et al. (1984)

First, values of becquerels per gram were converted to picocuries per gram using a factor of 27.027 pCi/Bq. Next, average, LCL_{05}, and UCL_{95} concentrations were determined. For the purposes of determining confidence limits, lognormal distributions were uniformly assumed. Though normal distributions were nominally better assumptions for two of the seven radionuclides, lognormal distributions were excellent fits for these two cases (greater than $W_{0.10}$ for ^{244}Cm and greater than $W_{0.50}$ for ^{239}Pu), and it was deemed to be better to maintain a consistent assumption for this parameter.

It was necessary to convert the wet-weight basis concentrations into dry-weight equivalents to use the concentrations reported in Huang et al. (1984) for subsequent comparisons. However, it was not clear from the text of the report whether the wet-weight basis of Huang et al. (1984) would be more closely analogous to the gross weights or the centrifuged weights in Tamura et al. (1977). Therefore, tests cases were constructed for both of these scenarios. For each test case, several possible influences were explored. When the cores were slit open to allow the overlying water to be drained, it was possible that significant portions of the topmost, light-weight layer was lost. Also, it was unclear whether the bottommost layer was included in the analyses performed. Finally, the range of possible weight ratios (LCL_{05}, average, and UCL_{95}) had to be considered. When the centrifuged weights were used, it was found that no good comparisons could be made for the transuranic radionuclides, and these results are therefore not

Table B5.3. Comparisons of decay-corrected Tamura concentrations to Francis and Sealand concentrations under various hypothesized scenarios, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Scenario	Radionuclide	Average Tamura concentration (1984 pCi/g)	Average Francis and Sealand concentration (1987 pCi/g)	Ratio of Tamura to Francis and Sealand concentrations (percent)
All layers included	Cesium-137	158,358	185,000	117
	Strontium-90	25,377	27,000	106
Top layer excluded	Cesium-137	113,818	185,000	163
	Strontium-90	19,906	27,000	136
Bottom layer excluded	Cesium-137	356,536	185,000	193
	Strontium-90	57,298	27,000	212
Top and bottom layers excluded	Cesium-137	306,327	185,000	166
	Strontium-90	54,066	27,000	200

g = gram
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit

reported. However, for dry-weight conversions, good comparisons could be made, and these results are given in Table B5.4. For comparison purposes, the appropriate, back-calculated Francis and Sealand (1987a) values are also given. Section 5.1.2 discusses the use of these comparisons, and the data are presented here for convenience only.

5.1.1.4 1994 RI sampling event

The data from the 1994 sediment sampling event were analyzed to obtain average, maximum, and UCL_{95} radionuclide concentrations. For the purposes of determining confidence limits, lognormal distributions were uniformly assumed. As with Huang et al. (1984), a normal distribution was nominally a better assumption for one of the nine analyses, but lognormal distribution was an excellent fit for this case (greater than $W_{0.10}$ for $^{239,240}Pu$). It was better to use a consistent methodology for determining confidence limits than to use a normal distribution on only one data set under such circumstances. Table B5.5 shows the results of these calculations.

Isotopic uranium values activity ratios were evaluated to ascertain the degree of enrichment implied, and it was discovered these values are, on the average, representative of

Table B5.4. Comparisons of Huang et al. concentrations to Francis and Sealand concentrations under various hypothesized scenarios, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

	Corrected Francis and Sealand	UCL_{95} ratio			Average ratio			LCL_{05} ratio		
		LCL_{05}	Average	UCL_{95}	LCL_{05}	Average	UCL_{95}	LCL_{05}	Average	UCL_{95}
All layers										
Cesium-137	198,184	115,614	189,997	776,538	130,416	214,322	875,956	149,565	245,791	1,004,570
Cobalt-60	1,633	1,119	1,642	3,537	1,262	1,853	3,990	1,447	2,125	4,576
Europium-154	326	322	322	322	363	363	363	417	417	417
Plutonium-239	8,501	2,592	3,864	9,613	2,924	4,359	10,843	3,353	4,999	12,436
Plutonium-238	225	95	132	243	107	149	275	123	171	315
Americium-241	1,909	539	741	1,321	608	835	1,491	697	958	1,709
Curium-244	N/A	137	188	348	154	213	392	177	244	450
Strontium-90	29,014	19,883	26,406	42,086	22,429	29,787	47,475	25,722	34,161	54,445
Excluding top layer samples										
Cesium-137	142,442	95,936	157,658	644,364	109,102	179,296	732,799	126,458	207,817	849,370
Cobalt-60	1,174	928	1,363	2,935	1,056	1,550	3,338	1,224	1,796	3,869
Europium-154	235	267	267	267	304	304	304	352	352	352
Plutonium-239	5,996	2,151	3,207	7,977	2,446	3,647	9,071	2,835	4,227	10,514
Plutonium-238	159	79	110	202	89	125	230	104	144	266
Americium-241	1,347	447	615	1,096	509	699	1,247	590	810	1,445
Curium-244	N/A	113	156	289	129	178	328	149	206	381
Strontium-90	22,760	16,499	21,912	34,923	18,763	24,919	39,716	21,748	28,883	46,034
Excluding bottom layer samples										
Cesium-137	446,202	176,813	290,570	1,187,587	209,918	344,974	1,409,941	241,352	396,632	1,621,075
Cobalt-60	3,678	1,711	2,512	5,410	2,032	2,982	6,423	2,336	3,429	7,384
Europium-154	735	492	492	492	585	585	585	672	672	672
Plutonium-239	19,155	3,964	5,910	14,701	4,706	7,016	17,454	5,411	8,067	20,067
Plutonium-238	508	145	202	372	172	240	442	198	276	508
Americium-241	4,302	824	1,133	2,021	979	1,345	2,399	1,125	1,546	2,758

Table B5.4 (continued)

	Corrected Francis and Sealand	UCL_{95} ratio			Average ratio			LCL_{05} ratio		
		LCL_{05}	Average	UCL_{95}	LCL_{05}	Average	UCL_{95}	LCL_{05}	Average	UCL_{95}
Curium-244	N/A	209	288	532	248	342	632	285	393	726
Strontium-90	65,511	30,408	40,384	64,364	36,101	47,945	76,415	41,507	55,125	87,858
Excluding top and bottom layer samples										
Cesium-137	383,366	146,468	240,702	983,772	187,185	307,614	1,257,250	223,658	367,554	1,502,228
Cobalt-60	3,160	1,417	2,512	4,481	1,812	2,659	5,727	2,164	3,177	6,843
Europium-154	631	408	408	408	521	521	521	623	623	623
Plutonium-239	16,145	3,284	4,896	12,178	4,197	6,257	15,564	5,014	7,476	18,596
Plutonium-238	428	120	167	308	153	214	394	183	255	471
Americium-241	3,626	683	938	1,674	873	1,199	2,139	1,043	1,433	2,556
Curium-244	N/A	173	239	441	221	305	563	264	364	673
Strontium-90	61,816	25,189	33,453	53,318	32,192	42,753	68,140	38,464	51,084	81,417

LCL_{05} = 5th percentile lower confidence limit of the mean
N/A = not applicable
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean

Table B5.5. Statistical analyses of data from the 1994 RI sampling event, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

	LCL_{05}	Average	UCL_{95}	Maximum	W_{normal}	$W_{lognormal}$
Plutonium-238	87	201	12,184	802	0.7882	0.9418
Plutonium-239, 240	3,850	4,948	7,581	9,046	0.9762	0.9257
Thorium-228	206	297	528	1,009	0.6603	0.9236
Thorium-230	31	41	63	97	0.8228	0.9204
Thorium-232	172	230	377	555	0.8652	0.9498
Uranium	790	1,205	3,165	2,778	0.8628	0.9227
Uranium-234	267	403	990	868	0.8488	0.9065
Uranium-235	12	18	49	43	0.8631	0.9227
Uranium-238	264	403	1,059	927	0.8635	0.9222

Note: W0.05 = 0.842.

LCL_{05} = 5th percentile lower confidence limit of the mean
ORNL = Oak Ridge National Laboratory
RI = remedial investigation
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean

natural uranium. Total uranium concentrations were then converted to activity units using this assumption, and the results compared favorably with the isotopic analyses.

5.1.2 Data Interpretations

As mentioned previously, it was determined that comparisons of Tamura et al. (1977) data to Francis and Sealand (1987a) data could use the assumption that all layers, including the bottommost clay horizon, were sampled by the steel dipper used by Francis and Sealand (1987a). Therefore, these concentrations were decay-corrected and converted using activity and weight ratios determined from Tamura et al. (1977) to concentrations representative of various layers being excluded. For these purposes, ^{90}Sr Tamura et al. (1977) ratios were used to convert Francis and Sealand (1987a) ^{90}Sr concentrations, ^{137}Cs ratios were used for all other beta-gamma emitters, and gross alpha ratios were used for all alpha emitters. These values were then imported to the summary spreadsheets in Table B5.4 to compare them to the results of the various analyses performed on Huang et al. (1984) data.

Selected values are also compared to values predicted by Tamura et al. (1977) in Table B5.6. Three ranges of values were deemed most valuable in this comparison: the range of values determined by average concentrations converted by LCL_{05}, average, and UCL_{95} weight ratios; the range of values determined by the average weight ratios converted by the range of LCL_{05}, average, and UCL_{95} concentrations; and the fullest range of possible values represented by the UCL_{95} concentrations divided by LCL_{05} weight ratios, average concentrations divided by

Table B5.6. Huang et al. data divided by decay-corrected Tamura et al. data (in percentages of Huang data) under several hypothesized scenarios, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(percent)

	All layers included		Excluding top layer		Excluding bottom layer		Excluding top and bottom layers	
	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
Full range (concentrations and weight ratios varying)								
UCL_{95}	597	201	703	217	428	144	462	141
Average	127	110	148	118	91	79	95	74
LCL_{05}	69	74	79	78	47	50	45	44
Average ratio and concentrations varying								
UCL_{95}	521	176	606	187	372	125	387	118
Average	127	110	148	118	91	79	95	74
LCL_{05}	78	83	90	89	55	59	58	44
Average concentration and ratios varying								
UCL_{95}	146	149	172	136	105	90	113	89
Average	127	110	148	118	91	79	95	74
LCL_{05}	113	98	130	103	77	66	74	58

Cs = cesium
LCL_{05} = 5th percentile lower confidence limit of the mean
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
Sr = strontium
UCL_{95} = 95th percentile upper confidence limit of the mean

average weight ratios, and LCL_{05} concentrations divided by UCL_{95} weight ratios. All four hypothesized scenarios bounded the Tamura et al. (1977) values when the fullest range of Huang et al. 1984 values were considered and when only the concentration was varied, but none of them did so when only the weight ratios were varied. It was therefore concluded that the deciding factor in choosing a scenario that best fit the Huang et al. (1984) data to the other two historical reports would be determined primarily by examining the comparison to Francis and Sealand (1987a).

These analyses narrowed the possibilities to either using ratios from all layer data, or excluding the top layer samples. The use of all layer data had the advantage of best explaining the behavior of the beta-gamma emitters, as well as presenting a consistent approach among all three reports. However, it had the disadvantage of having lower estimates of the alpha-emitting radionuclides [average values of 44 percent to 67 percent of the Francis and Sealand (1987a) values], with the upper bound concentration for ^{241}Am being less than the Francis and Sealand

(1987a) value. The exclusion of the top layer had an opposite effect and provided best fit to the alpha-emitting radionuclides while predicting average values 127 percent to 133 percent of the Francis and Sealand (1987a) values. Also, the lower bound estimate of ^{154}Eu was greater than the Francis and Sealand (1987a) value. Therefore, both possibilities were carried forward into the comparison with the 1994 RI event.

For the 1994 RI event, only ^{238}Pu and $^{239,240}Pu$ concentrations were directly comparable to other studies. Therefore, only the weight and activity ratios from Tamura et al. (1977) could be utilized in this analysis (the use of gross alpha analyses to approximate plutonium concentrations would create too many additional uncertainties). The same four scenarios were tested for this comparison as used before, and corrected Francis and Sealand (1987a) values were compared to the range of LCL_{05}, average, and UCL_{95} concentrations from the 1994 RI event. Table B5.7 presents these results. This comparison suggested that the 1994 RI event may have lost a significant portion of the top layer activity, perhaps as a dispersed and diluted suspension in the overlying water column that was subsequently discarded as the water was pumped out. It also suggested that the methodology used managed to representatively sample the remaining layers.

Finally, the results of the 1994 RI event were compared to the predictions of Huang et al. (1984) concentrations to decide which of its two remaining scenarios would best describe the data generated. Had the top layer of the sediments tested by Huang et al. (1984) also been lost, the concentrations should be directly comparable to decay-corrected concentrations (to express the data in 1984 activities) from the 1994 RI event. Alternatively, if Huang captured all sediment layers, these predicted concentrations would be comparable to decay- and layer-corrected 1994 concentrations, with the layer correction factor being derived from weight and activity ratios from Tamura et al. (1977) data. Table B5.8. presents the results of these comparisons. From these comparisons, it appears that Huang et al. (1984) also missed the top layer of sediment.

As a final note, it should be remembered that the underlying assumption for these derivations is that all sampling efforts managed to obtain correct estimates of radionuclide concentrations. If in fact this assumption is false, many of the relationships developed would fail. However, of all the comparisons performed, only one portion of one data set consistently presented a serious challenge to this underlying assumption: the Francis and Sealand (1987a) plutonium and americium concentrations. Exclusive of these data, the 1994 RI episode, the Huang et al. (1984), and even the gross alpha numbers reported as "$^{239,240}Pu$" conformed well with the other's results. Therefore, the potential effects of excluding the Francis and Sealand (1987a) plutonium and americium concentrations were assessed qualitatively to ascertain whether this uncertainty should be explored further. The largest effect would be to accept the Huang et

Table B5.7. Comparisons of the 1994 RI sampling data to Francis and Sealand, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

	LCL_{05}	Average	UCL_{95}	Maximum
Data from recent sampling event (1994)				
Plutonium-238	87	201	12,184	802
Plutonium-239, 240	3,850	4,948	7,581	9,046
Corrected Francis and Sealand values				
All layers				
Plutonium-238		208		
Plutonium-239		8,498		
Excluding top layer				
Plutonium-238		147		
Plutonium-239		5,994		
Excluding bottom layer				
Plutonium-238		469		
Plutonium-239		19,150		
Excluding top and bottom layers				
Plutonium-238		395		
Plutonium-239		16,140		

LCL_{05} = 5th percentile lower confidence limit of the mean
ORNL = Oak Ridge National Laboratory
RI = remedial investigation
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean

al. (1984) and 1994 RI data as representative of all layers being sampled. Although this is an appealing assumption and may in fact fit better with what has in reality happened, the net effect would be to accept lower estimates of radionuclide concentrations. Exclusive of compelling evidence supporting the contention that the Francis and Sealand (1987a) plutonium and americium concentrations are not legitimate results, it was decided to adopt the more conservative of the two assumptions. Therefore, Huang et al. (1984) and the 1994 RI event data were converted to representative concentrations assuming the top layer was missed by the sampling efforts.

5.1.3 Impoundment 3513 Conclusions

To make additional conclusions from the data for subsequent risk assessment and feasibility studies, concentrations for the overlying sediments (i.e., the top and middle layers as expressed in the above assessments) were derived separately from the subimpoundment soils (i.e., the bottom layer as expressed in the above assessments) in addition to the overall predicted concentrations. Once again, the weight and activity ratios from Tamura et al. (1977) served as a basis to derive these two data sets from each of the four data sets.

Table B5.8. Comparisons of 1994 RI data to remaining scenarios for Huang et al., Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

	1994 results	UCL_{95} ratio			Average ratio			LCL_{05} ratio		
		LCL_{05}	Avg.	UCL_{95}	LCL_{05}	Avg.	UCL_{95}	LCL_{05}	Avg.	UCL_{95}
All layers										
	Layer- and decay-corrected									
Plutonium-239	7,822	2,592	3,864	9,613	2,924	4,359	10,843	3,353	4,999	12,436
Plutonium-238	487	95	132	243	107	149	275	123	171	315
Excluding top layer samples										
	Decay-corrected									
Plutonium-239	4,949	2,151	3,207	7,977	2,446	3,647	9,071	2,835	4,227	10,514
Plutonium-238	218	79	110	202	89	125	230	104	144	266

LCL_{05} = 5th percentile lower confidence limit of the mean
ORNL = Oak Ridge National Laboratory
RI = remedial investigation
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean

Table B5.9 presents the best estimates of average, maximum detected, and UCL_{95} activities predicted by all reports combined in pCi/g of dry material. The values chosen were the maximum in each category predicted by the four sampling events, where the Francis and Sealand values are considered to be representative of average values and the gross alpha analyses of Tamura et al. (1977) are disregarded (note: the value reported as the UCL_{95} is determined by taking the lesser of the calculated UCL_{95} or maximum detected value for each report, and then bringing forward the maximum of these choices). These values have been decay-corrected to represent 1994 concentrations. For reference purposes, the sampling event from which the concentrations are derived are noted adjacent to the values.

5.2 IMPOUNDMENT 3524

Two historical investigations, Braunstein et al. (1984) and Francis and Sealand (1987a), have been performed in addition to the 1994 RI that assess the radiological concentrations in the sediments of Impoundment 3524. Comparisons of the data collected by the two historical and 1994 investigations were complicated by different sampling and analysis techniques. Braunstein et al. (1984) obtained samples from distinct points within cores, and thus has some sense of concentrations by depth in the sediments. However, by taking samples at set points along the top and bottom of the cores, and then obtaining additional samples in between based on high beta-

Table B5.9. Average, maximum detected, and UCL_{95} concentrations for the overlying sediment in Impoundment 3513, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(pCi/g dry)

Radionuclide	All layers		Overlying sediment		Subimpoundment soils	
	Average	UCL_{95}	Average	UCL_{95}	Average	UCL_{95}
Cesium-137	230,000[a]	440,000[a]	450,000[a]	1,100,000[b]	12,000[a]	92,000[b]
Cobalt-60	660[a]	1,500[a]	1,300[a]	3,000[a]	36[a]	80[a]
Europium-154	200[a]	230[a]	400[a]	460[a]	11[a]	12[a]
Plutonium-239, 240	8,500[c]	12,000[d]	19,000[c]	24,000[d]	510[c]	650[d]
Plutonium-238	320[d]	1,300[d]	630[d]	2,500[d]	17[d]	68[d]
Americium-241	1,900[c]	2,200[a,e]	4,200[c]	4,600[a,e]	110[c]	120[a,e]
Curium-244	190[a]	340[a]	390[a]	700[a]	10[a]	18[a]
Strontium-90	31,000[a]	88,000[b]	73,000[b]	140,000[b]	1,800[b]	11,000[b]
Thorium-228	470[d]	830[d]	930[d]	1,700[d]	25[d]	45[d]
Thorium-230	64[d]	99[d]	130[d]	200[d]	3[d]	5[d]
Thorium-232	360[d]	600[d]	720[d]	1200[d]	20[d]	32[d]
Uranium-234	640[d]	1,400[d]	1,300[d]	2,800[d]	34[d]	74[d]
Uranium-235	29[d]	67[d]	58[d]	130[d]	2[d]	4[d]
Uranium-238	640[d]	1,500[d]	1,300[d]	2,900[d]	34[d]	79[d]

[a]Huang et al. (1984)
[b]Tamura et al. (1977)
[c]Francis and Sealand (1987a)
[d]1994 RI event
[e]Used UCL_{95} value from Huang et al. (1984) instead of Francis and Sealand (1987a) value.

g = gram
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean

gamma readings, the sampling program had the potential for three biasing effects. Francis and Sealand (1987a) provided more recent analyses, and thus probably the more reliable of the two historical data sets from a sample QA/QC perspective, but the correlation between collecting samples using a dipper to those obtained within intact cores was uncertain.

The 1994 sampling event did not record the depths of sampling, nor did they indicate sediment appearance. As a result, the representativeness of these samples relative to other sampling programs was uncertain. It was initially thought that the top layer was probably obtained, but some of this material may have been lost when the overlying water column was pumped off. It was also uncertain how well the pump could move the deeper sediments.

Finally, both historical reports only interpreted the data for average concentrations and did not report a UCL_{95}. Therefore, the following data analyses were conducted to resolve these issues and present final, best estimates of average, maximum, and UCL_{95} radionuclide concentrations.

5.2.1 Data Interpretations

The following present analyses conducted on the data from each investigation conducted at Impoundment 3524.

5.2.1.1 Braunstein et al. (1984)

Based on an analysis of the Tamura et al. (1977) data for Impoundment 3513 (in which five distinct sediment horizons were identified, which could be grouped into three data sets with very different weight and radionuclide concentrations: a topmost layer of very loose, lightweight material; three middle layers of dark organic material with varying amounts of whitish-gray material; and a bottommost layer of dense compact material), it was hypothesized that a layering effect might be seen in Impoundment 3524 also. If so, taking samples at set distances from the top and bottom of each core could have a biasing effect, as they would be predominantly from only one of the hypothesized layers. In addition, by using a beta-gamma detector to preferentially select samples from core locations exhibiting high readings, the middle samples would likely be biased for beta-gamma-emitting radionuclides, as well as other radionuclides that would tend to concentrate along with them.

Therefore, the raw data was utilized for reanalysis with values reported as being less than an activity being converted to the reported sample minimum detection value. These data were then grouped into three sets for each radionuclide measured: all samples obtained 10 cm (4 in.) from the top of the core, all samples obtained 10 cm (4 in.) from the bottom of the cores, and all samples obtained in between.

It was then hypothesized that different sediment layers should exist within Impoundment 3524, and these sediment layers in Impoundment 3524 should exhibit measurably different concentrations of various radioisotopes in a manner similar to Impoundment 3513. This hypothesis was investigated by using the Wilcoxon Rank Sum Test, which is a nonparametric test to determine whether population means are expected to be significantly different. Table B5.10 presents the results, which generally are mixed results. For gross alpha, ^{137}Cs, and ^{241}Am, the mean of the top samples was significantly less than either the middle or bottom samples, but the middle and bottom sample means were not significantly different. For ^{90}Sr and ^{60}Co, the mean of the bottom samples was significantly less than either the top or middle samples, but the top

Table B5.10. Wilcoxon Rank Sum Test results for Braunstein et al., Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Radionuclide	Comparing		
	Top to middle	Middle to bottom	Top to bottom
Gross alpha	−2.71	−0.64	−2.04
Americium-241	−2.93	−0.98	−2.52
Cobalt-60	0.91	2.60	3.15
Strontium-90	0.41	2.30	2.78
Cesium-137	−2.10	−0.93	−2.45
Europium-154	−2.07	−0.19	−1.25
Critical values: < −1.645 or > 1.645			

ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

and middle sample means were not significantly different. Finally, for ^{154}Eu, the only significant difference was between the mean of the top samples and the mean of the middle samples.

The data sets were then reordered according to the results of the Wilcoxon Rank Sum Tests. For gross alpha, ^{241}Am, ^{137}Cs, and ^{154}Eu, the middle and bottom data sets were combined, and the top data set was kept separate. For ^{90}Sr and ^{60}Co, the top and middle data sets were combined, and the bottom data sets were kept separate.

Shapiro and Wilk Tests (*W*-tests) were then performed on each data set of less than 50 data points to determine on a case-by-case basis whether normal or lognormal distributions better described the data set. D'Agostino's Tests (*Y*-tests) were performed on data sets with more than 50 points. Averages and UCL_{95}s were calculated for each case, utilizing the appropriate equations presented in the EPA Publication 9285.7-081, *Supplemental Guidance to RAGS: Calculating the Concentration Term* (May 1992), as determined by the results of the *W*-tests or *Y*-tests.

Next, the raw data were examined to determine the best weighting mechanism available to express radionuclide concentrations for the entire impoundment. Two data sets were available, as sample depths and aliquot weights were given for each sample. It was desired to relate sample depth to sediment volume, and to relate sample aliquot weights to sediment layer densities, as both of these values would be appropriate for deriving weighted averages of overall average concentrations for the impoundment. However, since the aliquot volumes were not always measured, and since it was uncertain how well controlled the methodology was for pulling the

aliquots, it was deemed to be unreliable to relate the dry sample weights to sample densities or to total sample activity.

Therefore, average depths were calculated for the top, middle and bottom data sets, by assuming each sample represented an equal fraction of its core length, and only these averages were used as the weighting mechanisms. Table B5.11 presents the individual sample depths by core number and sediment layer and the average depths used to weight top, middle, and bottom concentrations.

Table B5.12 presents maximum, average, and UCL_{95} concentrations in pCi/g dry weight along with the calculated normal and lognormal *W* and *Y* values. This table presents the average, maximum detected, and UCL_{95} concentrations (in pCi/g dry weight) by radionuclide for each data grouping used, as well as their calculated overall weighted values.

Finally, Table B5.13 presents the final, rounded values from these analyses, decay-corrected to 1994 concentrations.

As a final note, it should be remembered that these results are derived from a biased sampling program. As a result, it is very likely that they are representative of the upper range of concentrations at Impoundment 3524, as opposed to the true distribution. Therefore, the true population mean may, in reality, be significantly less than the reported concentrations.

5.2.1.2 Francis and Sealand (1987a)

It has been previously established in an analysis of Impoundment 3513 data that the 3-L (0.8-gal) steel dipper used by the Francis and Sealand (1987a) investigation most likely managed to representatively sample all sediments layers within that impoundment. It is therefore reasonable to assume that all sediment layers of Impoundment 3524 were representatively sampled also. Table B5.14 summarizes the results of this investigation in decay-corrected pCi/g dry weight concentrations. Since these results are from a single composite sample, they are most representative of average concentrations.

5.2.1.3 1994 sampling event

The data from the 1994 sediment sampling event were analyzed to obtain average, maximum, and UCL_{95} radionuclide concentrations. For the purposes of determining confidence limits, lognormal distributions were uniformly assumed. Table B5.15 presents the results of these calculations.

Table B5.11. Depth-weighting values for Braunstein et al., Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Core	Samples	Length (cm)	Top	Middle	Bottom
1	3	40.6	13.53	13.53	13.53
2	3	34.3	11.43	11.43	11.43
3	4	68.6	17.15	34.30	17.15
4	4	83.8	20.95	41.90	20.95
5	4	64.8	16.20	32.40	16.20
6	3	45.7	15.23	15.23	15.23
7	3	26.7	8.90	8.90	8.90
8	2	31.8	15.90	0.00	15.90
9	3	48.9	16.30	16.30	16.30
10	4	106.7	26.68	53.35	26.68
11	5	95.3	19.06	57.18	19.06
12	2	27.9	13.95	0.00	13.95
13	3	34.9	11.63	11.63	11.63
14	3	29.2	9.73	9.73	9.73
15	4	43.2	10.80	21.60	10.80
16	5	139.7	27.94	83.82	27.94
17	4	134.6	33.65	67.30	33.65
18	3	33	11.00	11.00	11.00
19	3	49.5	16.50	16.50	16.50
20	3	38.1	12.70	12.70	12.70
21	3	55.9	18.63	18.63	18.63
22	4	59.7	14.93	29.85	14.93
23	3	29.2	9.73	9.73	9.73
24	2	20.3	10.15	0.00	10.15
		Average depths:	15.95	24.04	15.95

cm = centimeter
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

Table B5.12. *W* and *Y* values, and average, UCL_{95}, and maximum detected concentrations, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Analyte	*W* or *Y* normal	*W* or *Y* lognormal	Critical values	Average (pCi/g)	UCL_{95} (pCi/g)	Maximum (pCi/g)
Gross alpha						
Top	0.5446	0.9570	> 0.916	3,845	5,329	23,730
Middle and bottom	−37.7603	−2.0144	−2.7222 to 1.0842	51,175	79,725	1,091,891
			Overall	37,683	58,516	1,091,891
Americium-241						
Top	0.4463	0.9010	> 0.916	937	1,227	7,757
Middle and bottom	−38.2901	−0.5385	−2.7222 to 1.0842	21,711	46,901	494,594
			Overall	15,789	33,880	494,594
Cobalt-60						
Top and middle	−3.4636	0.5141	−2.7222 to 1.0842	13,634	25,044	52,162
Bottom	0.8633	0.8938	> 0.916	4,610	39,480	17,405
			Overall	11,062	29,159	52,162
Strontium-90						
Top and middle	−2.2263	−3.2815	−2.7222 to 1.0842	128,817	147,782	402,702
Bottom	0.8361	0.9099	> 0.916	81,039	233,020	297,297
			Overall	115,197	172,081	402,702
Cesium-137						
Top	0.7276	0.8865	> 0.916	152,082	664,488	554,054
Middle and bottom	−2.1770	−2.7822	−2.7222 to 1.0842	307,751	371,565	1,059,458
			Overall	263,374	455,070	1,059,458
Europium-154						
Top	0.7971	0.9554	> 0.916	845	1,156	2,676
Middle and bottom	0.1341	0.2802	−2.7222 to 1.0842	4,188	7,541	84,324
			Overall	3,235	5,721	84,324

g = gram
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean
W =
Y =

Table B5.13. Final weighted average, UCL_{95}, and maximum concentrations for Braunstein et al., Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(1994 decay-corrected pCi/g dry weight)

	Average	UCL_{95}	Maximum
Gross alpha	38,000	59,000	1,100,000
Americium-241	16,000	33,000	490,000
Cobalt-60	3,000	7,800	14,000
Strontium-90	91,000	140,000	320,000
Cesium-137	210,000	360,000	840,000
Europium-154	1,300	2,400	35,000

g = gram
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean

Isotopic uranium values activity ratios were also evaluated to ascertain the degree of enrichment implied. These values are generally representative of uranium that is depleted in ^{235}U. Total uranium concentrations were then converted to activity units using a conversion factor derived for natural uranium, and the results confirmed that it would be inappropriate to make this assumption, as the predicted results were low by up to 25 percent of the actual concentrations. It was also noted that the activity ratios of ^{238}U to $^{233,234}U$ were incongruous with the ratios of ^{238}U to ^{235}U. Specifically, while the ^{238}U:^{235}U ratio indicated the uranium was depleted, the ^{238}U:$^{233,234}U$ implied that it would be enriched. This was interpreted as indicating these presence of ^{233}U, the possibility of which was confirmed by process knowledge. The two radionuclides are similar enough, in types and energies of radioactive emissions, that there is no clear distinction between them from a risk perspective, and the use of the combined activity numbers is considered adequate. However, from a criticality safety perspective, the distinction is considered worthy of note. The predicted value of ^{234}U was therefore derived from the ^{235}U and ^{235}U activities, and the result was subtracted from the $^{233,234}U$ activity to derive the implied ^{233}U activity. It was determined that, on the average, the ^{233}U activity was predicted to be approximately 72 percent of the reported $^{233,234}U$ concentrations.

5.2.2 Impoundment 3524 Conclusions

Ideally, concentrations for the overlying sediments (i.e., the top and middle layers as expressed in the above assessments) would be derived separately from the subimpoundment soils (i.e., the bottom layer as expressed in the above assessments), as was done for Impoundment 3513. It was considered whether to use the weight and activity ratios from Tamura 1977 to serve as a basis to derive these two data sets from each of the three Impoundment 3524 data sets.

Table B5.14. 1994 decay-corrected composite sample concentrations for Francis and Sealand, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(pCi/g dry weight)

	Average
Gross alpha	18,000
Cesium-137	160,000
Europium-152	1,100
Europium-154	340
Plutonium-238	820
Plutonium-239	11,000
Americium-241	9,200
Cobalt-60	1,300
Strontium-90	82,000

g = gram
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit

However, given the different histories and input processes for these impoundments, no correlation should be expected to exist. Therefore, to artificially impose Impoundment 3513 activity and weight ratios upon Impoundment 3524 would, in effect, diminish the overall usefulness of the analyses, and this apportioning was not performed.

Each of the three data set had inherent strengths, as well as weaknesses, which had to be compensated for before the final data usage. Table B5.16 presents the best estimates of average, maximum detected, and UCL_{95} activities predicted by these analyses for the overlying sediment and the subimpoundment soils together in pCi/g of dry material. The values chosen were the maximum in each category predicted by the three sampling events, where the Francis and Sealand values are considered to be representative of average values and the gross alpha analyses of Braunstein et al. (1984) are disregarded. (Note: The value reported as the UCL_{95} is determined by taking the lesser of the calculated UCL_{95} or maximum detected value for each report, and then bringing forward the maximum of these values.) All concentrations have been decay-corrected to represent 1994 activities. For reference purposes, the sampling event from which the concentrations are derived are noted adjacent to the values.

5.3 IMPOUNDMENTS 3539 AND 3540

Francis and Sealand (1987a) conducted the earliest investigation at Impoundments 3539 and 3540. Samples were collected from 10 random locations using a 3-L (0.8-gal) stainless-steel dipper on a 4-m (12-ft) pole. Aliquots of equal weights from each sample were composited into

Table B5.15. Average, UCL_{95}, and maximum concentrations, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(pCi/g dry weight)

	Average	UCL_{95}	Maximum
Plutonium-238	1,100	3,500	3,600
Plutonium-239, 240	17,000	505,000	72,000
Thorium-228	270	7,600	990
Thorium-230	31	130	82
Thorium-232	140	2,400	640
Uranium-233, 234	150	710	590
Uranium-235	5	34	24
Uranium-238	120	550	530

g = gram
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean

a single sample that was analyzed for ^{137}Cs, ^{90}Sr, ^{60}Co, ^{152}Eu, ^{154}Eu, and ^{241}Am. Energy Systems conducted an RI in 1994 during which composite samples from two cores were obtained and analyzed for isotopic Pu, total and isotopic U, and isotopic Th.

5.3.1 Data Interpretations

Since the operating history is identical for these two ponds, the data were combined for analysis. Even so, only two samples could be accounted for within the data sets for the two sampling episodes, making statistical tests of populations meaningless. For risk assessment purposes, only lognormal distributions can be assumed without statistical proof otherwise. For a sample population of only two samples, the calculation of UCL_{95}s will invariably result in values greater than the maximum detected concentration. Since the maximum detected values are substituted for UCL_{95}s when this occurs, it was deemed to be trivial to calculate these numbers. Therefore, only averages and maximum detected concentrations are reported.

5.3.1.1 Francis and Sealand (1987a)

Table B5.17 summarizes the results of this investigation in decay-corrected pCi/g dry weight concentrations. Since these results are from a single composite sample, they are most representative of average concentrations.

5.3.1.2 1994 RI sampling event

The data from the 1994 RI sediment sampling event were analyzed to obtain average and maximum radionuclide concentrations. Table B5.18 summarizes the results of these calculations. Also, isotopic uranium values activity ratios were evaluated to ascertain the degree of enrichment

Table B5.16. Final average, UCL_{95}, and maximum concentrations for Impoundment 3524, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(pCi/g dry weight)

Radionuclide	Average	UCL_{95}
Plutonium-238	1,100[a]	3,500[a]
Plutonium-239, 240	17,000[a]	72,000[a]
Thorium-228	270[a]	990[a]
Thorium-230	31[a]	82[a]
Thorium-232	140[a]	640[a]
Uranium-233, 234	150[a]	590[a]
Uranium-235	5[a]	24[a]
Uranium-238	120[a]	530[a]
Americium-241	16,000[b]	33,000[b]
Cesium-137	210,000[b]	360,000[b]
Europium-152	1,100[c]	1,100[c]
Europium-154	1,300[b]	2,400[b]
Cobalt-60	3,000[b]	7,800[b]
Strontium-90	91,000[b]	140,000[b]

[a]Recent sampling event
[b]Braunstein 1984
[c]Francis and Sealand 1987a

g = gram
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean

Table B5.17. Average and maximum decay-corrected concentrations, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(pCi/g dry weight)

	Average	Maximum
Gross alpha	1,200	1,700
Cesium-137	54	92
Europium-152	6	6
Europium-155	2	2
Americium-241	< 270	< 270
Cobalt-60	5	6
Strontium-90	96	140

g = gram
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit

Table B5.18. Average and maximum concentrations, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(pCi/g dry weight)

	Average	Maximum
Plutonium-238	−10	20
Plutonium-239, 240	93	162
Thorium-228	72	74
Thorium-230	10	11
Thorium-232	86	86
Uranium-234	152	199
Uranium-235	4	4
Uranium-238	53	56

g = gram
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit

implied. These values are generally representative of uranium that is slightly enriched in ^{235}U, on the order of less than 2 percent by weight ^{235}U.

5.3.2 Impoundments 3529 and 3540 Conclusions

Since the two sampling events did not have overlapping analyses, it is appropriate to use the reported results of each sampling event without further analysis.

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APPENDIX C

RISK ASSESSMENT

1. TOXICITY ASSESSMENT

This section briefly summarizes the effects of ionizing radiation and chemicals on exposed populations. It discusses methods used to evaluate toxicity.

1.1 RADIATION TOXICITY

The potential health effects associated with exposure to radionuclides at the SIOU site are caused by low-level ionizing alpha, beta, and gamma radiation emitted by the members of the ^{137}Cs, ^{241}Pu, ^{90}Sr, ^{60}Co, and ^{241}Am decay series. The primary effects include an increase in the occurrence of cancer in irradiated individuals and possible genetic effects that may occur in future generations. The risk of serious genetic effects is much lower than the risk of cancer induction (EPA 1989a). Therefore, genetic effects are not the focus of this toxicity assessment, and radiological risks are evaluated only with respect to incremental cancer probabilities per EPA guidance (EPA 1989a). Nonradiological health effects of uranium are considered, as appropriate, in the chemical toxicity section.

Radiation-induced health effects for humans have been confirmed only at relatively high doses or high dose rates with large populations. Exposure to a high dose of radiation (e.g., a thousand times the average annual background dose rate) during a short period of time (a few hours) produces detrimental effects in all the organs and systems of the body. For low doses, health effects are presumed to occur but can only be estimated statistically. Risk estimates are strictly applicable to large populations, because the appearance of health effects after an exposure is a chance event. For purposes of radiological impact assessment, the health effects are measured by cancer incidence in the exposed population. However, risk estimates in the low-dose range are uncertain because of extrapolation from high doses and because of assumptions made on dose-effect relationships and the underlying mechanisms of carcinogenesis. Radiation effects in the exposed population cannot be readily identified since radiogenic cancers are indistinguishable from those resulting from other factors. Studies of populations chronically exposed to low-level radiation, such as those residing in regions of elevated natural background, have not shown consistent evidence of an associated increase in the risk of cancer.

The exposure routes can be classified as either external or internal. External exposure occurs when the radioactive material is outside the body. Internal exposure occurs when the radioactive material enters the body by routes such as inhalation or ingestion. Inhaled material can be exhaled, expelled from the lungs to be spit or swallowed and excreted, deposited in the lungs, or absorbed by the blood and relocated to systemic organs where it may be excreted over

time. Some ingested material enters the blood and is either excreted or relocated to other organs and excreted over time. Most insoluble ingested material is not absorbed into the blood but is excreted directly in the feces.

Alpha, beta, and gamma radiations are released during the radioactive decay processes series. Each type of radiation differs in its physical properties and in its ability to induce damage to biological tissue. The BEIR IV report (National Research Council 1988) addresses the risk from radon and alpha radiations. Alpha particles are an internal exposure hazard rather than an external hazard because they are unable to penetrate the dead skin cell layer of the body to reach living tissue. Within the body, alpha particles are the most effective of the three types of radiation in damaging cells because they have high linear energy transfer, that is, their energy is completely absorbed by tissue within a short distance. High linear energy transfer radiation is more damaging to cells than low linear energy transfer radiation. The BEIR V report (National Research Council 1990) addresses the risk from low linear energy transfer radiation such as gamma and beta particles. Beta particles are primarily an internal hazard; however, in cases of external skin exposure, energetic beta particles can penetrate living skin cells, representing an external hazard as well. Beta particles deposit less energy to small volumes of tissue than alpha particles and, therefore, induce much less damage than alpha particles. Gamma radiation is primarily an external hazard because it can penetrate tissue and reach internal organs without being taken into the body.

1.2 RADIATION TOXICITY RELATED TO THE SIOU SITE

The only exposures at the SIOU site are chronic (long-term) low-level exposures. Although lethal effects in human populations from chronic low-level exposure have never been documented, the effects have been projected from animal experiments (at high doses and dose rates). Studies assessing the difference between acute (short-term) and chronic (long-term) exposures show that, for a given dose, the radiation effects decrease dramatically as the exposure period is extended (National Research Council 1990). Thus for sites like SIOU, where all exposures are longer term and low level, no immediate harmful effects are expected. Rather the statistical impacts of possible increases in cancer or genetic changes are the only credible potential radiation effects (National Research Council 1990).

The radionuclides that occur at the SIOU site include the various decay series. The toxicity of the various radionuclides is based on:

- the types and energies of radiation they emit,
- the biological importance of the organs/tissues being irradiated,
- the radiological sensitivity of the organs/tissues being irradiated, and
- for internal exposure only, metabolic behavior in the body and biological retention characteristics in the body.

These factors were considered by ICRP, which established the concept of committed effective dose equivalent (CEDE) to measure the detriment of exposure to radiation or radioactive materials. The CEDE value is calculated based on the models and criteria established by ICRP (ICRP 1977 and 1978) to allow quantification of this detriment, using all of the factors discussed above. Thus an estimate of risk from exposure to radiation or radioactive material may be made by determining the CEDE and multiplying by a dose-to-risk (e.g., cancer risk) conversion factor. The radiogenic cancer risk factor was estimated by the National Academy of Sciences in BEIR IV (National Research Council 1988) and BEIR V (National Research Council 1990). For detailed discussion of radiation dosimetry and toxicity, refer to publications of the ICRP (1977, 1978), National Research Council (1988, 1990), and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1988).

1.3 METHODS OF EVALUATING RADIATION TOXICITY

For this baseline risk assessment, a risk factor of 6×10^{-7}/mrem (EPA 1989c, National Research Council 1990) was used to estimate the likelihood of cancer induction from radiation exposure. EPA used this risk factor to develop revisions to the National Emission Standards for Hazardous Air Pollutants for radionuclides under Section 112 of the Clean Air Act (EPA 1989c). It is a lifetime average value and believed to be representative of conditions defined for the exposure scenarios at the SIOU site.

The BEIR V study (National Research Council 1990) also presents a detailed description of current data on the health risks associated with radiation exposure. A mortality risk factor of about 8×10^{-7}/mrem is estimated in the BEIR V report. To compare this mortality risk factor with the risk factor used in this baseline risk assessment for induction of all cancers, whether fatal or not, the mortality risk factor must be adjusted. On average, the cancer mortality rate is about 60 percent of the cancer induction rate (EPA 1989d). The mortality risk factor (8×10^{-7} per mrem) can be modified to a total cancer induction rate of 1.3×10^{-6} per mrem (8×10^{-7} = 60% of 1.3×10^{-6}). BEIR V estimates were derived primarily from data on acute exposures

(a single instantaneous exposure), and the BEIR V report suggests that it is appropriate to reduce this risk by applying a dose rate effectiveness factor of two or more in cases of continuous low-level exposure. Thus, the radiation risk factor of 6×10^{-7}/mrem used in this report is consistent with the value recommended in BEIR V.

In addition to using dose-to-risk conversion factors to estimate risk, EPA also has developed guidance for radiological risk assessment consistent with existing guidance for assessing chemical carcinogenic risks (EPA 1989b). Carcinogenic risks are calculated for the radionuclides of potential concern in a manner similar to existing methods for chemical carcinogens by using an age-averaged lifetime excess cancer incidence per unit intake (and per unit external exposure). EPA has developed cancer slope factors per unit intake that are analogous to the slope factors developed for chemical carcinogens. Radiological carcinogenic risk estimated using EPA slope factors and conventional dose conversion factors for the future employee is presented in Appendix B.

In this baseline risk assessment, the risk of cancer induction from inhalation of ^{222}Rn decay products has been estimated by converting ^{222}Rn exposure (in working level month) to millirem for CEDE. National Commission on Radiation Protection and Measurements (NCRP) report number 92 (NCRP 1987) indicates that 1 working level month is equal to about 14 rem. Weighting this by the 0.12 lung weighting factor (ICRP 1978) results in a CEDE of roughly 1,000 mrem per working level month.

1.4 CHEMICAL TOXICITY

The toxicity information considered in the assessment of potential carcinogenic risks from chemical exposure includes (1) a weight-of-evidence classification and (2) a slope factor. The weight-of-evidence classification qualitatively describes the likelihood that an agent is a human carcinogenic and is based on the available data from animal and human studies. A chemical may be placed in one of three groups to indicate its potential for carcinogenic effects: Group A, a human carcinogen; Group B1 or B2, a probable human carcinogen; and Group C, a possible human carcinogen. Chemicals that cannot be classified as human carcinogens because of a lack of data are categorized in Group D; and those for which there is evidence of noncarcinogenicity in humans are categorized in Group E.

One chemical potential COC (arsenic) is classified as a Class A known human carcinogen. Fifteen chemical COCs are classified as probable human carcinogen. These include aldrin, Aroclor-1254, Aroclor-1260, beryllium, lead, bis(2-ethylhexyl)phthalate, chrysene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, methylene chloride, trichloroethylene, and the

polycyclic aromatic hydrocarbons: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthrene, and benzo(k)fluoranthrene. Toxicological properties of the potential chemical COCs, including both carcinogenic and noncarcinogenic factors, are summarized in Appendix D. The table briefly describes chemical routes of exposure, critical effects, and carcinogenicity of the chemicals.

1.4.1 Methods of Evaluating Chemical Toxicity

Toxicity values used in the risk characterization of chemical potential COCs also are presented in Appendix D. This table includes supporting toxicological information along with source identifiers. Toxicity values used in risk calculations include the chronic reference dose for noncarcinogenic risk and the slope factors for the carcinogenic risk.

The chronic reference dose is defined as "an estimate of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime" (EPA 1989a). If the sum of the ratios of intake to reference dose value (i.e., hazard indices) for all contaminants is less than one, noncarcinogenic toxicity is unlikely. The slope factor is defined as a "plausible upper-bound estimate of the probability of a response (i.e., cancer) per unit intake of a chemical over a lifetime" (EPA 1989a). The slope factors multiplied by the estimated lifetime intake levels yield lifetime cancer risk estimates. Both reference dose and slope factor values are specific to the route of exposure (e.g., either ingestion or inhalation exposure).

1.4.2 Chemicals for which EPA Toxicity Values are Available

The EPA IRIS database was used to provide up-to-date toxicity values to use in SIOU risk calculations (EPA 1993a). When values were not available in IRIS, the 1993 EPA HEAST were used (EPA 1993a). A chemical may be under review or reexamination by EPA according to IRIS, and a value still may be obtained from HEAST. When values were not available in IRIS or HEAST, the Superfund Health Risk Technical Support Center—Environmental Criteria and Assessment Office was contacted. Provisional or interim values were obtained for these potential COCs if they were available.

Oral slope factors are available for 15 of the potential chemicals of concern. Polycyclic aromatic hydrocarbons assume the oral and inhalation slope factors for benzo(a)pyrene. Inhalation slope factors are available for only four carcinogenic potential chemicals of concern. Oral reference doses are available for 42 of the 47 total potential COCs. Inhalation reference concentrations are available for eight of the noncarcinogenic potential COCs. Because of the potential for inaccuracy, derivation/conversion of reference concentrations to reference doses was not employed in the risk assessment.

1.4.3 Chemicals for which No EPA Toxicity Values are Available

A number of the potential chemical COCs presently do not have reference doses and/or slope factors for determination of potential noncarcinogenic and carcinogenic health effects from oral and inhalation exposure. They are listed in Appendix D. The possible impacts of the absence of the risk estimation for these contaminants are discussed in Section 5.3.

As shown in Appendix D, EPA-derived reference dose values incorporate uncertainty factors to account for data that were used but would not apply to chronic exposures in the most sensitive human subpopulations. In general, the use of these uncertainty factors provides confidence that exposure levels less than the reference dose values are unlikely to cause toxic effects. However, the reference dose values may actually be much lower than levels that will cause toxic effects in sensitive human subpopulations. Table C1.1 summarizes toxicity values.

Table C1.1. Toxicity values for carcinogenic chemicals of potential concern, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Chemical	Slope factor $(mg/kg\text{-}day)^{-1}$	Weight-of-evidence classification	Type of cancer	Route of exposure	Source
Arsenic	1.8	A	Skin	Ingestion	IRIS
	15	A	Lung	Inhalation	IRIS
Beryllium	4.3	B2	Total tumors	Ingestion	HEAST
	8.4	B2	Lung	Inhalation	HEAST
Cadmium	6.1	B1	Respiratory track	Inhalation	IRIS
Chromium (VI)	41	A	Lung	Inhalation	IRIS
Nickel (refinery dusts)	0.084	A	Lung, nasal cavity	Inhalation	HEAST
Benzo(a)pyrene	7.3	B2	Gastrointestinal tract	Ingestion	IRIS
	17	B2	Skin	Dermal absorption	IRIS
Benzo(a)anthracene	0.73	B2	Gastrointestinal tract	Ingestion	*a*
	1.7	B2	Skin	Dermal absorption	*a*
Benzo(b)fluoranthene	0.73	B2	Gastrointestinal tract	Ingestion	*a*
	1.7	B2	Skin	Dermal absorption	*a*
Dibenzo(a,h)anthracene	7.3	B2	Gastrointestinal tract	Ingestion	*a*
	17	B2	Skin	Dermal absorption	*a*
Indeno(1,2,3-cd)pyrene	0.73	B2	Gastrointestinal tract	Ingestion	*a*
	1.7	B2	Skin	Dermal absorption	*a*
bis(2-Ethylhexyl)phthalate	0.014	B2	Liver	Ingestion	IRIS
Chloroform	0.0061	B2	Liver, kidney	Ingestion	IRIS
	0.081	B2	Respiratory tract	Inhalation	IRIS
Aroclor-1260	7.7	B2	Liver	Ingestion	IRIS
Aroclor-1254	7.7	B2	Liver	Ingestion	IRIS
Antimony	0.0004 (oral)	Low	Reduced life span, altered blood chemistry	UF = 1000 MF = 1	IRIS
Arsenic	0.0003 (oral)	NA	Keratosis and hyperpigmentation	NA	IRIS

Table C1.1 (continued)

Chemical	Slope factor $(mg/kg \cdot day)^{-1}$	Weight-of-evidence classification	Type of cancer	Route of exposure	Source
Barium	0.07 (oral) 0.0017 (inhalation)	Medium (oral)	Increased blood pressure, fetotoxicity	UF = 3 (oral) MF = 1	IRIS HEAST
Beryllium	0.005 (oral)	Low	NOAEL (for beryllium salts)	UF = 100 MF = 1	IRIS
Cadmium	0.001 (oral-diet) 0.0005 (oral-water)	High	Kidney damage	UF = 10 MF = 1	IRIS
Chromium (VI)	0.005 (oral) 5.7×10^{-7} (inhalation)	Low (oral)	Not defined Nasal mucosa atrophy	UF = 500 (oral) MF = 1	IRIS HEAST
Mercury (inorganic)	0.0003 (oral) 8.710^{-5} (inhalation)	NA	Kidney effects (mercury salts) Neurotoxicity	NA	IRIS HEAST
Nickel (soluble salts)	0.02 (oral)	Medium	Decreased body and organ weights	UF = 100 MF = 3	IRIS
Silver	0.005 (oral)	Medium	Argyria	UF = 2 MF = 1	IRIS
Zinc (metallic)	0.3 (oral)	NA	Anemia	NA	HEAST
bis(2-Ethylhexyl)phthalate	0.02 (oral)	Medium	Increased relative liver weight	UF = 1000 MF = 1	IRIS
Chloroform	0.01 (oral)	Medium	Fatty cyst formation in liver	UF = 1000 MF = 1	IRIS

[a]Carcinogenicity derived using carcinogenicity equivalency factor based on carcinogenicity of benzo(a)pyrene.

HEAST = Health Effects Assessment Summary Tables
IRIS = Integrated Risk Information System
kg = kilogram
MF = modifying factor
mg = milligram
NA = data not available
NOAEL = no-observed-adverse-effect level
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
UF = uncertainty factor

2. RISK CHARACTERIZATION

This section presents risk estimates for reasonable current use and hypothetical future use scenarios for human receptors at the SIOU site. Human receptors include employees, on-site residents, off-site residents, and children wading in White Oak Creek. Radiological risks and chemical risks are estimated separately. The overall human health risk and associated uncertainties from exposure to both radiological and chemical contaminants are discussed.

For the radiological assessment, risk is defined as the lifetime probability of cancer morbidity and does not include genetic or noncarcinogenic effects. For the chemical assessment, risk is defined as the lifetime probability of cancer incidence for carcinogens and the estimate of exceeding toxic effect thresholds for noncarcinogens.

Cancer risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of pathway-specific exposure to carcinogenic contaminants. Results of the cancer risk estimates can be compared to the target risk range of 10^{-6} to 10^{-4}, or 1 in 1 million to 1 in 10,000, that is the goal of EPA outlined in the National Contingency Plan.

EPA does not use a probabilistic approach to estimate the potential for noncarcinogenic health effects (EPA 1989a). Instead, the potential for noncarcinogenic effects is evaluated by comparing the average daily exposure (intake) over a specified time period (exposure duration) with a reference dose derived for similar exposure periods for each chemical (EPA 1989a). This ratio of exposure is called a hazard quotient. Hazard quotients for each potential COC are then summed to obtain a hazard index for the specific pathway. A hazard index greater than one has been defined as the level of concern for potential adverse noncarcinogenic health effects (EPA 1989a).

3. UNCERTAINTY IN THE ASSESSMENT PROCESS

The risks presented in the SIOU baseline risk assessment are single point estimates of risk rather than probabilistic estimates. Therefore, it is important to attempt to specify the uncertainties inherent in the risk assessment in order to place the risk estimates in proper perspective.

A quantitative statistical analysis of uncertainty has not been performed. Instead, key assumptions and site-related variables which contribute most to the uncertainty have been identified. The uncertainty associated with each variable discussed is described as low (i.e., probably will not impact the risk outcome), moderate (i.e., may impact the risk outcome slightly), or high (i.e., is likely to significantly impact the risk estimate).

There are several categories of uncertainties associated with site risk assessments. These include:

- sampling data adequacy,
- selection of potential COCs,
- exposure assessment variables, and
- toxicity values.

Each of these categories is discussed for radiological risk characterization and chemical risk characterization. Uncertainties for ecological risk assessment are discussed in Section 6.4.3.

3.1 UNCERTAINTY IN RADIOLOGICAL RISK ESTIMATES

3.1.1 Data

Limitations in data relative to locations and substances sampled and to analytical considerations (e.g., laboratory procedures) may affect the contaminants identified for a site. The uncertainty associated with the SIOU site sampling data is considered to be low because the sampling plans generally targeted appropriate areas and analytes using historical information, visual observations, and both phased and biased and nonbiased characterization strategies.

Site sampling data for evaluation of sediment and surface water is associated with high uncertainty due to the limited number of samples and the location of sampling stations. Use of soil background values for sediment screening and the lack of surface water background concentrations introduces uncertainty into the selection of COCs.

Uncertainty relative to sample analysis and data evaluation is considered low because an extensive, site-specific QA program has been implemented and is ongoing.

3.1.2 Contaminants of Potential Concern

Uncertainty is inherent in the selection of potential COCs for a baseline risk assessment and is associated with a number of factors. The identification of potential COCs for a human health evaluation relies on both information from site characterization activities and the application of a selection process. Considerable data have been collected for the site under both DOE's environmental monitoring program and the site characterization effort. The potential COC selection process was based on historical knowledge of site processes. Because samples were not analyzed for all radionuclides, the conservative assumption of secular equilibrium between the parent and daughter radionuclides in each decay series was made. Including all radionuclides in the decay series in the health evaluation could result in an overestimation of risk.

The approach used in this baseline risk assessment is consistent with the history of site operations (i.e., as a processing facility/laboratory) and the characteristics of radionuclides in the decay series (i.e., the half-lives of the various radionuclides). The radionuclides of concern included in this assessment are considered to represent the possible extent of on-site contamination adequately. Hence, the uncertainty in selection of radiological potential COCs is low.

3.1.3 Exposure Assessment

An exposure assessment is constructed from a number of site-specific considerations, including exposure point concentrations, scenario assumptions and intake parameters, and primary exposure pathways.

3.1.3.1 Exposure point concentrations

Factors that can contribute to uncertainty in exposure point concentrations include data availability and data heterogeneity. Extensive data are available for radionuclide concentrations in soil, but heterogeneity in the spatial distribution of contaminants could contribute to uncertainties when estimating appropriate exposure point concentrations. The mean and UCL_{95} confidence of the mean were used for the exposure point concentrations. This spatial averaging may overestimate or underestimate exposures for a receptor who may preferentially spend time at a particular location. However, the use of the UCL_{95} values reduces the probability of underestimating the risk. The method used to estimate the mean and UCL_{95} depended on the underlying distribution of the data for each analyte. The majority of samples were collected using a biased methodology. The distributions were assumed to be log normal unless, based on the Shapiro-Wilk statistic, the distribution was significantly different from log normal (at the 0.05

probability level) and not different from normal. The formula used for the mean and UCL_{95} for normal data are unbiased but uncertainties become larger as sample size becomes smaller. The formula for the mean of log normal distributions (Gilbert 1987) was chosen because it is a minimum variance unbiased estimate of the mean. This bias could cause overestimation of the mean for analytes with log normal distributions and few samples. This is a conservative error in that risk would tend to be overestimated. However, the uncertainties related to data heterogeneity in soil remain significant and are one of the most important components of total uncertainty in exposure assessment.

The method for addressing nondetects (less than detection limit values) also affects the exposure point concentrations. The inclusion of the detection limit as a proxy value for nondetects tends to increase the reported concentrations and resultant uncertainty. The detection limits for most analyses were low relative to background or the appropriate soil concentration guidelines. The uncertainty associated with the incorporation of nondetects is considered small.

Data aggregation introduces moderate uncertainty into the development of exposure point concentrations. A property-wide analysis may underestimate the radiological risk from exposure to a particular region of soil, by diluting the exposure point concentration by combining areas containing significantly elevated concentrations with surrounding areas of lesser contamination.

Ingestion of contaminated drinking water was shown to be a major contributor to risk in future scenarios. Exposure point concentrations were modeled as being leached into the groundwater based on soil contaminant data including the impoundments. The dose from radionuclides present in the groundwater was modeled using RESRAD, as explained in Section 4.4.1.3. Because of the unknown migration rate of and the limited number of monitoring wells in which contamination was detected, modeled data were used. The lack of definitive soil partition coefficient (K_d) values for contaminants, as well as a lack of site-specific hydrological information, can greatly affect the modeling effort. A conservative approach was used which assumes that the contaminants have migrated off site and reached steady-state at the same concentrations found in an on-site well located in a highly-contaminated area. Therefore, a high amount of uncertainty is associated with the derived exposure point concentration in groundwater. This uncertainty translates into a significant uncertainty in the dose received via the drinking water pathway.

In the absence of measurements needed to assess the inhalation pathway at the site, air particulate concentrations have been modeled to estimate exposure point concentrations. High uncertainty is associated with the exposures calculated for this pathway, inhalation is generally

a major contributor to radiological risks associated with the site. Therefore, the effect of this uncertainty on the exposure assessment is considered to be high.

3.1.3.2 Exposure assumptions

Assumptions used to identify scenarios and intake parameters for the exposure estimates are a source of uncertainty. Site-specific factors were used to select the scenario assumptions such as the extent of exposure (i.e., the exposure time, frequency, and duration) and to identify potential receptors. These assumptions use information on current land use and reasonable projections of future land use that consider the time frame of the assessment. The uncertainty in the scenarios developed for the current conditions is low because the assumptions reflect the actual conditions at the site.

Future site use is hypothetical but based on reasonable projections for land use within the time frame of this assessment. For example, it is reasonable to project that a commercial property on a main road next to and across the street from other commercial/industrial/residential properties could become a non-DOE commercial operation. The locations and durations associated with exposure to contaminants were considered reasonable for future commercial/residential use. The uncertainty in the selected scenarios is considered low.

An excavation worker scenario was evaluated in the initial assessment of receptors. Because parameters for this scenario rely on professional judgment without guidance of published references, there is a high uncertainty associated with assumptions for intake parameters and subsequent calculations. This scenario was not considered in this baseline risk assessment because screening indicated this receptor most likely would not have the highest exposure. Any exposure this receptor would receive would be short-term and acute, and the associated uncertainty would be high.

The exposure pathways quantified in this baseline risk assessment were determined on the basis of the site conceptual model and related characterization data. The uncertainty associated with selected pathways for this assessment is low because site characterization data support the conceptual model.

Best professional judgment was used to define the variables used to estimate mean and RME exposures for the identified receptors. Intake parameters used in the exposure assessment were derived from data in the literature, including EPA guidelines. Since considerable information is available with respect to reasonable assumptions for intake parameters (e.g., inhalation rates), the related uncertainty is expected to be low. Furthermore, uncertainties

associated with selecting values from the typical ranges identified for these parameters are not expected to significantly affect potential exposure estimates.

3.1.4 Toxicity Assessment

Standard dose conversion factors and risk estimates were used to estimate the carcinogenic hazards associated with radioactive contaminants. The health effects associated with radiation exposure have been studied for many years and are well known. The risk estimators used in this assessment are generally accepted by the scientific community as representing reasonable projections of the hazards associated with radiation exposure.

Human epidemiological data on carcinogenesis from exposure to ionizing radiation is more extensive than that for most chemical carcinogens. However, these data are based primarily upon studies of populations exposed to radiation doses and dose rates that are orders of magnitude higher than the levels of concern at the SIOU site (e.g., atomic bomb survivors, uranium mine workers, radium dial painters). Use of these data to predict excess cancer risk from low-level radiation exposure requires extrapolation based upon very uncertain dose-response assumptions. This uncertainty is evidenced by the revision in cancer risk estimates presented in the BEIR V report (National Research Council 1990) by a factor of 3 to 4 over those presented only 10 years earlier in the BEIR III report (National Research Council 1990), due primarily to additional study of the atomic bomb survivors and reassessment of the atomic bomb dosimetry. Whereas this revision would indicate higher radiological risks than previously predicted, the BEIR V report also states that "...epidemiological data cannot rigorously exclude the existence of a threshold in the millirem dose range. Thus, the possibility that there may be no risks from exposures comparable to the external natural background radiation cannot be ruled out. At such low doses and dose rates, it must be acknowledged that the lower limit of the range of uncertainty in the risk estimates extends to zero" (National Research Council 1990).

3.1.5 Risk Characterization

Most of the assumptions used in the characterization of risk tend to overestimate potential risks. Therefore, actual risks are most likely to be lower than those presented in this assessment. However, some of the procedures used and uncertainties inherent in the human health assessment process may tend to underestimate potential risks, including the use of standard dose conversion factors based on adult exposures for estimating radiation doses. The radiological dose conversion factors used in this assessment are based on the ICRP reference man. The reference man is an adult male weighing 70 kg (154 lb). The ICRP selected such a standardized individual for their dosimetry models because their main concern is associated with worker protection; the majority of radiation workers are adult males. Children are more susceptible to radiation exposure, and

such effects are particularly significant for young children. Therefore, use of dose conversion factors derived for adult males may introduce some uncertainty into the risk assessment.

The estimation of health effects associated with radiation doses was based on lifetime-average risk estimators for all routes of exposure. These lifetime-average risk estimators are appropriate because they reflect the likely conditions of exposure (i.e., any given age group could be exposed to the radiological contaminants). The uncertainty associated with the use of these average risk estimators rather than the multiple age-specific risk estimators to assess radiation toxicity in this baseline risk assessment is, therefore, low.

The limited characterization of airborne contamination could affect the risk estimates. No airborne particulate concentration measurements were made, and the estimated risks associated with airborne exposure could be either overestimated or underestimated as a result. The uncertainty could be expected to significantly affect the results of this assessment since the particulate inhalation pathway is a major contributor to the projected radiation exposure for the off-site resident at the Clinch River.

3.2 UNCERTAINTY IN CHEMICAL RISK ESTIMATES

3.2.1 Data

Chemical process operations conducted at the SIOU site have limited documentation. Processing conducted from 1948 to 1994 is likely to have generated the organic chemicals detected at the SIOU property. There is conclusive evidence, either from historical information or from the chemical investigation during the RI, that uniquely associates the organic contaminants with the thorium processing operations.

Uncertainty in site sampling data is considered low because the sampling plans generally targeted appropriate analytes based on historical information available, information about similar processes, and guidance. Reasonable certainty also is assumed because of the sample data validation and QA/QC procedures applied to sample analysis and data evaluation.

Site sampling data for evaluation of sediment and surface water is associated with high uncertainty due to the limited number of samples and the location of sampling stations. Samples collected for background comparison were not included in this assessment due to the large uncertainties associated with these numbers. Use of soil background for sediment screening introduces uncertainty into the selection of COCs.

The absence of on-site ambient air sampling for chemicals introduces additional uncertainty into this route of exposure.

3.2.2 Potential COCs

Uncertainty is inherent in the selection of potential COCs for the baseline risk assessment. Eliminating contaminants in the potential COC screening process can lead to lower estimates of potential health effects than inclusion of all analytes. However, other than common laboratory contaminants, the only chemicals excluded from the risk assessment were those detected at very low frequencies and at concentrations approaching background. The way that the data are aggregated can also effect the COC selection. The uncertainty associated with the identification of potential COCs in soil is moderate due to the potential exclusion of chemicals from the risk characterization because of the aggregation of soil data over the entire site.

The inclusion of chemicals as potential COCs in surface water based on the lack of representative background values against which to screen, and the inclusion of sediment screened against soil background values, is conservative and tends to increase uncertainty. The estimated chemical risks associated with the surface water and sediment are small (less than 6×10^{-6}); the uncertainty introduced by the screening process is therefore considered to be insignificant.

The impoundments are a potential source of contamination to site groundwater. Their impact on current groundwater conditions continues to be evaluated with the monitoring well system. Most of the contamination currently is confined to the vadose zone because of generally high sorption of the contaminants on the soil matrix. Therefore, the potential COCs for the groundwater pathway were identified using the subsurface soil and sediment concentrations. The conservative uncertainty associated with the selection of contaminants for the groundwater is high since these contaminants are not currently present in the groundwater.

3.2.3 Exposure Assessment

Factors that can contribute to uncertainty in the exposure assessment include derivation of exposure point concentrations, assumptions for scenario development and intake parameters, and exposure pathways.

3.2.3.1 Exposure point concentrations

Data aggregation introduces moderate uncertainty into the development of exposure point concentrations. Given that assumptions on the distribution of the data are correct, there is a quantifiable degree of uncertainty about the actual spatial distribution of contaminants, that is , whether a site chosen at random would have a contaminant concentration above or below a given

value. For example, the concentration in 95 of every 100 samples will, on average, not be greater than the UCL_{95} concentration. Also, because the estimated UCL_{95} concentrations were used to calculate exposure point concentrations, the estimates of risk from potential COCs were conservative. Using UCL_{95} concentrations decreases the likelihood of underestimating the risk posed by each potential COC, and it increases the likelihood of overestimating the risk. If the data do not fit well the assumed distribution, the number of potential COCs and their exposure concentrations could be overestimated or underestimated depending on how the actual data distribution differs from the assumed data distribution.

Results from monitoring of groundwater wells in both the upper and lower aquifers are presented in Appendix C. With the exception of low concentrations of iron and manganese in the lower and upper aquifers, and a trace of radionuclides in the lower aquifer, there is no other migration of chemical contaminants into the groundwater at present. However, the contaminants in the subsurface soil and waste burial pits are in contact with the groundwater and have the potential for future migration. The exposure point concentrations to estimate the risk from groundwater were modeled from subsurface soil concentrations. A site-specific K_d for americium was developed from soil boring data and related documents for use in the modeling; other K_d values were assumed from previous modeling efforts by Energy Systems. Appendix C compares the groundwater concentrations modeled from the subsurface soil with the monitoring well data. The modeled concentrations do not include naturally occurring chemicals such as iron and manganese which were not contaminants of potential concern in the subsurface soil. Because the assumptions used in the modeling are conservative, the exposure point concentrations may be overestimated. The monitoring data show that contaminants have not migrated into the groundwater in significant or consistent concentrations in the 10 years of site monitoring. The modeling estimates future contaminant migration. Given the site conditions, it is reasonable to expect the contaminants to migrate into the groundwater in the future, however, there is high uncertainty as to when in the future the modeled concentrations would be representative of actual conditions.

Several data assumptions included in the exposure assessment introduced high uncertainty into the risk assessment. All surface soil data was aggregated sitewide. Since the impoundment is homogenous and would easily erode if not maintained, surface and sediment soil from all depths of the impoundments were conservatively included in the assessment. At present, the impoundments (and thus a large fraction of the surface soil and sediment) is covered, adding to the conservatism in the assessment. Additionally, volatile compounds were present in samples from the impoundments with higher frequency and at higher concentrations than were found in the rest of the sitewide soils. These conservative assumptions may lead to a high estimation of inhalation of volatile chemicals in current use scenarios.

3.2.3.2 Exposure assumptions

Values assumed for exposure parameters (e.g., inhalation rate and exposure frequency) used in calculations for intakes were based primarily on EPA guidance (EPA 1990b, 1991b). These assumptions might result in underestimating or overestimating the intakes calculated for specific receptors, depending on the accuracy of the assumptions relative to actual site conditions and uses. For example, a 50 mL/event water ingestion rate and a 200 mg/day sediment ingestion rate were used for the RME child wading in White Oak Creek. The water ingestion rate is the EPA recommended value for incidental ingestion while swimming, and the sediment ingestion rate is the default value for child soil ingestion. Both of these assumptions are conservative and may overestimate intake, and thus risk, for the wading scenario.

Due to the evolving nature of EPA's policy on quantifying the dermal pathways, there is uncertainty in the parameters (i.e., dermal absorption coefficients, permeability coefficients) necessary to calculate or estimate these pathways. Quantitative evaluation of the dermal pathway from soil was considered only for those chemicals for which dermal absorption values were present (EPA 1992a). Absorption values were available for PCBs, therefore, the pathway was assessed. The omission of other contaminants, based on lack of absorption values, may result in an underestimation of chemical risk but it is not expected to affect the assessment significantly.

Dermal absorption was also assessed for chemicals leached into groundwater and contacted by showering or bathing. Quantitative evaluation of the dermal pathway from modeled groundwater data was considered only for those chemicals for which permeability coefficient values were available (EPA 1992a). Permeability coefficients were available for 14 organic chemicals, therefore this pathway was assessed.

The identification of potential receptors was based on site-specific reasonable current use and hypothetical future land use. Site-specific receptors were identified to the extent possible and exposure parameters tailored to these receptors to minimize uncertainty in the postulated scenarios and exposure assessment.

3.2.4 Toxicity Assessment

Uncertainty also is inherent in the toxicity values utilized in characterizing the carcinogenic and noncarcinogenic risks. Such uncertainty is chemical-specific and is incorporated into the toxicity value during its development. For example, an uncertainty factor may be applied for interspecies and intrahuman variability, for extrapolation from subchronic to chronic duration of exposure, or for epidemiological data limitations.

A number of identified potential COCs are currently under EPA review with the possibility of changed reference doses, slope factors, or carcinogenic weight of evidence. Interim and provisional toxicity values were used, where available, when values could not be obtained from IRIS or HEAST. Additional uncertainty in risk estimates is introduced when all potential COCs do not have valid toxicity factors for use in quantitative estimates. Inhalation slope factors and reference doses in particular were largely unavailable for the potential COCs in the particulate pathway. Inhalation slope factors are not available for nine carcinogenic potential COCs in soil. In addition, toxicity values could not be obtained for some potential COCs, thereby precluding their inclusion in the quantitative risk estimates. The resulting risk estimates do not include the incremental chemical-specific risks from these potential COCs and, therefore, may underestimate risk, although the magnitude of this underestimation is not quantifiable. However, some of the metals for which toxicity values are unavailable are naturally occurring chemicals found throughout the region in concentrations similar to the SIOU site. Although there were no toxicity values available for the rare earths, these chemicals are generally associated with the radionuclides and will be addressed by any remedial action undertaken. In addition, a single factor was used to estimate the risk for all polycyclic aromatic hydrocarbons present, another potentially conservative assumption.

3.2.5 Risk Characterization

Some of the procedures used and uncertainties inherent in the human health assessment process may tend to underestimate potential risk. However, assumptions built into this baseline risk assessment tend to overestimate rather than underestimate potential risks, including conservative assumptions for the exposure scenarios. For example, contamination is assumed to remain constant over time. Actual concentrations may change over time, which would influence the intake and related risk values. Thus, actual risks are likely to be lower than those presented in this assessment.

For potential COCs, oral reference doses were available for most of the toxicologically important chemicals, but few inhalation reference doses were available, precluding effective estimation of this pathway contribution to health hazard. In addition, toxicity factors are not available for any of the rare earth elements that were potential COCs.

Although lead exposure causes significant toxic effects and lead may also be carcinogenic, toxicity factors are not available as they are currently under review by EPA. Recent draft guidance from EPA (1992a) suggest a quantitative method for estimating detrimental environmental lead levels using an uptake biokinetic model. This model predicts blood lead levels in the most sensitive populations (children 0-6 years old) exposed to lead in air, dust, drinking water, soil, and paint. The calculated blood levels can then be compared to the adverse

effects level of 10 μg/dL. Using the RME exposure point concentration for lead in soil and the non-linear absorption model, calculated blood levels for children under 6 were all less than 1 μg/dL. Although this lead model is not applicable to adult employees, it is reasonable to expect exposure would be lower than that of resident children. The RME lead concentration in soil was 57 mg/kg, much lower than the interim soil cleanup level of 500–1,000 ppm recommended by Office of Solid Waste and Emergency Response Directive 935.4-02 (EPA 1992a).

Finally, for this assessment, it was assumed that the toxic and carcinogenic effects of the potential chemical COCs are additive. This assumption could result in the underestimation of risks because concurrent exposure to several contaminants might have synergistic toxic effects, (i.e., exposure to two of the potential COCs concurrently might induce a greater toxic effect than that expected if the separate effects were simply added). Conversely, concurrent exposure to some of the potential COCs might also mitigate the toxic effects of exposure to the individual contaminants.

3.2.6 Air Concentrations

3.2.6.1 Radiological data

Air concentrations of resuspended particles of radiological COCs were derived from surface soil and sediment concentrations for the SIOU site in the following manner:

1. For on-site receptors, the inhalation of airborne radionuclide particulates was calculated by RESRAD. The RESRAD code uses a mass loading model in which an average value of the airborne dust concentration is specified on the basis of empirical data which allows the effective depth of the disturbed layer to be ignored and considers site-specific human activities (Yu et al. 1993).

2. For off-site receptors, airborne concentrations of resuspended radionuclide particulates (population exposure calculations) were derived using emission factors for soil erosion (EPA 1985) as follows:

$$C_{air} = C_s \times R \times VF \times A \times T \times CF \qquad \text{(C3.1)}$$

where:

C_{air} = concentration released in air (Ci/year),
C_s = concentration in soil (pCi/g),
R = release rate (0.05 kg/1000 m^2•day),
VF = vegetation reduction factor (unitless) (0.1),
A = area (m^2),

T = time (365 day/year), and
CF = conversion factors, 10^{-12} Ci/pCi; 10^3 g/kg.

The off-site airborne radionuclide exposure point concentrations are presented in Appendix D.

3.2.6.2 Chemical data

Airborne concentrations of resuspended chemical particulates were calculated using a particulate emission factor derived using a combination of site-specific information, where available, and recommended default values (EPA 1991a) and an equation derived from EPA 1989a and EPA 1991a as follows:

$$C_{air} = \frac{C_s}{PEF} \tag{C3.2}$$

where:

C_{air} = concentration in air (mg/m^3),
C_s = concentration in soil (mg/kg), and
PEF = particulate emission factor (m^3/kg).

A site-specific PEF was calculated as follows:

$$PEF\ (m^3/kg) = \frac{\dfrac{LS \times V \times DH \times 3600\ s/hour}{A} \times 1000\ g/kg}{0.036 \times (1-G) \times \left[\dfrac{U_m}{U_t}\right]^3 \times F(x)} \tag{C3.3}$$

where:

PEF = particulate emission factor (1.3×10^{-8} m^3/kg),
LS = width of contaminated area (158 m) (site specific),
V = wind speed in mixing zone (1.5 m/second) (site specific),
DH = diffusion height (2 m) (EPA 1985),
A = area of contamination (25,000 m^2) (site specific),
0.036 = respirable fraction (g/m^2•hour) (EPA 1985),
G = fraction of vegetative cover (0.9 unitless) (site specific),
U_m = mean annual wind speed (4.5 m/second) (site specific),

U_t = equivalent threshold value of wind speed at 10 m (3.03 m/second), (site specific) and

$F(x)$ = function dependent on U_m/U_t (0.0497 unitless) (EPA 1985).

Airborne concentrations of VOCs were calculated using the following equations derived from EPA 1991a and EPA 1989a.

$$C_{air} = \frac{C_s}{VF} \qquad \text{(C3.4)}$$

where:

C_{air} = contaminant concentration in air (mg/m^3),

C_s = contaminant concentration in soil (mg/kg), and

VF = volatilization factor (m^3/kg).

The volatilization factor was calculated as follows:

$$VF\ (m^3/kg) = \frac{LS \times V \times DH}{A} \times \frac{(3.14 \times \alpha \times T)^{1/2}}{(2 \times D_{ei} \times E \times K_{as} \times 10^{-3} kg/g)} \qquad \text{(C3.5)}$$

where: $\alpha\ (cm^2/s) = \dfrac{D_{ei} \times E}{E + (P_s)(1-E)/K_{as}}$

VF = volatilization factor (m^3/kg) (chemical specific),

LS = length of side of contaminated area (158 m),

V = wind speed in mixing zone (1.5 m/second),

DH = diffusion height (2 m),

A = area of contamination (25,000,000 cm^2),

D_{ei} = effective diffusivity (cm^2/second),

$= D_i \times E^{0.33}$

E = true soil porosity (0.035 unitless),

K_{as} = soil/air partition coefficient (g soil/cm^3 air),

$= (H/K_d) \times 41$,

P_s = true soil density or particulate density (2.65 g/cm^3),

T = exposure interval (10,000 second),

D_i = molecular diffusivity (cm^2/s) (chemical specific),

H = Henry's law constant (atm•m^3/mol) (chemical specific), and

K_d = soil-water partition coefficient (cm^3/g) (chemical specific).

3.2.6.3 Radiological data

Exposure associated with future groundwater contamination due to radionuclides leaching from subsurface soil and sediment was calculated using RESRAD which uses a nondispersion model to predict concentrations of radionuclides in a hypothetical well at the downstream edge of the contamination (Gilbert et al. 1989, Yu et al. 1993). Site-specific geophysical parameters were used with RESRAD to generate exposure point concentrations and resulting exposure doses.

3.2.6.4 Chemical data

The Summers model (Summers et al. 1980) was used to predict chemical exposure point concentrations in groundwater using subsurface soil concentrations. The model is very conservative and assumes the soil/water system is at equilibrium, no contaminant degradation or retardation is occurring, the unsaturated soil zone is homogenous down to the aquifer, and contaminants are mixed throughout the depth of the aquifer beneath the contaminant source, which is constant. The model also conservatively ignores dispersion or attenuation processes. The equation for the Summers analytical model is:

$$C_{gw} = \frac{(Q_p \times C_p) + (Q_a \times C_a)}{Q_a + Q_p} \qquad \text{(C3.6)}$$

where:

C_{gw} = contaminant concentration in the groundwater (mg/L),

Q_p = volumetric flow rate of infiltration into the aquifer (ft^3/day), where:

$Q_p = (A_p)(V_d)$,

A_p = horizontal area of spill (ft^2), and

V_d = Darcy velocity in the downward direction (ft/day).

C_p = concentration of pollutant in the infiltration at the unsaturated-saturated zone interface (mg/L),

Q_a = volumetric flow rate of groundwater (ft^3/day), where:

$Q_a = (V_a)(h)(w)$,

V_a = Darcy velocity in aquifer (ft/day),

h = aquifer thickness (ft)

w = width of spill perpendicular to flow direction in aquifer (ft), and

C_a= initial or background concentration of the pollutant in aquifer (mg/L).

The Darcy velocity in the aquifer is estimated by:

$$V_a = (K)(I) \tag{C3.7}$$

where:

K = saturated hydraulic conductivity (ft/day), and

I = horizontal hydraulic gradient in the saturated zone (unitless).

The exposure point concentrations for chemicals in groundwater as predicted by this model are shown in Appendix D. The assumptions for the Summers model and the computer algorithms are in Appendix D.

4. PARAMETERS AND ASSUMPTIONS

Tables C4.1 through C4.7 contain parameters and assumptions used in the human health risk assessment.

Table C4.1. Soil and sediment ingestion, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Parameter (unit)	Value			Reference
	Employee	Resident	Child wading	
Soil/sediment ingestion rate (mg/day)	avg: 30 RME: 50	NA	avg: 100 RME: 200	EPA 1991b
Fraction ingested from contaminated source (unitless)	1.0	NA	1.0	Conservative judgment
Exposure frequency (days/year)	avg: 250 RME: 250			EPA 1989a, based on days employee works on site per year
		NA		
			7	EPA 1989a
Exposure duration (years)	avg: 7 RME: 25			EPA 1989a, based on 50th and 90th percentile for employee
		NA		
			6	Based on age classification
Body weight (kg)	70			EPA 1989a, EPA 1991b, combined mean of male and female body weights
		NA		
			15	EPA 1989a, children 1-6 years old, 50th percentile
Carcinogen averaging time (days)	25,550	NA	25,550	EPA 1991a, equivalent to 70-year lifetime exposure at 365 days/year
Noncarcinogen averaging time (days)	avg: 2,555 RME: 9,125	NA	2,190	EPA 1991b, exposure duration × 365 days/year

Table C4.1 (continued)

Equation for ingestion of chemicals in soil and sediment (EPA 1989a):

$$\text{Intake } (\text{mg/kg} \cdot \text{d}) = \frac{C_s \times IR_s \times CF \times FI \times EF \times ED}{BW \times AT}$$

where:

C_s	=	chemical soil concentration in soil (mg/kg),
IR_s	=	soil ingestion rate (mg soil/day),
CF	=	conversion factor (10^{-6} kg/mg),
FI	=	fraction ingested from contaminated source (unitless),
EF	=	exposure frequency (days/year),
ED	=	exposure duration (year),
BW	=	body weight (kg), and
AT	=	averaging time (days).

Equation for ingestion of radionuclides in soil and sediment (Gilbert et al. 1989):

$$D_i = C_{soil,i} \times IRs \times EF \times DCF_i \times CF_m$$

where:

D_i	=	dose from radionuclide i (mrem/year),
$C_{soil,i}$	=	soil concentration of radionuclide i (pCi/g),
IR_s	=	soil,sediment ingestion rate (mg/day),
EF	=	exposure frequency (days/year),
DCF_i	=	ingestion dose conversion factor for radionuclide i (mrem/pCi), and
CF_m	=	conversion factor, 10^{-3} g/mg.

g = gram
kg = kilogram
mg = milligram
mrem = millirem
NA = not applicable
ORNL = Oak Ridge National Laboratory
pCi = picocurie
RME = reasonable maximum exposure
SIOU = Surface Impoundments Operable Unit

Table C4.2. Water ingestion, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Parameter (unit)	Value			Reference
	Employee	Resident	Child wading	
Groundwater ingestion rate (L/day)	avg: 0.7 RME: 1.0	avg: 1.4 RME: 2.0	NA	EPA 1989a; 1991b, 50th and 90th percentile
Fraction from contaminated source (unitless)	1.0	1.0	NA	EPA 1989a
Exposure frequency (days/year)	avg: 250 RME: 250			EPA 1989a, number of days employee works onsite per year
		avg: 350 RME: 350		EPA 1989a and EPA 1991b, allows for 2 weeks/year away from residence
			NA	
Exposure duration (years)	avg: 7 RME: 25			EPA 1989a, based on 50th and 90th percentile for employee
		avg: 9 RME: 30		EPA 1989a, national median time, 50th percentile and 90th percentile at one residence
			NA	
Body weight (kg)	adult: 70	adult: 70	NA	EPA 1989a
Carcinogen averaging time (days)	25,550	25,550	NA	EPA 1991a, equivalent to 70-year lifetime exposure at 365 days/year
Noncarcinogen averaging time (days)	avg: 2,555 RME: 9,125	avg: 3,285 RME: 10,950	NA	EPA 1991b, exposure duration × 365 days/year

Table C4.2 (continued)

Equation for ingestion of chemicals in drinking water (EPA 1989a):

$$\text{Intake (mg/kg}\cdot\text{d)} = \frac{C_{gw} \times IR_{gw} \times EF \times ED}{BW \times AT}$$

where:

C_{gw} = chemical concentration in groundwater (mg/L)
IR_{gw} = water ingestion rate (L/day),
EF = exposure frequency (days/year),
ED = exposure duration (year),
BW = body weight (kg), and
AT = averaging time (days).

Equation for ingestion of radionuclides in drinking water for RESRAD (Gilbert et al. 1989):

$$D_i = C_{gw,i} \times IR_w \times EF \times DCF_i$$

where:

D_i = dose from radionuclide i (mrem/year),
$C_{gw,i}$ = concentration of radionuclide i (pCi/L)
IR_w = water ingestion rate (L/day),
EF = exposure frequency (days/year), and
DCF_i = ingestion dose conversion factor for radionuclide i (mrem/pCi).

EPA = U.S. Environmental Protection Agency
kg = kilogram
L = liter
mg = milligram
mrem = millirem
NA = not applicable
pCi = picocurie
ORNL = Oak Ridge National Laboratory
RME = reasonable maximum exposure
SIOU = Surface Impoundments Operable Unit

Table C4.3. Exposure assumptions for inhalation of volatiles for household water use, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Parameter (unit)	Value			Reference
	Employee	Resident	Child wading	
Time in home per day (hours/day)	NA	20	NA	EPA 1989b, 90th percentile
Quantity of household water used (L/day)	NA	980	NA	Murphy 1987
Air exchange quantity in house (m^3/day)	NA	8,700	NA	Murphy 1987
Mixing constant (unitless)	NA	0.5	NA	Murphy 1987
Showers per day (unitless)	NA	1	NA	EPA 1990
Length of showers per day (hour/shower)	NA	0.2	NA	Murphy 1987
Inhalation rate (m^3/hour)	NA	0.83	NA	EPA 1991b
Shower water flow rate (m^3/hour)	NA	0.48	NA	Murphy 1987
Air exchange rate between shower and rest of house (h^{-1})	NA	12	NA	Murphy 1987
Volume of shower or bathroom (m^3)	NA	12	NA	Murphy 1987
Body weight (kg)	NA	70	NA	EPA 1989a, EPA 1991b, combined mean of male and female body weights
Exposure frequency (days/year)	NA	350	NA	EPA 1991b, assumes 2 weeks/year away from residence
Exposure duration (years)	NA	30	NA	EPA 1991a, 90th percentile exposure
Carcinogen averaging time (days)	NA	25,550	NA	EPA 1991b, equivalent to 70-year lifetime exposure, 365 days/year
Noncarcinogen averaging time (days)	NA	10,950	NA	EPA 1991b, 30-year period of exposure, 365 days/year

Table C4.3 (continued)

Inhalation of chemicals that have volatilized from groundwater may occur where there is domestic use of contaminated water (e.g., bathing or showering). The potential volatilization of chemicals predicted to be in groundwater was calculated using the following model (Murphy 1987):

$$\text{Intake (mg/kg}\cdot\text{d)} = \frac{I_s \times EF \times ED}{BW \times AT}$$

$$I_s = \frac{1000 \times N_s \times T_s \times IR \times C_w \times F}{A \times V} \times \left[1 + \left[\frac{1}{A \times T_s}\right]\left(e^{-A * T_s} - 1\right)\right] \times \left[1 - e^{-(0.93 \times 1.48 \times 10^{-3/H})^{-1}}\right]$$

where:

I_s = estimated inhalation exposure during showering (mg/kg•d),
EF = exposure frequency (events/year),
ED = exposure duration (years),
BW = average body weight (kg),
AT = averaging time (days); for noncarcinogens, AT = ED × 265 days/year; for carcinogens, AT = 70-year lifetime × 365 days/year,
N_s = average number of showers per day,
T_s = average length of shower (hour/shower),
IR = average inhalation rate (m^3/hour),
C_w = chemical concentration modeled in water (mg/L),
F = shower water flow rate (m^3/hour),
A = air exchange rate between shower and rest of house (h^{-1}),
V = volume of shower or bathroom (m^3), and
H = Henry's Law Constant (atm × m/mol)(chemical-specific).

atm = atmosphere
kg = kilogram
L = liter
m = meter
mg = milligram
mol = mole
NA = not applicable
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

Table C4.4. Surface water ingestion, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Parameter (unit)	Value			Reference
	Employee	Resident	Child wading	
Surface water contact rate (L/hour)	NA	NA	avg: 0.035 RME: 0.050	EPA 1989a, based on 50th and 90th percentile
Exposure time (hours/event)	NA	NA	1	Pathway specific
Exposure frequency (events/year)	NA	NA	avg: 7	EPA 1989a, national average for swimming
Exposure duration (years)	NA	NA	6	EPA 1990, based on age classification
Body weight (kg)	NA	NA	15	EPA 1989a, 1-6 year old; 50th percentile
Carcinogen averaging time (days)	NA	NA	25,550	EPA 1991a, equivalent to 70-year lifetime exposure at 365 days/year
Noncarcinogen averaging time (days)	NA	NA	2,190	EPA 1991a, exposure duration × 365 days/year

Equation for ingestion of chemicals in surface water (EPA 1989a):

$$\text{Intake (mg/kg}\cdot\text{d)} = \frac{C_{sw} \times CR \times ET \times EF \times ED}{BW \times AT}$$

where:

C_{gw} = chemical soil concentration in groundwater (mg/L)
CR = contact rate (L/hour),
ET = exposure time (hours/event),
EF = exposure frequency (events/year),
ED = exposure duration (years),
BW = body weight (kg), and
AT = averaging time (days); for noncarcinogens, AT = ED × 365 days/year; for carcinogens, AT = 70-year lifetime × 365 days/year.

Table C4.4 (continued)

Equation for ingestion of radionuclides in surface water for RESRAD (Gilbert et al. 1989):

$$D_i = C_{gw,i} \times IR_w \times EF \times DCF_i$$

where:

D_i = dose from radionuclide i (mrem/year),
$C_{gw,i}$ = concentration of radionuclide i in groundwater (pCi/L)
IR_w = water ingestion rate (L/event); from L/hour × hour/event,
EF = exposure frequency (events/year), and
DCF_i = ingestion dose conversion factor for radionuclide i (mrem/pCi).

kg = kilogram
L = liter
mg = milligram
mrem = millirem
NA = not applicable
ORNL = Oak Ridge National Laboratory
pCi = picocurie
RME = reasonable maximum exposure
SIOU = Surface Impoundments Operable Unit

Table C4.5. Radon inhalation, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Parameter (unit)	Value			Reference
	Employee	Resident	Child wading	
Equilibrium conversion factor - indoor air (unitless)	0.45	NA	NA	ICRP 1986
Equilibrium conversion factor - outdoor air (unitless)	0.10	NA	NA	based on best judgment
Fraction of a working month spent indoors at location (month)	0.88	NA	NA	7 hour/day exposure represents 0.88 of a WLM (170 hours/month)
Fraction of a working month spent outdoors at location (month)	0.13	NA	NA	1 hour/day exposure represents 0.13 of a WLM (170 hours/month)

The following equation was used to calculate radon exposure:

$$E_{Rn} = E_{RnI} + E_{RnO}$$

$$E_{RnI} = C_{Rn-I} \times ECF_I \times \frac{1\,WL}{100\ pCi/L} \times RT_I$$

$$E_{RnO} = C_{Rn-O} \times ECF_O \times \frac{1\,WL}{100\ pCi/L} \times RT_O$$

where:

E_{Rn} = radon exposure in working level months (WLM) (1 WLM = 100 mrem, ICRP 1985)
E_{RnI} & E_{RnO} = exposure for indoor and outdoor exposure, respectively (in WLM),
C_{Rn-I} & C_{Rn-O} = radon concentrations in indoor and outdoor air, respectively (pCi/L),
ECF_I & ECF_O = equilibrium factors for indoor and outdoor air,
RT_I & RT_O = fraction of a working month (170 hours) spent indoors and outdoors at the location, respectively (month), and
WL = working level.

L = liter
mrem = millirem
NA = not applicable
pCi = picocurie
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
WLM = working level month
ICRP = International Commission on Radiological Protection

Table C4.6. Dermal absorption of volatiles, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Parameter (unit)	Value			Reference
	Employee	Resident	Child wading	
Skin surface area for contact (cm^2)	NA	avg: 20,000 RME: 23,000	NA	EPA 1992b, based on 50th and 90th percentile
Exposure time (hours/event)	NA	avg: 0.17 RME: 0.25	NA	EPA 1992b, based on 50th and 90th percentile
Exposure frequency (days/year)	NA	350	NA	EPA 1991b, assumes 2 weeks/year away from residence
Exposure duration (years)	NA	avg: 9 RME: 30	NA	EPA 1992b, based on 50th and 90th percentile
Body weight (kg)	NA	70	NA	EPA 1989a, EPA 1989b, EPA 1991b, combined mean of male and female body weights
Carcinogen averaging time (days)	NA	25,550	NA	EPA 1991b, equivalent to 70-year lifetime exposure at 365 days/year
Noncarcinogen averaging time (days)	NA	avg: 3,285 RME: 10,950	NA	EPA 1991b, 30-year period of exposures 365 days/year

Equation for dermal absorption while showering (EPA 1989a):

$$\text{Absorbed Dose (mg/kg}\cdot\text{d)} = \frac{C_w \times SA \times PC \times ET \times ED \times EF \times CF}{BW \times AT}$$

where:

C_w = chemical concentration in groundwater (mg/L),
SA = skin surface area for contact (cm^2),
PC = dermal permeability constant (cm/hour),
ET = exposure time (hours/day),
ED = exposure duration (days/year),
EF = exposure frequency (years),
CF = volumetric conversion factor (L/cm^3),
BW = body weight (kg), and
AT = averaging time (days).

cm = centimeter
d = day
kg = kilogram
mg = milligram

NA = not applicable
ORNL = Oak Ridge National Laboratory
RME = reasonable maximum exposure
SIOU = Surface Impoundments Operable Unit

Table C4.7. Dermal contact with chemicals in soil, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Parameter (unit)	Value			Reference
	Employee	Resident	Child wading	
Skin surface area for contact (cm^2)	5,300	NA	NA	EPA 1992b, based on 50th percentile
Exposure frequency (events/year)	250	NA	NA	EPA 1989a, number of days employee works on site per year
Exposure duration (years)	avg: 7 RME: 25	NA	NA	EPA 1989a, based on 50th and 90th percentile for employee
Body weight (kg)	70	NA	NA	EPA 1989a, EPA 1989b, EPA 1991b, combined mean of male and female body weights
Carcinogen averaging time (days)	25,550	NA	NA	EPA 1991b, equivalent to 70-year lifetime exposure at 365 days/year
Noncarcinogen averaging time (days)	avg: 2,555 RME: 9,125	NA	NA	EPA 1991b, 25-year period of exposures 365 days/year

Equation for dermal contact with chemicals in soil (EPA 1989a):

$$\text{Absorbed Dose (mg/kg}\cdot\text{d)} = \frac{CS \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}$$

where:

CS = chemical concentration in soil (mg/kg),
CF = conversion factor (10^{-6} kg/mg),
SA = skin surface area for contact (cm^2/event),
AF = soil to skin adherence factor (mg/cm^2) (0.2),
ABS = absorption factor (unitless) (0.06),
EF = exposure frequency (events/year),
ED = exposure duration (years),
BW = body weight (kg), and
AT = averaging time (days).

cm = centimeter
kg = kilogram
mg = milligram
NA = not applicable
ORNL = Oak Ridge National Laboratory
RME = reasonable maximum exposure
SIOU = Surface Impoundments Operable Unit

5. BASELINE ECOLOGICAL RISK ASSESSMENT SUMMARY

This section presents a summary of the baseline ecological risk assessment for SIOU. This baseline ecological risk assessment evaluates risks to populations and communities of nonhuman organisms that are currently on SIOU or may live there in the future. It also assesses the contribution of the site contaminants to off-site risks (i.e., White Oak Creek).

CERCLA, as amended by Superfund Amendments and Reauthorization Act, requires protection of wildlife, fisheries, threatened and endangered species, and sensitive habitats. The ecological risk assessment for SIOU adheres to the proposed general framework for ecological assessments in the Superfund Program (EPA 1991b, 1992c). Because of the qualitative nature of the characterization of biota and habitats at risk, the assessment of potential impacts to wildlife from exposure to contaminants must be based largely on expected mechanisms of transport, biological uptake, and toxicological effects reported in the literature for many of the contaminants of potential ecological concern.

The ecological risk assessment consists of the following elements:

- ecological problem formulation,
- ecological exposure assessment,
- ecological effects assessment, and
- ecological risk characterization

5.1 ECOLOGICAL PROBLEM FORMULATION

The problem formulation phase defines the scope of the assessment, the sources being assessed, the endpoints of the assessment, and the site conceptual model. An ecological hazard consists of a source of potentially toxic exposure, combined with a potentially susceptible receptor (the endpoint population) in a particular environment.

5.1.1 Objective and Scope

The objective of ecological risk assessment is to provide a basis for decisions on remediation as it concerns risks to nonhuman species. Qualitative habitat characterization identifies biotic components of the ecosystem, including organisms potentially exposed to contaminants. Field measurements of contaminant concentrations and published toxicity data for aquatic and terrestrial organisms allow a semiquantitative estimate of risk. This information is

used to characterize the magnitudes of relative risks to ecological resources from contaminated media at SIOU.

The assessment is performed in two stages. First, chemicals detected on the site are screened against ecotoxicological benchmarks to determine which are contaminants of potential ecological concern. Second, a more definitive assessment of the contaminants of potential ecological concern is performed to identify the contaminants of ecological concern and to estimate the nature and magnitude of the risk. This assessment employs an analysis of the relationship of the estimated exposure to effects and includes consideration of site-specific conditions. This assessment evaluates the potential risks to piscivorous wildlife foraging at SIOU and potential risks to piscivorous wildlife, fish, and benthic macroinvertebrates in White Oak Creek kilometer 3.9 (WCK 3.9) adjacent to SIOU, near White Oak Dam, and at Clinch River.

5.1.2 Potentially Affected Habitat and Potentially Exposed Species

SIOU, which is composed of four man-made impoundments, has minimal natural habitat. No ditches, creeks, or outfalls directly link SIOU to nearby White Oak Creek. Although SIOU is primarily an industrial area, some species may visit the site on a rather limited basis. Also, the power lines around the impoundments provide perches for piscivorous birds [e.g., green-backed heron (*Butorides striatus*), kingfisher (*Ceryle alcyon*)].

Habitat in White Oak Creek, adjacent to SIOU, may be affected by contaminant migration via groundwater. Contaminant concentrations found in surface water in White Oak Creek may affect the fish and benthic macroinvertebrate communities. Contaminants in surface water may also bioaccumulate in fish tissue, thereby exposing piscivorous wildlife.

5.1.2.1 Impoundments 3513 and 3524

Fish were introduced into these impoundments in May 1977 (Garten et al. 1982). Species included goldfish (*Carassius auratus*), channel catfish (*Ictalurus punctatus*), mosquito fish (*Gambusia affinis*), and bluegill sunfish (*Lepomis macrochirus*). These fish species supplemented an existing vertebrate fauna consisting of frogs (*Rana catesbeiana* and *R. palustris*) and possibly some turtles. In addition to aquatic species, small mammals including mink (*Mustela vison*) may forage in and around the impoundments.

5.1.2.2 Impoundments 3539 and 3540

Impoundments 3539 and 3540 do not contain fish; therefore, they were not evaluated for impacts to the piscivorous wildlife assessment endpoints. Because they have a clay lining and presumably do not contribute to groundwater contamination, they were not included in the

determination of risks to off-site receptors (i.e., those in White Oak Creek), resulting from migration of contaminants from SIOU. These factors, in conjunction with their not being waters of the state, resulted in Impoundments 3539 and 3540 being eliminated from further evaluation in this baseline ecological risk assessment.

5.1.3 Ecological Assessment Endpoints

The assessment endpoints are environmental characteristics which, if they were found to be significantly affected, would indicate the need for possible remediation. The assessment endpoints were agreed to during a data quality objective workshop in December 1993, and were recently confirmed by EPA Region IV (Lynn Wellman, personal communication). In some cases, the assessment endpoints cannot be directly measured, so a measurement endpoint (or several measurement endpoints) is selected that is related to the assessment endpoint (Risk Assessment Forum 1992).

5.1.3.1 Aquatic endpoints

Abundance and species richness of the fish and aquatic invertebrate communities in White Oak Creek are assessment endpoints for aquatic exposures resulting from contaminant releases from SIOU. It was not necessary to designate a particular species as a surrogate for the group. The National Ambient Water Quality Criteria and most other aquatic toxicological benchmarks are not based on particular species; all fish and aquatic invertebrate populations are included. The aquatic communities of the impoundments are not included in this endpoint because of (1) the artificial nature of these waste impoundments and the biotic communities experimentally introduced, and (2) the expectation that piscivorous wildlife would constitute a more sensitive endpoint.

5.1.3.2 Piscivorous endpoints

The belted kingfisher (*Ceryle alcyon*) and mink (*Mustela vison*) were selected for evaluation. The belted kingfisher was selected as the avian endpoint receptor species because it is common in the vicinity of SIOU. The mink was selected as the mammalian endpoint receptor species because it is a piscivorous mammal sensitive to contaminants. A reduction in the abundance or production of a local population of piscivorous birds or mammals are assessment endpoints for exposure resulting from contaminants at SIOU and White Oak Creek.

5.1.3.3 Threatened and endangered species

Although threatened and endangered species comprise an additional category of special receptors, there are no threatened or endangered bird or mammal species listed by the U.S. Fish and Wildlife Service or the state of Tennessee known to use the minimal habitat within SIOU.

5.1.4 Site Conceptual Model

The site conceptual model defines the sources, modes of contaminant transport and exposure, and receptors to be included in the assessment (Fig. C5.1). Contaminants occur in the water and sediments of SIOU. The aquatic biota of these ponds are directly exposed to those contaminants. Wildlife may drink from the ponds and feed on the aquatic organisms. Water leaches from these ponds and contaminates White Oak Creek. There, aquatic biota are directly exposed to contaminants in the diluted leach water, and wildlife are exposed by drinking and feeding on aquatic organisms. Consumption of contaminated soil on the periphery of the ponds was judged to be a negligible source of exposure because of the small soil intake of the endpoint wildlife species (< 2 percent of dietary intake for mink) and the small area of the contaminated soils relative to foraging areas. Inhalation of VOCs was also judged to be negligible because of the low concentrations of VOCs relative to the atmospheric dilution potential.

For this assessment, risks were evaluated based on a conservative estimate of exposure where mink and kingfishers received 100 percent of fish and aquatic organisms in the diet from SIOU and each location within White Oak Creek. A future baseline case would not result in greater ecological risks. Abandonment of the site would simply make the scenario of mink and kingfishers receiving 100 percent of their diets from the impoundments a little more realistic due to reduced human presence.

An ORR-wide assessment will evaluate risks to wide-ranging species such as the mink and belted kingfisher that may occasionally use a site (Suter et al. 1992). Data from individual waste sites will provide estimates of the contaminant exposure that wide-ranging species experience at each site. These exposure estimates will be incorporated into the ORR-wide assessment to evaluate the contribution of SIOU to the risk experienced by populations of these species at the ORR level.

5.2 ECOLOGICAL EXPOSURE ASSESSMENT

This section describes the modes of exposure that occur at SIOU for the selected assessment endpoints, the ways in which exposure is estimated, and the available exposure data for ecological risk assessment.

5.2.1 Description of Exposure Routes and Models

5.2.1.1 Aquatic biota

Fish and benthic macroinvertebrates may be exposed to contaminants through respiration of waterborne contaminants and ingestion of contaminated water and food. It was assumed that

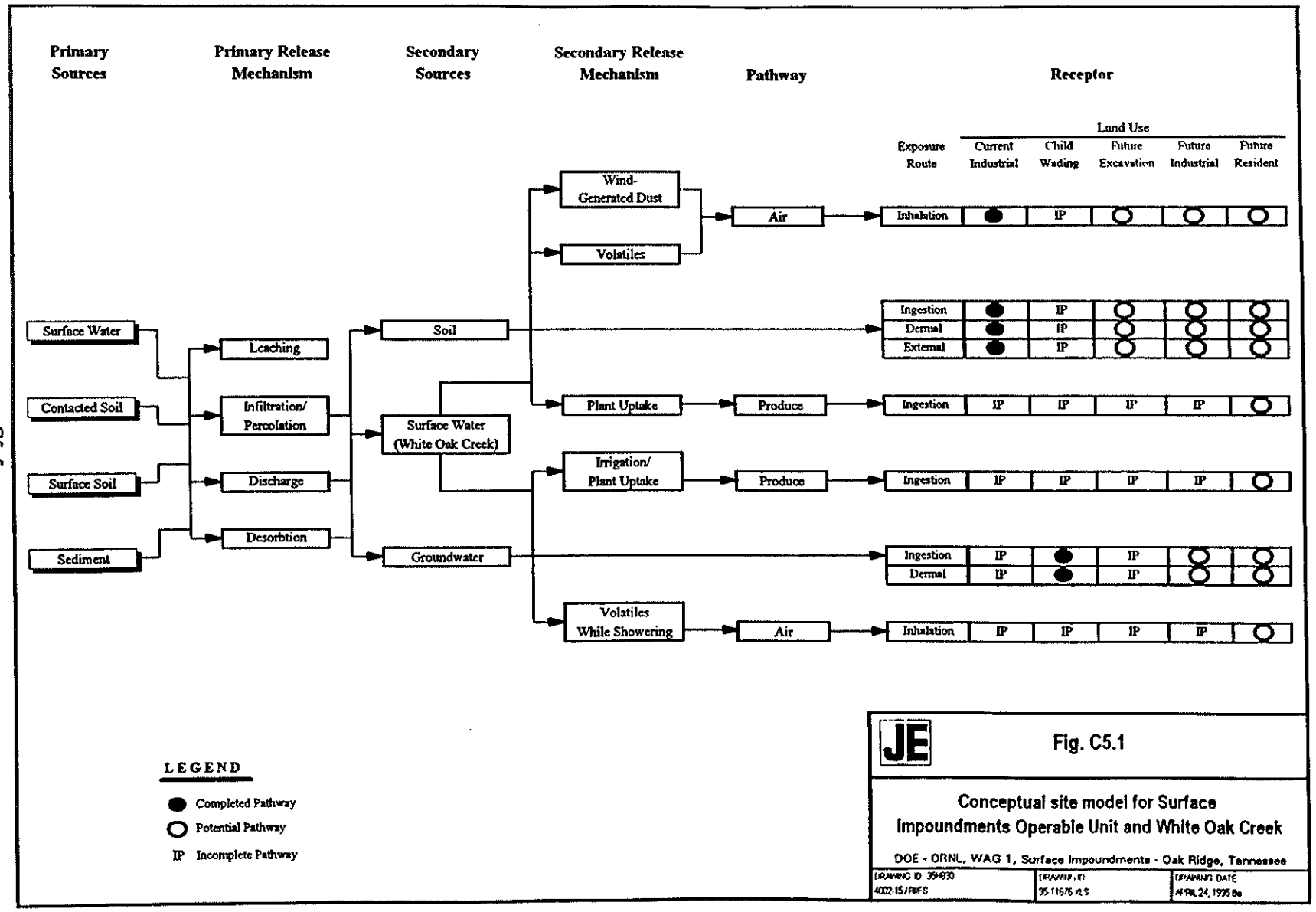

Fig. C5.1

Conceptual site model for Surface Impoundments Operable Unit and White Oak Creek

DOE - ORNL, WAG 1, Surface Impoundments - Oak Ridge, Tennessee

the only significant route of exposure was respiratory uptake. This assumption underlies the derivation of the National Ambient Water Quality Criteria (OWRS 1986). Therefore, measured concentrations of contaminants in water constitute a complete model of exposure for aquatic biota. Exposure to metals is best measured by concentrations of dissolved metals, which are bioavailable (Prothro 1993).

Concentrations of 10 analytes and a radionuclide were modeled from sediments of Impoundments 3513 and 3524 to White Oak Creek (Table C5.1). These modeled concentrations were used to assess risks to the fish and benthic macroinvertebrate communities in White Oak Creek. The modeled concentrations of contaminants into White Oak Creek are total concentrations, and adsorption onto sediments and other particulates was not taken into account, which provides a conservative estimate. Since sediment samples were not collected in White Oak Creek, the modeled surface water concentration was assumed to be identical to that in the sediment pore water. It was also assumed that benthic organisms were approximately as sensitive as water-column species. Therefore, the modeled contaminant concentrations in White Oak Creek surface water were used to predict risks to piscivorous wildlife, fish, and benthic macroinvertebrates in White Oak Creek. Risks were evaluated for these receptors at White Oak Creek (WCK 3.9), White Oak Dam, and Clinch River.

5.2.1.2 Piscivorous wildlife

No surface water samples were collected at the impoundments for contaminant analyses. Therefore, contaminant concentrations in surface water for Impoundment 3513 were represented by historical data found in Stansfield and Frances (1986). Historical data were used to calculate exposure of contaminants to each piscivorous receptor drinking water from SIOU.

Since fish were collected only from Impoundment 3513, risks to piscivorous wildlife feeding from this impoundment were assessed. Risks to piscivorous wildlife feeding from Impoundment 3524 are assumed to be similar. Therefore, discussions of risks to piscivorous wildlife feeding from the impoundments will be evaluated with Impoundment 3513 data only.

The total exposure experienced by wildlife is represented by the sum of the exposures from each individual source. Exposure from inhalation and ingestion of soil are considered insignificant. Therefore, total exposure can be represented as:

$$E_{total} = E_{food} + E_{water} \qquad \text{(C5.8)}$$

where

E_{total} = exposure from all sources
E_{food} = exposure from food consumption
E_{water} = exposure from water consumption

Table C5.1. Modeled contributions of each impoundment to White Oak Creek and the resulting total concentration from all impoundments, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(all concentrations mg/L, except ^{90}Sr, which is pCi/L)

Constituent	Contribution from Impoundment		Total in White Oak Creek at WCK 3.9	Total in White Oak Creek at White Oak Dam	Total in Clinch River at White Oak Creek
	3513	3524			
Barium	NA	1.99×10^{-3}	1.99×10^{-3}	9.95×10^{-4}	3.98×10^{-6}
Beryllium	2.67×10^{-5}	8.23×10^{-4}	8.50×10^{-4}	4.25×10^{-4}	1.70×10^{-6}
Cadmium	4.49×10^{-5}	1.50×10^{-4}	1.95×10^{-4}	9.75×10^{-5}	3.90×10^{-7}
Chromium	8.69×10^{-5}	2.39×10^{-4}	3.26×10^{-4}	1.63×10^{-4}	6.52×10^{-7}
Mercury	8.37×10^{-3}	2.43×10^{-2}	3.27×10^{-2}	1.64×10^{-2}	6.54×10^{-5}
Silver	NA	2.40×10^{-3}	2.40×10^{-3}	1.20×10^{-3}	4.80×10^{-6}
N-nitroso-di-n-propylamine	6.47×10^{-6}	1.15×10^{-5}	1.80×10^{-5}	9.00×10^{-6}	3.60×10^{-8}
Aroclor-1254	4.70×10^{-10}	1.84×10^{-9}	2.31×10^{-9}	1.16×10^{-9}	4.62×10^{-12}
Aroclor-1260	1.56×10^{-11}	ND	1.56×10^{-11}	7.80×10^{-12}	3.12×10^{-14}
2,4-Dinitrotoluene	ND	2.00×10^{-7}	2.00×10^{-7}	1.00×10^{-7}	4.00×10^{-10}
Strontium-90	ND	ND	20	10	0.04

L = liter
mg = milligram
NA =
ND = contaminant contribution was not determined
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit
Sr = strontium
WCK 3.9 = White Oak Creek kilometer 3.9

The daily total exposure from contaminants via ingestion of food and water may be estimated by the following formula:

$$\text{Total exposure} = \frac{(C_{prey} \times IR_{prey}) F_{prey} + (C_{water} \times IR_{water}) F_{water}}{BW} \qquad (C5.9)$$

where

Total exposure = estimated contaminant exposure for generalized piscivorous animal (mg/day•kg)

C_{prey} = contaminant concentration in prey (mg/kg, wet weight)

IR_{prey} = ingestion rate of prey (kg/day)

F_{prey} = fraction of prey ingested that is contaminated (unitless)

C_{water} = contaminant concentration in water (mg/L)

IR_{water} = ingestion rate of water (L/day)

F_{water} = fraction of water ingested that is contaminated (unitless)

BW = body weight of animal (kg)

Exposure parameters used to estimate contaminant exposure to wildlife endpoint species are provided in Table C5.2.

As outlined by EPA (1992c), all contaminant exposure estimates experienced by wildlife were calculated using the one-tailed UCL_{95} contaminant concentration or the maximum detected value, whichever was lower. Because wildlife are mobile and use various portions of a site, it is believed that the UCL_{95} best represents the spatial integration of contaminants wildlife will experience.

Contaminant concentrations below the detection limit were assigned a value of 0 if all samples were below the detection limit. If one or more values for a contaminant were above the detection limit, sample concentrations of that contaminant below the detection limit were assigned a value of half the detection limit. These values were used to calculate the UCL_{95}. A discussion of assumptions and exposure estimates for each wildlife endpoint species follows.

Belted kingfisher. The diet of belted kingfisher includes 86.7 percent fish and 13.3 percent aquatic invertebrates (Sample and Suter 1994). The assessment assumed the contaminant concentration in aquatic invertebrates was the same as in fish and that 100 percent of the kingfisher's aquatic dietary needs came from the site. It also assumed that 100 percent of water (0.016 L/day; Sample and Suter 1994) was obtained from the site. The home range size for kingfisher, relative to the size of SIOU and White Oak Creek, was not factored into this assessment.

Table C5.2. Parameters used to estimate contaminant exposure to wildlife endpoint species, Waste Area Grouping 1
SIOU, ORNL, Oak Ridge, Tennessee

Endpoint species	Body weight (kg)	Food consumption rate (kg/day)	Water consumption rate (L/day)[b]	Diet
Belted kingfisher (*Ceryle alcyon*)	0.148	0.075	0.016	Diet includes fish (86.6%) and aquatic invertebrates (13.4%). This assessment assumes 100% fish
Mink (*Mustela vison*)	1.0	0.137	0.099	Diverse diet includes mammals (46%), fish (16%), aquatic invertebrates (15%), amphibians (13%), and birds (8%). This assessment assumes 44% fish (sum of fish, aquatic invertebrates, and amphibians)

Source: Sample and Suter (1994).

[a]All values calculated according to Calder and Braun (1983), as recommended in EPA (1993a).

kg = kilogram
L = liter
ORNL = Oak Ridge National Laboratory
% = percent
SIOU = Surface Impoundments Operable Unit

Mink. The diet of mink consists of approximately 46 percent mammal, 8 percent birds (assumed to be captured off site and uncontaminated), 16 percent fish, 13 percent amphibians, and 15 percent aquatic invertebrates (Sample and Suter 1994). The contaminant concentration in fish was assumed to be representative of all aquatic organisms in the diet where 100 percent of the aquatic dietary needs were assumed to come from the site. All of the water consumption (0.099 L/day; Sample and Suter 1994) was also assumed to come from the site. The home range size for mink, relative to the size of SIOU and White Oak Creek, was not factored into this assessment. Exposure parameters for mink are listed in Table C5.1.

5.2.2 Nonradiological exposure estimates for piscivorous wildlife

5.2.2.1 Exposure from SIOU

Nonradiological exposure estimates for belted kingfishers and mink feeding on fish from SIOU are listed in Tables C5.3 and C5.4, respectively.

5.2.2.2 Exposure from White Oak Creek

Contaminant concentrations potentially found in fish inhabiting White Oak Creek were predicted using bioconcentration factors obtained from the open literature (Table C5.5) and modeled surface water data (Table C5.1). Modeled surface water data for WCK 3.9, White Oak Dam, and Clinch River were multiplied by the average and maximum bioconcentration factor for each contaminant. The maximum and average bioconcentration factor were used to determine the maximum and average contaminant concentrations found in fish. Average and maximum fish concentrations were then used to calculate average and maximum exposure for the belted kingfisher (Tables C5.6 and C5.7) and mink (Table C5.9 and C5.10) feeding within White Oak Creek.

Calculated mercury concentrations in fish at WCK 3.9, White Oak Dam, and Clinch River were substantially higher than that found in SIOU. The mercury concentrations estimated in fish at WCK 3.9 were approximately 3,557 times greater than concentrations found in the impoundments (Tables C5.8 and C5.11). The average and maximum bioconcentration factors were 34,611 and 85,700, respectively (EPA 1984b). These bioconcentration factors, in conjunction with conservative modeled surface water data, produced unrealistic mercury concentrations in fish. Since mercury concentrations in White Oak Creek due to SIOU cannot be greater than the total mercury concentrations from all sources, potential mercury exposure for mink and kingfishers feeding in White Oak Creek were calculated using mercury concentrations from fish collected by the Biological Monitoring and Abatement Program during 1992 and 1993. The average mercury concentration in fish from White Oak Creek, downstream of SIOU, was 0.185 ± 0.056 mg/kg (Ashwood 1994 and personal communication with M. J. Peterson, ESD,

Table C5.3. Exposure estimates for kingfishers at SIOU and resulting hazard quotients using both NOAEL and LOAEL, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Contaminant[a]	UCL_{95} fish concentration (mg/kg)	Water concentration (mg/L)	Exposure estimate from fish (mg/kg·day)	Exposure estimate from water (mg/kg·day)	Total exposure (mg/kg·day)	NOAEL for kingfishers (mg/kg·day)	Hazard quotient (exposure/NOAEL)	LOAEL for kingfishers (mg/kg·day)	Hazard quotient (exposure/LOAEL)
Aluminum	0.373	NA	0.1892	0.0000	0.1892	113	0.002	45.83	0.004
Antimony	0.0329	NA	0.0169	0.0000	0.0169	—	—	—	—
Arsenic	0.0224	NA	0.0115	0.0000	0.0115	9.65[b]	0.001	24.12	0.001
Barium	0.280	0.0636	0.1419	0.0068	0.1487	19.5	0.008	38.97	0.004
Cadmium	0.00630	NA	0.0034	0.0000	0.0034	2.86	0.001	39.43	8.6×10^{-6}
Chromium	0.00766	0.0702	0.0041	0.0074	0.0115	2.02[c]	0.006	10.11	0.001
Cobalt	0.00427	NA	0.0020	0.0000	0.0020	—	—	—	—
Copper	0.165	0.352	0.0838	0.0378	0.1216	50.7	0.002	—	—
Manganese	0.469	0.460	0.2378	0.0500	0.2878	—	—	—	—
Mercury	0.795	0.0003	0.4027	0.0000	0.4027	0.012[d]	33.558	0.12	3.356
Potassium	240	2.40	121.6216	0.2595	121.8811	—	—	—	—
Zinc	3.60	11.8	1.8243	1.2757	3.1000	5.64	0.550	56.4	0.055
Aroclor-1254	24.1	NA	12.2128	0.0000	12.2128	0.338	36.133	4.1	3.10
Aroclor-1260	5.36	NA	2.7162	0.0000	2.7162	0.338[e]	8.036	4.1	0.69

[a]The macronutrients calcium, iron, magnesium, and sodium are excluded for lack of toxicity dietary concentrations.
[b]Arsenic benchmark for kingfishers is for arsenite.
[c]Chromium benchmark for kingfishers assumes Cr III.
[d]Mercury benchmark for kingfishers is for methyl mercury.
[e]Because no benchmark exists for Aroclor-1260, the Aroclor-1254 benchmark was used.

kg = kilogram
L = liter
LOAEL = lowest observed adverse effect level
mg = milligram
NA = data were not available
NOAEL = no observed adverse effect level
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence of the mean
— = benchmark was not available and therefore no hazard quotient was calculated

Table C5.4. Exposure estimates for mink at SIOU, and resulting hazard quotients using both the NOAEL and LOAEL, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Contaminant[a]	UCL_{95} fish concentration (mg/kg)	Water concentration (mg/L)	Exposure estimate from fish (mg/kg-day)	Exposure estimate from water (mg/kg-day)	Total exposure (mg/kg-day)	NOAEL for mink (mg/kg-day)	Hazard quotient (exposure/NOAEL)	LOAEL for mink (mg/kg-day)	Hazard quotient (exposure/LOAEL)
Aluminum	0.373	NA	0.0225	0.0	0.0225	0.607	0.037	13.65	0.002
Antimony	0.0329	NA	0.0020	0.0	0.0020	0.039	0.051	—	—
Arsenic	0.0224	NA	0.0013	0.0	0.0013	0.040[b]	0.033	0.39	0.003
Barium	0.280	0.0636	0.0169	0.0063	0.0232	3.85	0.006	1.4	0.017
Cadmium	0.00630	NA	0.0004	0.0	0.0004	0.060	0.007	0.79	0.001
Chromium	0.00766	0.0702	0.0005	0.0069	0.0074	2.32[c]	0.003	9.29	0.001
Cobalt	0.00427	NA	0.0003	0.0	0.0003	—	—	—	—
Copper	0.165	0.352	0.0099	0.0348	0.0447	11.7	0.004	—	—
Manganese	0.469	0.460	0.0282	0.0455	0.0737	62.2	0.001	—	—
Mercury	0.795	0.0003	0.0479	0.0	0.0479	0.015[d]	3.193	0.025	1.916
Potassium	240	2.40	14.4480	0.2376	14.6856	482	0.031	—	—
Zinc	3.60	11.8	0.2167	1.1682	1.3849	113	0.012	—	—
Aroclor-1254	24.1	NA	1.4508	0.0	1.4508	0.137	10.590	0.685	2.118
Aroclor-1260	5.36	NA	0.3227	0.0	0.3227	0.137[e]	2.5	0.685	0.471

[a]The macronutrients calcium, iron, magnesium, and sodium are excluded for lack of toxicity dietary concentrations.
[b]Arsenic benchmark for mink is for arsenite.
[c]Chromium benchmark for mink assumes Cr VI.
[d]Mercury benchmark for mink is for methyl mercury.
[e]Because no benchmark exists for Aroclor-1260, the Aroclor-1254 benchmark was used.

kg = kilogram
L = liter
LOAEL = lowest observed adverse effect level
mg = milligram
NA = data were not available
NOAEL = no observed adverse effect level
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit of the mean
— = no benchmark was available and therefore no hazard quotient was calculated

Table C5.5. Bioconcentration factors for fish species, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Analyte	Bioconcentration factor	Range	Mean	Number of studies	Species	References
Beryllium	19	—	—	1	Bluegill	EPA 1980a
Cadmium		3–12,400	2591.2	11	All fish	EPA 1980b
Chromium (VI)		< 1–2.8	1.6	3	Rainbow trout	EPA 1984a
Silver	< 1	—	—	1	Bluegill	EPA 1980c
Aroclor-1254		42,000–238,000	86,840	5	All fish	EPA 1980d
Aroclor-1260	270,000	—	—	1	Fathead minnow	EPA 1980d
Mercury (II)		1,800–4,994	3,397	2	All fish	EPA 1984b
Mercury (methyl)		10,000–85,700	34,611	6	All fish	EPA 1984b

Summary: Combined bioconcentration factor values for each analyte for all fish studied.

ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
— = only one bioconcentration factor documented, therefore range and mean do not apply

Table C5.6. Exposure estimates for belted kingfishers at White Oak Creek (WCK 3.9), White Oak Dam, and Clinch River using mean fish concentrations, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Contaminant	Modeled water concentration (mg/L)	Modeled average fish concentration (mg/kg)	Water exposure (mg/kg-day)	Exposure from fish (mg/kg-day)	Total exposure (mg/kg-day)	Toxicity benchmark (NOAEL) (mg/kg-day)	Hazard quotient (exposure/ NOAEL)
WCK 3.9							
Beryllium	0.0009	0.016	0.00009	0.0081	0.0081	—	—
Cadmium	0.0002	0.505	0.00002	0.2561	0.2561	2.855	0.090
Chromium	0.0003	0.0005	0.00004	0.0003	0.0003	2.022	1.5×10^{-4}
Silver	0.002	0.002	0.0003	0.0014	0.0017	—	—
Aroclor-1254	2.3×10^{-9}	0.0002	2.5×10^{-10}	0.0001	0.0001	0.338	2.9×10^{-4}
Aroclor-1260	1.6×10^{-11}	4.2×10^{-6}	1.7×10^{-12}	2.1×10^{-6}	2.1×10^{-6}	0.338	6.2×10^{-6}
White Oak Dam							
Beryllium	0.0004	0.008	0.00005	0.004	0.004	—	—
Cadmium	0.0001	0.253	0.00001	0.111	0.111	2.855	0.039
Chromium	0.0002	0.0002	0.00002	0.0001	0.0001	2.022	4.9×10^{-5}
Silver	0.001	0.001	0.0001	0.0005	0.0007	—	—
Aroclor-1254	1.2×10^{-9}	0.0001	1.3×10^{-10}	0.00004	0.00004	0.338	1.2×10^{-4}
Aroclor-1260	7.8×10^{-12}	2.1×10^{-6}	8.4×10^{-13}	9.2×10^{-7}	9.2×10^{-7}	0.338	2.8×10^{-6}
Clinch River							
Beryllium	1.7×10^{-6}	0.00003	1.8×10^{-7}	0.00002	0.00002	—	—
Cadmium	3.9×10^{-7}	0.001	4.0×10^{-8}	0.0005	0.0005	2.855	1.8×10^{-4}
Chromium	6.5×10^{-7}	9.1×10^{-7}	7.0×10^{-8}	4.6×10^{-7}	4.7×10^{-7}	2.022	2.3×10^{-7}
Silver	4.8×10^{-6}	4.8×10^{-6}	5.2×10^{-7}	2.4×10^{-6}	2.9×10^{-6}	—	—
Aroclor-1254	4.6×10^{-12}	4.0×10^{-7}	5.0×10^{-13}	2.0×10^{-7}	1.8×10^{-7}	0.338	5.3×10^{-7}
Aroclor-1260	3.1×10^{-14}	8.4×10^{-9}	3.4×10^{-15}	4.0×10^{-9}	4.0×10^{-9}	0.338	1.2×10^{-8}

kg = kilogram
L = liter
mg = milligram
NOAEL = no observed adverse effect level
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
WCK 3.9 = White Oak Creek kilometer 3.9
— = no benchmark available

Table C5.7. Maximum exposure estimates for belted kingfishers at White Oak Creek (WCK 3.9), White Oak Dam, and Clinch River using maximum fish concentrations, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Contaminant	Modeled water concentration (mg/L)	Maximum modeled fish concentration (mg/kg)	Water exposure (mg/kg·day)	Maximum exposure from fish (mg/kg·day)	Maximum total exposure (mg/kg·day)	Toxicity benchmark (NOAEL) (mg/kg·day)	Hazard quotient (maximum exposure/ NOAEL)
WCK 3.9							
Beryllium	0.0009	0.016	0.00009	0.0081	0.0081	—	—
Cadmium	0.0002	2.418	0.00002	1.2257	1.2257	2.855	0.429
Chromium	0.0003	0.0009	0.00004	0.0007	0.0007	2.022	3.5×10^{-4}
Silver	0.002	0.002	0.0003	0.0014	0.0017	—	—
Aroclor-1254	2.3×10^{-9}	0.0006	2.5×10^{-10}	0.0003	0.0003	0.338	0.001
Aroclor-1260	1.6×10^{-11}	4.2×10^{-6}	1.7×10^{-12}	2.1×10^{-6}	2.1×10^{-6}	0.338	6.2×10^{-6}
White Oak Dam							
Beryllium	0.0004	0.008	0.00004	0.004	0.0040	—	—
Cadmium	0.0001	1.209	0.00001	0.613	0.6130	2.855	0.215
Chromium	0.0002	0.0005	0.0002	0.0025	0.0027	2.022	0.001
Silver	0.001	0.001	0.0001	0.0005	0.0006	—	—
Aroclor-1254	1.2×10^{-9}	0.0003	1.3×10^{-10}	0.0002	0.0002	0.338	0.001
Aroclor-1260	7.8×10^{-12}	2.1×10^{-6}	8.4×10^{-13}	1.1×10^{-6}	1.1×10^{-6}	0.338	3.3×10^{-6}
Clinch River							
Beryllium	1.7×10^{-6}	0.00003	1.8×10^{-7}	0.00002	0.00002	—	—
Cadmium	3.9×10^{-7}	0.00484	4.0×10^{-8}	0.0025	0.0025	2.855	0.009
Chromium	6.5×10^{-7}	1.8×10^{-6}	7.0×10^{-8}	9.1×10^{-7}	1.0×10^{-6}	2.022	5.0×10^{-7}
Silver	4.8×10^{-6}	4.8×10^{-6}	5.2×10^{-7}	2.4×10^{-6}	2.9×10^{-6}	—	—
Aroclor-1254	4.6×10^{-12}	1.1×10^{-6}	4.9×10^{-13}	5.6×10^{-7}	5.6×10^{-7}	0.338	1.7×10^{-6}
Aroclor-1260	3.1×10^{-14}	8.4×10^{-9}	3.4×10^{-15}	4.0×10^{-9}	4.0×10^{-9}	0.338	1.2×10^{-9}

kg = kilogram
L = liter
LOAEL = lowest observed adverse effect level
mg = milligram
NOAEL = no observed adverse effect level
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
WCK 3.9 = White Oak Creek kilometer 3.9
— = no benchmark available

Table C5.8. Mercury (methyl) exposure to belted kingfishers using average and maximum literature bioconcentration factors and mercury concentrations found in fish in White Oak Creek, downstream of SIOU (WCK 3.9), Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Location	Modeled water concentration (mg/L)	Fish concentration (mg/kg)	Water exposure (mg/kg-day)	Exposure from fish (mg/kg-day)	Total exposure (mg/kg-day)	Toxicity benchmark (NOAEL) (mg/kg-day)	Hazard quotient (exposure/NOAEL)	Toxicity benchmark (LOAEL) (mg/kg-day)	Hazard quotient (exposure/LOAEL)
Exposure estimated from modeled water concentrations and average bioconcentration factors[a]									
WCK 3.9	0.033	1,142	0.004	578.716	578.720	0.012	48,227	0.12	4,823
White Oak Dam	0.016	554	0.002	280.743	280.745	0.012	23,395	0.12	2,339
Clinch River	0.00007	2.42	7.1×10^{-6}	1.226	1.226	0.012	102	0.12	10.2
Exposure estimated from modeled water concentrations and maximum bioconcentration factors[b]									
WCK 3.9	0.033	2,828	0.004	1,433.108	1,433.112	0.012	119,426	0.12	11,943
White Oak Dam	0.016	1,371	0.002	694.764	694.766	0.012	57,897	0.12	5,789
Clinch River	0.00007	5.99	7.1×10^{-6}	3.036	3.036	0.012	253	0.12	25.3
Exposure from fish collected downstream of WCK 3.9									
WCK 3.9	0.033	0.185	0.004	0.094	0.098	0.012	8.2	0.12	0.82

[a]Average bioconcentration factor for methyl mercury = 34,611.
[b]Maximum bioconcentration factor for methyl mercury = 85,700.

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mg = milligram
NOAEL = no observed adverse effect level
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
WCK 3.9 = White Oak Creek kilometer 3.9

Table C5.9. Exposure estimates for mink at White Oak Creek (WCK 3.9), White Oak Dam, and Clinch River using mean fish concentrations, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Contaminant	Modeled water concentration (mg/L)	Modeled average fish concentration (mg/kg)	Water exposure (mg/kg-day)	Exposure from fish (mg/kg-day)	Total exposure (mg/kg-day)	Toxicity benchmark (NOAEL) (mg/kg-day)	Hazard quotient (exposure/ NOAEL)
WCK 3.9							
Beryllium	0.0009	0.016	0.0001	0.0010	0.0011	—	—
Cadmium	0.0002	0.505	2.0×10^{-5}	0.0304	0.0304	0.06	0.507
Chromium	0.0003	0.0005	3.0×10^{-5}	3.0×10^{-5}	6.0×10^{-5}	2.32	2.6×10^{-5}
Silver	0.002	0.002	0.0002	0.0001	0.0003	—	—
Aroclor-1254	2.3×10^{-9}	0.0002	2.3×10^{-10}	1.2×10^{-5}	1.2×10^{-5}	0.137	8.8×10^{-5}
Aroclor-1260	1.6×10^{-11}	4.2×10^{-6}	1.6×10^{-12}	2.7×10^{-7}	2.7×10^{-7}	0.137	2.0×10^{-6}
White Oak Dam							
Beryllium	0.0004	0.008	4.0×10^{-5}	0.0005	0.0005	—	—
Cadmium	0.0001	0.253	9.7×10^{-6}	0.0152	0.0152	0.06	0.253
Chromium	0.0002	0.0002	2.0×10^{-5}	1.2×10^{-5}	3.2×10^{-5}	2.32	1.4×10^{-5}
Silver	0.001	0.001	0.0001	0.0001	0.0002	—	—
Aroclor-1254	1.2×10^{-9}	0.0001	1.2×10^{-10}	6.0×10^{-6}	6.0×10^{-6}	0.137	4.4×10^{-5}
Aroclor-1260	7.8×10^{-12}	2.1×10^{-6}	7.7×10^{-13}	1.3×10^{-7}	1.3×10^{-7}	0.137	9.5×10^{-7}
Clinch River							
Beryllium	1.7×10^{-6}	0.00003	1.7×10^{-7}	1.8×10^{-6}	2.0×10^{-6}	—	—
Cadmium	3.9×10^{-7}	0.00101	4.0×10^{-8}	6.1×10^{-5}	6.1×10^{-5}	0.06	0.001
Chromium	6.5×10^{-7}	9.1×10^{-7}	6.0×10^{-8}	5.5×10^{-8}	1.1×10^{-7}	2.32	4.7×10^{-8}
Silver	4.8×10^{-6}	4.8×10^{-6}	4.8×10^{-7}	2.9×10^{-7}	7.7×10^{-7}	—	—
Aroclor-1254	4.6×10^{-12}	4.0×10^{-7}	4.6×10^{-13}	2.4×10^{-8}	2.4×10^{-8}	0.137	1.8×10^{-7}
Aroclor-1260	3.1×10^{-14}	8.4×10^{-9}	3.1×10^{-15}	5.1×10^{-10}	5.1×10^{-10}	0.137	4.0×10^{-9}

kg = kilogram
L = liter
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ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
WCK 3.9 = White Oak Creek kilometer 3.9
— = no benchmark available

Table C5.10. Maximum exposure estimates for mink at White Oak Creek (WCK 3.9), White Oak Dam, and Clinch River using maximum fish concentrations, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Contaminant	Modeled water concentration (mg/L)	Modeled maximum fish concentration (mg/kg)	Water exposure (mg/kg·day)	Maximum exposure from fish (mg/kg·day)	Maximum total exposure (mg/kg·day)	Toxicity benchmark (NOAEL) (mg/kg·day)	Hazard quotient (maximum exposure/ NOAEL)	Toxicity benchmark (LOAEL) (mg/kg·day)	Hazard quotient (maximum exposure/ LOAEL)
WCK 3.9									
Beryllium	0.0009	0.016	9.0×10^{-5}	0.0010	0.0011	—	—	—	—
Cadmium	0.0002	2.42	2.0×10^{-5}	0.1457	0.1457	0.06	2.428	0.79	0.184
Chromium	0.0003	0.0009	3.0×10^{-5}	0.0001	0.0001	2.32	4.3×10^{-5}	9.29	1.1×10^{-5}
Silver	0.002	0.002	0.0002	0.0001	0.0003	—	—	—	—
Aroclor-1254	2.3×10^{-9}	0.0006	2.3×10^{-10}	3.6×10^{-5}	3.6×10^{-5}	0.137	2.6×10^{-4}	0.685	5.3×10^{-5}
Aroclor-1260	1.6×10^{-11}	4.2×10^{-6}	1.6×10^{-12}	2.5×10^{-7}	2.5×10^{-7}	0.137	1.8×10^{-6}	0.685	3.7×10^{-7}
White Oak Dam									
Beryllium	0.0004	0.008	4.0×10^{-5}	0.0005	0.0005	—	—	—	—
Cadmium	0.0001	1.21	9.7×10^{-6}	0.0728	0.0728	0.06	1.213	0.79	0.092
Chromium	0.0002	0.0005	2.0×10^{-5}	3.0×10^{-5}	5.0×10^{-5}	2.32	2.2×10^{-5}	9.29	5.4×10^{-6}
Silver	0.0012	0.001	0.0001	0.0001	0.0002	—	—	—	—
Aroclor-1254	1.2×10^{-9}	0.0003	1.2×10^{-10}	1.8×10^{-56}	2.1×10^{-5}	0.137	1.5×10^{-4}	0.685	3.1×10^{-5}
Aroclor-1260	7.8×10^{-12}	2.1×10^{-6}	7.7×10^{-13}	1.3×10^{-7}	1.3×10^{-7}	0.137	9.5×10^{-7}	0.685	1.9×10^{-7}
Clinch River									
Beryllium	1.7×10^{-6}	0.00003	3.9×10^{-7}	1.8×10^{-6}	2.2×10^{-6}	—	—	—	—
Cadmium	3.9×10^{-7}	0.00484	4.0×10^{-8}	0.0003	0.0003	0.06	0.005	0.79	3.8×10^{-4}
Chromium	6.5×10^{-7}	1.8×10^{-6}	6.0×10^{-8}	1.1×10^{-7}	1.7×10^{-7}	2.32	7.3×10^{-8}	9.29	1.8×10^{-8}
Silver	4.8×10^{-6}	4.8×10^{-6}	4.8×10^{-7}	2.9×10^{-7}	7.7×10^{-7}	—	—	—	—
Aroclor-1254	4.6×10^{-12}	1.1×10^{-6}	1.6×10^{-13}	6.6×10^{-8}	6.6×10^{-8}	0.137	4.8×10^{-7}	0.685	9.6×10^{-8}
Aroclor-1260	3.1×10^{-14}	8.4×10^{-9}	3.1×10^{-15}	5.1×10^{-10}	5.1×10^{-10}	0.137	4.9×10^{-9}	0.685	7.4×10^{-10}

kg = kilogram
L = liter
LOAEL = lowest observed adverse effect level
mg = milligram
NOAEL = no observed adverse effect level
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
WCK 3.9 = White Oak Creek kilometer 3.9
— = no benchmark available

Table C5.11. Mercury exposure to mink using average and maximum literature bioconcentration factors and mercury concentrations found in fish in White Oak Creek, downstream of SIOU (WCK 3.9), Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Location	Modeled water concentration (mg/L)	Fish concentration (mg/kg)	Water exposure (mg/kg·day)	Fish exposure (mg/kg·day)	Total exposure (mg/kg·day)	Toxicity benchmark (NOAEL) (mg/kg·day)	Hazard quotient (exposure/NOAEL)	Toxicity benchmark (LOAEL) (mg/kg·day)	Hazard quotient (exposure/LOAEL)
Exposure estimated from modeled water concentrations and average bioconcentration factors[a]									
WCK 3.9	0.033	1,142	0.0033	68.748	68.751	0.015	4,583	0.025	2,750
White Oak Dam	0.016	554	0.0016	33.351	33.353	0.015	2,224	0.025	1,334
Clinch River	0.00007	2.42	6.9×10^{-6}	0.146	0.1457	0.015	9.073	0.025	5.44
Exposure estimated from modeled water concentrations and maximum bioconcentration factors[b]									
WCK 3.9	0.033	2,828	0.0033	170.246	170.249	0.015	11,350	0.025	6,747
White Oak Dam	0.016	1,371	0.0016	82.534	82.536	0.015	5,502	0.025	3,383
Clinch River	0.00007	5.99	6.9×10^{-6}	0.361	0.3606	0.015	24.0	0.025	13.5
Exposure from fish collected downstream of WCK 3.9									
WCK 3.9	0.033	0.185	0.0033	0.011	0.014	0.015	0.960	0.025	0.576

[a]Average bioconcentration factor for methyl mercury = 34,611.
[b]Maximum bioconcentration factor for methyl mercury = 85,700.

kg = kilogram
L = liter
LOAEL = no observed adverse effect level
mg = milligram
NOAEL = lowest observed adverse effect level
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
WCK 3.9 = White Oak Creek kilometer 3.9

November 7, 1994). Mercury exposures to belted kingfishers and mink feeding from WCK 3.9 are found in Tables C5.8 and C5.11, respectively.

Although concentrations of N-nitroso-di-n-propylamine, 2,4-dinitrotoluene, and barium were modeled for White Oak Creek surface water, exposures to kingfishers and mink were not calculated for these analytes. These contaminants were not detected in any fish collected from the impoundments. Barium, although detected in fish from SIOU, produced hazard quotients of less than 0.005 for both belted kingfishers and mink feeding directly from SIOU. Since these contaminants were either not found in fish or posed an insignificant risk at SIOU, it is assumed that fish would not accumulate these contaminants as a result of contributions from diluted groundwater flowing into White Oak Creek. Therefore, exposure and risk to belted kingfishers and mink in White Oak Creek and Clinch River would be negligible.

5.2.3 Radionuclide Exposure

Dose rates are calculated for each endpoint species: small fish, mink, and kingfisher using a conservative screening approach presented in Blaylock et al. (1993). Dose rates for internal and external doses from gamma-radiation and beta-radiation are calculated separately, and then summed to give the dose rate for the organism for each radionuclide. The total dose rate to the organism is determined by summing the dose rates from all radioisotopes.

5.2.3.1 Dose calculations for small fish exposed to ^{90}Sr in White Oak Creek

Modeled concentrations of ^{90}Sr in White Oak Creek, WCK 3.9, White Oak Dam, and Clinch River were approximately 20, 10, and 0.04 pCi/L, respectively.

The energy of the gamma-radiation of ^{90}Sr is insignificant (1.69×10^{-6} MeV) compared to the beta-radiation (1.13 MeV) and therefore can be ignored. Therefore, the internal dose rate may be calculated from:

$$D_\beta = 5.76 \times 10^{-4} E_\beta \, n \, \phi \, C_o \, \mu\text{Gy/hour} \qquad \text{(C5.10)}$$

where

D_β = internal dose rate from beta activity (μGy/hour)
E_β = the average energy of the beta-particle = 1.13 MeV
n = the proportion of transitions producing a beta-particle of energy E = 1
Φ = the absorbed fraction from Figure A.4 in Blaylock et al. (1993) = 0.81 (unitless)
C_o = the concentration of the radionuclide in the organism (Bq/kg wet weight)

and

$$C_o = C_w \, BCF \tag{C5.11}$$

where

C_w = the concentration in water (Bq/L)

BCF = the bioconcentration factor = 60 (unitless)

The external dose rate from ^{90}Sr in water may be calculated from:

$$D_\beta = 5.76 \times 10^{-4} E_\beta \, n \, (1 - \phi) \, C_w \, \mu Gy/hour \tag{C5.12}$$

Doses to small fish in White Oak Creek at three exposure locations was determined using the modeled ^{90}Sr data. Total dose including both external and internal exposures (from water via bioconcentration) were calculated for each location.

5.2.3.2 Dose calculation for piscivorous wildlife consuming fish from SIOU

Radiation exposure from ^{137}Cs and ^{90}Sr received by mink and kingfishers consuming fish and water was also calculated following the conservative screening approach presented in Blaylock et. al. (1993). Although the above formulas were derived for estimating exposure to aquatic organisms, they were modified slightly to assess doses to terrestrial wildlife. Immersion of fish in the contaminated medium is the principal difference between terrestrial and aquatic exposure. In the absence of body burden information for belted kingfishers and mink, ^{90}Sr and ^{137}Cs activities in fish collected from SIOU were assumed to be a conservative estimate of activities found in the kingfisher and mink. Therefore, the fish radiological activities represent the C_o value (concentration of the radionuclide in the organism) within the internal dose calculation.

Kingfishers are known to spend a major portion of their time perched above the water, therefore, it was assumed the external dose would be approximately background levels. The body length of a kingfisher was assumed to be 33 cm. The total dose rates from ^{137}Cs and ^{90}Sr to kingfishers (38.1 μGy/hour) are given in Table C5.12.

The mink was assumed to spend 20 percent of its time around Impoundment 3513 for the calculation of external radiation dose rates. Ground level radiation dose rates were not available for the impoundment shoreline. However, the average dose at the perimeter, 1 m above the ground, was 3 mrem/hour. Using this information, the mink would receive an external dose of approximately 6.08 μGy/hour. Mink were assumed to be 45 cm in length. The total dose rate from ^{137}Cs and ^{90}Sr to mink (44.8 μGy/hour) is given in Table C5. 13.

Table C5.12. Concentrations of ^{137}Cs and ^{90}Sr in mosquitofish (*Gambusia affinis*) taken from Surface Impoundment 3513 and resulting exposure estimates for kingfisher, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Radionuclide	UCL_{95} concentration in fish (Bq/kg)	Internal beta dose (μGy/hour)	Internal gamma dose (μGy/hour)	Total dose (μGy/hour)	Total dose from both radionuclides (μGy/hour)
Cesium-137	40,279	5.85	1.38	7.23	38.8
Strontium-90	48,611	31.6	4.5×10^{-5}	31.6	

Bq = becquerel
Cs = cesium
kg = kilogram
μGy = microgray
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
Sr = strontium
UCL_{95} = 95th percentile upper confidence level of the mean

Table C5.13. Concentration (UCL_{95}) of ^{137}Cs and ^{90}Sr in mosquitofish (*Gambusia affinis*) taken from Impoundment 3513 and resulting exposure estimates for mink, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Radionuclide	UCL_{95} concentration in fish (Bq/kg)	Internal beta dose (μGy/hour)	Internal gamma dose (μGy/hour)	External dose from SIOU (μGy/hour)	Total dose from both radionuclides (μGy/hour)
Cesium-137	40,279	5.85	1.38	6	44.8
Strontium-90	48,611	31.6	4.50×10^{-5}		

Bq = becquerel
Cs = cesium
kg = kilogram
μGy = microgray
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
Sr = strontium
UCL_{95} = 95th percentile upper confidence level of the mean

Dose rates were not calculated for kingfishers and mink consuming fish from White Oak Creek since the dose received from feeding at SIOU was equivalent or slightly in excess of the wildlife radiological benchmark of 42 μGy/hour (IAEA 1992). The dilution of radiological contamination contributed from SIOU within White Oak Creek would result in exposures much less than SIOU directly.

5.3 ECOLOGICAL EFFECTS ASSESSMENT

Effects assessment involves identifying levels of contaminant exposures associated with various levels of effects on the endpoint organisms. The first expression of effects is ecotoxicological benchmarks that are used to screen detected chemicals for contaminants of potential concern. The second is the ecotoxicological profiles that are developed for each contaminant of potential concern.

5.3.1 Ecotoxicological Benchmarks

5.3.1.1 Toxicity benchmarks for aquatic biota

Toxicity benchmarks were used to determine if contaminant concentrations in surface water in White Oak Creek could potentially cause adverse affects on aquatic biota. The full description of the derivation, use, and limitations of benchmarks for aquatic biota assessment is described in detail in Suter and Mabrey (1994). Because there are no standard screening benchmarks available, sets of alternative benchmarks were calculated. For this assessment, the benchmarks used were: (1) the acute and chronic National Ambient Water Quality Criterion, or in their absence, Secondary Acute and Chronic Values (from the Great Lakes Initiative); (2) the lowest chronic value for fish species; (3) the lowest chronic value for a daphnid species; and (4) the lowest chronic value for a nondaphnid invertebrate.

5.3.1.2 Toxicity benchmarks for wildlife

The wildlife benchmarks are NOAELs derived according to the methods outlined by Opresko et al. (1994) and EPA (1993b). Due to differences in physiology between birds and mammals, separate studies were located for each wildlife class. Only studies of the effects of long-term, chronic oral exposures were used. To make the NOAELs relevant to possible population effects, preference was given to studies that evaluated effects on reproductive parameters. In the absence of a reproduction endpoint, studies that considered effects on growth, survival, and longevity were used.

Metal speciation/form was not determined. To be conservative, the benchmarks for mink assume Cr VI as opposed to Cr III. For kingfisher, the chromium benchmark is for Cr III because there is no benchmark for Cr VI.

5.3.2 Toxicological Profiles for Contaminants of Potential Ecological Concern

The following subsections summarize toxicity information for the potential COCs at SIOU. The toxicity profiles are discussed by endpoint.

5.3.2.1 Toxicological profiles for fish and benthic macroinvertebrates

Cadmium. There is no evidence that cadmium is a biologically essential or beneficial element (Eisler 1985a). Cadmium toxicity is related to water hardness, with a reduction in toxicity associated with increased water hardness (EPA 1980b). Aquatic organisms are able to bioconcentrate cadmium, although there is evidence that only the lower trophic levels can biomagnify this element.

Freshwater acute toxicity values for cadmium range from 0.001 to 73.5 mg/L for various fish species. Among fish, salmonids are the most sensitive to cadmium. Chronic values for three trout species (Brook, *Salvelinus fontinalis*; Lake, *Salvelinus namaycush*; and Brown, *Salmo trutta*) were 0.002, 0.0074, and 0.0067 mg/L, respectively, for soft water (44 mg/L hardness). In hard water (185 to 207 mg/L hardness), chronic values were 0.0143, 0.046, and 0.050 mg/L for channel catfish (*Ictalurus punctatus*), fathead minnow (*Pimephales promelas*), and bluegill sunfish (*Lepomis macrochirus*), respectively.

Studies with two comparatively sensitive species of freshwater fish (brook trout and channel catfish) exposed to cadmium for 60 days demonstrated that concentrations of 0.001–0.003 mg/L and 0.011–0.017 mg/L cadmium in soft water caused reductions in growth, survival and reproduction. In hard water, concentrations ranged from 0.011–0.017 mg/L for brook trout to 0.012–0.017 mg/L for channel catfish (Eisler 1985a). In embryos of fathead minnows from adults reared in water containing 0.037–0.057 mg/L cadmium, and eggs transferred directly to water of those same concentrations, percent hatching was reduced, deformities were increased, and various blood clots developed (Eisler 1985a).

Freshwater acute toxicity values for cadmium range from 0.0035 to 28.0 mg/L for invertebrates. Cladocerans are the most sensitive species, while mayflies and stoneflies are the most resistant. Chronic values for *Daphnia magna* ranged from 0.00015 to 0.00044 mg/L for waters of hardness ranging from 45 to 209 mg/L (EPA 1980b).

Among the species of freshwater biota examined by Eisler (1985a), including algae, arthropods, annelids, macroinvertebrates and fish, cadmium concentrations of 0.00047–0.005 mg/L were associated with decreases in standing crop, decreases in growth, inhibition of reproduction, immobilization, and population alterations.

Mercury. Mercury in the environment commonly occurs as mercury (II) and methyl mercury (EPA 1984b). Elemental mercury is oxidized to mercury (II) under natural conditions, and mercury (II) can be methylated by both aerobic and anaerobic bacteria. Mercury (II) can also be methylated in the slime coat, liver, and intestines of fish. Numerous factors such as alkalinity, ascorbic acid, chloride, dissolved oxygen, hardness, organic complexing agents, pH, sediment, and temperature probably affect the acute and chronic toxicity and bioaccumulation of the various forms of mercury.

Data are available on the acute toxicity of mercury (II) to 28 genera of freshwater animals and ranged from 0.0022 mg/L for a cladoceran (*Daphnia pulex*) to 2.0 mg/L for mayfly (*Ephemerella subvaria*), stonefly (*Acroneuria lycorias*), and caddisfly (*Hydropsyche betteni*) species. Fish had a similar range of 0.03 mg/L for the guppy (*Poecilla reticulata*) to 1.0 mg/L for the mozambique tilapia (*Tilapia mossambica*). In a study of the acute toxicity of mercuric chloride to rainbow trout (*Oncorhynchus mykiss*), at 5, 10, and 15°C, the LC_{50}s were 0.40, 0.28, and 0.22 mg/L, respectively. The chronic value for mercury (II) toxicity to *Daphnia magna* was about 0.0011 mg/L.

Comparatively little toxicity data are available for methyl mercury. Acute toxicity values for rainbow trout and brook trout range from 0.024–0.084 mg/L. Methyl mercury is also the most chronically toxic form that was tested: cladoceran and brook trout values were both < 0.00007 mg/L.

Silver. Toxicity of silver to freshwater fish and invertebrates is dependent on water hardness and chloride concentration, with silver being more toxic in soft and low chloride water.

Acute toxicity data are available for four invertebrate species (EPA 1980c), with acute values ranging from 0.00025 mg/L for *Daphnia magna* to 4.5 mg/L for the scud *Gammarus pseudolimnaeus*, both of which were tested in Lake Superior water. Most of the acute toxicity data for fish are for the rainbow trout and fathead minnow. Acute values range from 0.0039 mg/L for fathead minnow (*Pimephales promelas*) in soft water to 0.28 mg/L for rainbow trout (*Oncorhynchus mykiss*) in hard water (EPA 1980c).

Chronic values for rainbow trout listed in EPA (1980c) are between 0.00004 and 0.00027 mg/L. Davies et al. (1978) conducted an 18-month study to evaluate the effects on silver nitrate in soft water on survival and growth of rainbow trout. The exposure was initiated with eyed embryos that hatched after 26 days. The "no-effect" concentration was between 0.00009 and 0.00017 mg/L, based on mortality data. However, this concentration does not reflect possible effects of silver on spawning behavior or reproduction. From 3.5 months of exposure to the end of the experiment, significant decreases in growth occurred in fish exposed to 0.00069 mg/L silver. Egg and sac-fry mortality was 52 percent in the 0.00069 mg/L concentration.

Toxicity of silver is dependent upon the form of the element. In tests with fathead minnows, the free ion is the form of silver most acutely toxic to fish, with a 96-hour LC_{50} of 0.016 mg/L. The 96-hour LC_{50} for silver thiosulfate complex is between 280 and 360 mg/L, and the 96-hour LC_{50} for silver sulfide is > 240 mg/L. Results of exposing fathead minnow embryos and larvae to silver sulfide at 11 mg/L (total silver) resulted in no significant effects on average wet weight or total length of larvae after 30 days of continuous exposure. Exposures of silver thiosulfate complex at total silver concentrations greater than 35 mg/L caused significant effects in survival and total length. Concentrations of 140 mg/L total silver resulted in a significant reduction in egg hatch (LeBlanc et al. 1984).

5.3.2.2 Toxicological Profiles for Piscivorous Wildlife

Mercury. Mercury has no known biological function and is potentially toxic to wildlife. Mercury is a mutagen, teratogen, and carcinogen that adversely affects the central nervous, renal, and reproductive systems of wildlife (Eisler 1987). Inorganic mercury compounds in aquatic systems are readily converted to organomercury by microbial action (Berlin 1979), with organomercury compounds being more toxic than inorganic mercury compounds. Biota bioconcentrate mercury compounds which can be further biomagnified through food chains (Wren 1986).

Daily doses of 0.1–0.5 mg/kg bw/day and dietary concentrations of 1.0–5.0 ppm are lethal to sensitive mammals (Eisler 1987). Central nervous system toxicity, weight loss, and mortality were observed among rats fed a diet containing 250 ppm methyl mercury for 2 weeks (Verschuuren et al. 1976a). Rats consuming 2.5 ppm methyl mercury in the diet for 2 years displayed reduced growth, increased kidney weight, and altered kidney histochemistry (Verschuuren et al. 1976b). To study effects on reproduction, Verschuuren et al. (1976c) fed rats a diet containing 0, 0.1, 0.5, and 2.5 ppm methyl mercury for three generations. While no effects were observed among rats fed 0.1 or 0.5 ppm methyl mercury, offspring viability was reduced among rats in the 2.5 ppm treatment. Among mink, 93-day consumption of diets

containing 1.8 to 15.0 ppm methyl mercury produced mortality, ataxia, anorexia, and paralysis (Wobeser et al. 1976), with the highest exposures showing the greatest effects.

The LD_{50} for methyl mercury for *Coturnix* quail ranges from 14.4 to 33.7 mg/kg body weight (Eisler 1987). Growth was decreased and mortality increased among leghorn cockerels fed diets containing 6–18 ppm of methyl mercury (Fimreite 1970). Ring-necked pheasants fed diets of methyl mercury-treated grains displayed reduced egg production and hatchability, and laid more shell-less eggs than controls (Fimreite 1971). Heinz (1979) fed mallard ducks a diet containing 0.5 ppm methyl mercury for three generations. While methyl mercury consumption did not affect adult weights or weight change during the reproductive season, methyl mercury-exposed females laid fewer eggs (with more eggs outside the nest box), produced fewer young, and displayed slightly thinner eggshells. Young of methyl mercury-treated adults were less responsive to maternal calls and hyper-responsive to fright stimuli.

Polychlorinated biphenyls. PCBs are a family of man-made chemicals consisting of 209 individual compounds with varying toxicity (ATSDR 1989). Aroclor is the trade name for PCBs made by the Monsanto Company. Because of their insulating and nonflammable properties, PCBs were widely used in industrial applications such as coolants and lubricants in transformers, capacitors, and electrical equipment (ATSDR 1989). The United States stopped manufacturing PCBs in 1977 due to evidence that they accumulate in the environment. PCBs have become widespread environmental contaminants.

Most exposures to PCBs are oral. Absorption of PCBs following oral exposure is often > 90 percent (ATSDR 1989). PCBs are preferentially stored in adipose tissues in animals. They may cross the placenta or be transferred to offspring through milk. PCBs with higher chlorine content (the last 2 digits of the Aroclor designation indicate the percent chlorine content of the compound) tend to persist in the environment longer than those with lower chlorine content, and PCBs are known to bioaccumulate and biomagnify to toxic concentrations in animals (Eisler 1986; ATSDR 1989). Chronic exposures are of particular concern. PCBs with high K_{ow} values and high numbers of chlorines in adjacent positions are generally the most toxic. Although relatively insoluble in water, PCBs are generally freely soluble in nonpolar organic solvents and in biological lipids (EPA 1980d).

Mink are one of the most susceptible mammals; dietary levels as low as 0.1 ppm fresh weight have caused death and reproductive toxicity (Eisler 1986). Diets containing 20 ppm Aroclor-1242 were lethal to mink in a 247-day experiment. The LC_{50} for chronic exposures is 6.65 ppm Aroclor-1254 for mink over an 8-month period (Ringer et al. 1981 cited in ATSDR 1989). Diets containing 5 ppm Aroclor-1242 caused complete reproductive failure (Bleavins et

al. 1980). Exposure for 160 days to 3.57 ppm Aroclor-1254 resulted in 100 percent mortality of adult mink (Platonow and Karstad 1973).

A chronic study was conducted over 4.5 months exposing mink to 1, 5, and 15 ppm Aroclor-1254 in the diet. There was a significant reduction in the number of offspring born alive at the 5- and 15-mg/kg exposures (Aulerich and Ringer 1977). Mink fed carp containing 1.5 ppm Aroclor-1254 for 6 months produced no offspring that survived to 24 hours (Hornshaw et al. 1983). No effects were observed in mink fed 0.64 ppm Aroclor-1254 for 160 days (Platonow and Karstad 1973). Mink exposured for 6 months to 1 ppm Aroclor-1254 resulted in no significant difference from controls in number of offspring, or offspring mortality (Wren et al. 1987). Therefore, the 1-ppm dose was considered to be a chronic NOAEL.

A dietary dose of 25 ppm Aroclor-1254 fed for at least 1 month before egg-laying in mallard ducks had no detrimental effect on reproductive success (Custer and Heinz 1980). Dietary exposure of 5 ppm Aroclor-1254 for 39 weeks to laying hens and roosters resulted in reduced egg production, although hatchability of fertile eggs was not affected (Platonow and Reinhart 1973). Screech owls fed 3 ppm Aroclor-1248 through two breeding seasons did not have significantly different reproductive success, relative to controls (McLane and Hughes 1980). Exposure of pheasants to 12.5 mg/bird•week (1.8 mg/kg•day) of Aroclor-1254 for 17 weeks resulted in significantly reduced egg hatchability (Dahlgren et al. 1972). Because this study considered exposure throughout a critical lifestage (reproduction), the 12.5 mg/bird•week dose was considered to be a chronic LOAEL.

Radionuclides. Chronic effects of ionizing radiation on terrestrial organisms has been reviewed by the International Atomic Energy Agency (IAEA 1992). The following section is a summary of this section. Terrestrial populations considered in this summary include mammals and birds.

Reproduction is the population attribute most sensitive to damage from chronic irradiation and is the most significant parameter having ecological relevance. Mammalian studies indicated that a dose rate of 420 μGy/hour represented an approximate threshold at which effects became apparent in irradiated populations. Tentative conclusions also suggest annual doses of several grays would be required to bring about the extinction of the most sensitive populations. Mammals inhabiting a hardwood forest detected no effects on survival at dose rates of 830 μGy/hour. However, pigs and donkeys exposed to a dose rate of 4 μGy/hour showed deterioration in a few weeks and died following a few months of continuous exposure.

The recommended chronic dose rate for terrestrial biota is 42 μGy/hour (100 mrad/day). This level of exposure to the maximally exposed individual appears to be protective of the population (IAEA 1992). If conservative screening results in a dose rate above 10 μGy/hour, a more detailed evaluation of the ecological effects to natural population should be made.

5.4 ECOLOGICAL RISK CHARACTERIZATION

Risk characterization is the phase of risk assessment in which the information concerning exposure (Sect. 5.2) and the information concerning the potential effects of exposure (Sect. 5.3) are integrated to estimate risks (the likelihood of effects given the exposure). Procedurally, the risk characterization in this assessment is performed for each assessment endpoint by (1) screening all measured contaminants against toxicological benchmarks, (2) estimating the effects of the contaminants retained by the screening analysis, and (3) listing and discussing the uncertainties in the assessment.

5.4.1 Aquatic Biota

5.4.1.1 Chemical screening for aquatic biota

Concentrations in surface water were compared to ecotoxicological benchmarks to derive hazard quotients by the formula:

$$\text{Hazard quotient} = \frac{\text{water concentration}}{\text{toxicological benchmark}} \qquad \text{(C5.13)}$$

Hazard quotients greater than 1 suggest that the chemical may be hazardous to the endpoint biota and therefore worthy of further assessment, and hazard quotients less than 1 suggest that the chemical is nonhazardous and need not be considered further.

In White Oak Creek, adjacent to SIOU, modeled concentrations of Ba, Be, Cr, Aroclor-1254 and Aroclor-1260 did not exceed any aquatic toxicity benchmarks (Table C5.14), and therefore these analytes were omitted from further characterization. Cadmium levels at this location exceeded only the lowest chronic value for daphnids (hazard quotient = 1.3). Cadmium levels were below this benchmark at White Oak Dam (Table C5.15).

Modeled mercury concentrations (0.033 mg/L) exceeded several benchmarks for fish and daphnids in White Oak Creek (WCK 3.9) (Table C5.14) and at White Oak Dam (Table C5.15), regardless of whether inorganic or methyl mercury was assumed to be the dominant form. In Clinch River (Table C5.16), mercury levels fell below benchmark values if inorganic mercury was assumed. If the dominant form was assumed to be methyl mercury, the secondary chronic

Table C5.14. Exposure estimates in White Oak Creek at SIOU and hazard quotients for the fish and benthic macroinvertebrate community endpoints, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(mg/L)

Constituent	Concentration in White Oak Creek at SIOU	Hazard quotient						
		Acute NAWQC	Chronic NAWQC	Secondary acute value	Secondary chronic value	Lowest chronic value		
						Fish	Daphnids	Nondaphnid invertebrates
Barium	1.99×10^{-3}	—	—	0.029	0.52	—	3.4×10^{-4}	—
Beryllium	8.50×10^{-4}	—	—	0.003	0.17	0.015	0.16	—
Cadmium	1.95×10^{-4}	0.05[a]	0.18[a]	—	—	0.11	1.3	—
Chromium	3.26×10^{-4}	0.02[b]	0.03[b]	—	—	0.004[b]	0.05[b]	—
Mercury, inorganic	3.27×10^{-2}[c]	13.6	—	—	25.2	142.2	34.1	—
Mercury (methyl)		—	—	285.2	10934	63.0	820	—
Silver	2.40×10^{-3}	0.59[a]	—	—	6.7	20.0	0.92	—
N-nitroso-di-n-propylamine	1.80×10^{-5}	—	—	—	—	—	—	—
Aroclor-1254	2.31×10^{-9}	—	—	1.1×10^{-5}	1.2×10^{-4}	2.3×10^{-6}	1.1×10^{-6}	2.9×10^{-6}
Aroclor-1260	1.56×10^{-11}	—	—	8.34×10^{-11}	1.5×10^{-9}	1.2×10^{-8}	—	—
2,4-Dinitrotoluene	2.00×10^{-7}	—	—	—	—	—	—	—

[a]Hardness-dependent criterion, normalized to 100 mg/L.
[b]Assumes Cr VI.
[c]Concentration compared to benchmarks for both inorganic and methyl mercury.

L = liter
mg = milligram
NAWQC = National Ambient Water Quality Criterion
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
— = no benchmark was available and therefore no hazard quotient was calculated

Table C5.15. Exposure estimates in White Oak Creek at White Oak Dam and hazard quotients for the fish and benthic macroinvertebrate community endpoints, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee[a]

(mg/L)

Constituent	Concentration in White Oak Creek at White Oak Dam	Hazard quotient					
		Acute NAWQC	Chronic NAWQC	Secondary acute value	Secondary chronic value	Lowest chronic value	
						Fish	Daphnids
Cadmium	9.75×10^{-5}	0.025[b]	0.09[b]	—	—	0.06	0.65
Mercury, inorganic	1.64×10^{-2}[c]	6.8	—	—	12.6	71.3	17.1
Mercury (methyl)		—	—	142.6	5,467	31.5	410
Silver	1.20×10^{-3}	0.3[b]	—	—	3.3	10.0	0.46

[a]Only those contaminants which exceeded benchmarks in White Oak Creek at SIOU were retained for the evaluation at White Oak Dam.
[b]Hardness-dependent criterion, normalized to 100 mg/L.
[c]Concentration compared to benchmarks for both inorganic and methyl mercury.

L = liter
mg = milligram
NAWQC = National Ambient Water Quality Criterion
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
— = no benchmark was available and therefore no hazard quotient was calculated

Table C5.16. Exposure estimates in Clinch River at White Oak Creek and hazard quotients for the fish and benthic macroinvertebrate community endpoints, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee[a]

(mg/L)

Constituent	Concentration in Clinch River at White Oak Creek	Hazard quotient					
		Acute NAWQC	Chronic NAWQC	Secondary acute value	Secondary chronic value	Lowest chronic value	
						Fish	Daphnids
Mercury, inorganic	6.54×10^{-5}[b]	0.03	—	—	0.05	0.28	0.07
Mercury (methyl)		—	—	0.57	21.8	0.11	1.6

[a]Only those contaminants which exceeded benchmarks in White Oak Creek at White Oak Dam were retained for the evaluation at Clinch River.
[b]Concentration compared to benchmarks for both inorganic and methyl mercury.

L = liter
mg = milligram
NAWQC = National Ambient Water Quality Criterion
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
— = no benchmark was available and therefore no hazard quotient was calculated

value and lowest chronic value for daphnids was exceeded at this location. The modeled mercury concentrations in White Oak Creek compared to current surface water concentrations are highly conservative. Actual mercury levels in White Oak Creek downstream of SIOU (upstream of the First Creek confluence) were measured in June 1994 (Hicks, personal communication). The current concentration of mercury was 0.00002 mg/L, which is three orders of magnitude below the modeled concentration. A concentration of 0.00002 mg/L exceeds only the Tier II chronic value for methyl mercury.

Silver concentrations at WCK 3.9 (Table C5.14) and at White Oak Dam (Table C5.15) exceeded the secondary chronic value and the lowest chronic value for fish. Concentrations fell well below the benchmarks in Clinch River (Table C5.16).

5.4.1.2 Effects estimation for aquatic biota

Cadmium. There is weak evidence to support a risk to fish and benthic macroinvertebrate communities resulting from exposure to cadmium. Acute or chronic National Ambient Water Quality Criterion were not exceeded. The lowest chronic value for fish was not exceeded, and the lowest chronic value for daphnids (hardness = 53 mg/L) was exceeded only by a factor of 1.3. Since the toxicity of cadmium is hardness dependent, a chronic value for a daphnid with a hardness of 103 mg/L was used for comparison. Surface water at WCK 3.9 did not exceed this chronic value (0.0002117 mg/L). Sufficient dilution occurs in the creek at White Oak Dam to eliminate cadmium as a COC. Since the groundwater modeling effort does not account for subsequent adsorption of analytes to sediments or other creek constituents, the concentration assumed to be in the creek surface water and pore water is conservative.

Mercury. Current mercury concentrations (< 0.00002 mg/L) in surface water in White Oak Creek, adjacent to SIOU, are not expected to impact the fish and benthic invertebrate communities. However, if the total mercury concentration is assumed to be methyl mercury, chronic toxicity could result at such levels. Chronic toxicity to methyl mercury was observed for a cladoceran at values < 0.00007 mg/L (EPA 1984a).

If modeled mercury concentrations are used to estimate risks to fish and benthic macroinvertebrates in White Oak Creek, impacts on these communities would be evident. Modeled mercury concentrations were estimated to be 0.0327, 0.0164, and 0.000065 mg/L in WCK 3.9, White Oak Dam, and Clinch River, respectively. The modeled concentrations at WCK 3.9 and White Oak Dam strongly suggest impacts to the fish and invertebrate communities, regardless of whether or not the mercury was assumed to be inorganic or methyl mercury. Concentrations at both locations exceed the acute National Ambient Water Quality Criterion,

LC_{50}s for sensitive species of fish and invertebrates, and chronic values for most species (Tables C5.14 and C5.15, Sect. 5.3.2.1).

Silver. There is evidence to suggest silver concentrations may impact the fish community in WCK 3.9 and White Oak Dam. Silver concentrations at these locations were estimated at 0.0024 mg/L and 0.0012 mg/L, respectively. Since the groundwater modeling effort does not account for subsequent adsorption of analytes to sediments or other creek constituents, the concentration assumed to be in the creek surface water and pore water is conservative. These values exceed documented "no-effect" concentrations for 18-month rainbow trout that resulted in significant mortality. Since silver concentrations are less than the acute toxicity values but are higher than the no-effect concentrations, adverse effects may be occurring on the fish community (Sect. 5.3.2.1).

Radionuclides. Radiation doses were calculated for small fish at WCK 3.9, White Oak Dam and Clinch River (Sect. 5.2.3). Doses at these three locations were 0.024, 0.012, and 4.7×10^{-5} μGy/hour, which are below the National Council on Radiation Protection and Measurements benchmark of 400 μGy/hour considered protective of populations of aquatic organisms (NCRP 1991).

Media Toxicity Tests. The Biological Monitoring and Abatement Program has conducted aquatic toxicity tests on surface water downstream of SIOU (WCK 3.8) since 1986. Aquatic toxicity has been evaluated using 7-day static renewal chronic toxicity tests based on the survival and growth of the fathead minnow (*Pimephales promelas*) larvae and the survival and reproduction of a daphnid (*Ceriodaphnia dubia*) (Ashwood 1994). Toxicity test results from 1992 to 1994 suggest no evidence of toxicity to fathead minnow larvae or *Ceriodaphnia*. Fathead minnow larvae exceeded survival (> 60 percent) and growth (0.4 mg/fish) criteria for 13/13 and 12/13 tests, respectively. *Ceriodaphnia* exceeded survival (> 60 percent) and reproductive (> 15 offspring/female) criteria for 13/14 and 12/14 tests, respectively (Stewart, personal communication). Therefore, this line of evidence suggests that surface water at WCK 3.8 is nontoxic to these test species.

Biological Surveys. The Biological Monitoring and Abatement Program has conducted fish community surveys at WCK 3.9 for the past 7 years (Schilling 1994). WCK 3.9 has experienced substantial increases in fish densities since 1989 (when no fish were found). The increase in fish population densities and biomass, may be attributed to continued improvements in water quality from pollution abatement projects (i.e., decrease in chlorine concentrations through elimination of point source discharge; and/or contaminant dilution, and nutrient enrichment due to Nonradiological Waste Treatment Facility (Schilling 1993). Since the

population of fish at WCK 3.9 has been substantially increasing over the past several years, there is no indication that predicted mercury concentrations, contributed from SIOU, are affecting the abundance of the fish population.

Benthic macroinvertebrate surveys have also been performed at WCK 3.9 since 1988 (Southworth et. al. 1994). Density, taxonomic richness, and combined richness of Ephemeroptera, Plecoptera, and Tricoptera taxa (EPT richness) were evaluated to determine adverse impacts within White Oak Creek. Adverse changes in benthic invertebrate communities are evident at WCK 3.9 as determined by a loss of numbers of sensitive (EPT) taxa and low densities of the representatives of that group which are present. The sensitive fauna (mayflies, stoneflies, and caddisflies) are virtually absent at WCK 3.9, and total taxonomic richness is approximately half that typically observed in unimpacted streams. The invertebrate fauna at WCK 3.9 is dominated by midges (Chironomidae). Therefore, these surveys suggest that adverse effects on the benthic invertebrate community may be occurring at this site. However, effects due to contaminants (mercury) leaching from SIOU and many other factors such as thermal discharges, residual chlorine, nutrient enrichment, sediment loading can not be differentiated.

5.4.1.3 Weight of evidence

Three lines of evidence, literature toxicity data, toxicity test results, and biosurveys were available to evaluate ecological risk to fish and benthic macroinvertebrates (Table C5.17). Based on modeling results, mercury concentrations may result in unacceptable risks at WCK 3.9 and at White Oak Dam. All mercury toxicity benchmarks were exceeded at both locations, regardless of whether or not the mercury was assumed to be inorganic or methyl mercury. However, based on measured concentrations of mercury in White Oak Creek (Hicks, personal communication) from June 1994, these exposure estimates are highly conservative. The concentrations of mercury below SIOU, but above First Creek was at the detection limit (0.00002 mg/L) which is three orders of magnitude below the modeled concentration of 0.033 mg/L estimated to leach from SIOU. Also, although modeled surface water values exceeded ecotoxicological benchmarks and acute toxicity values for both fish and daphnids, toxicity was not demonstrated during laboratory toxicity tests from 1992 to 1994 (Stewart, personal communication). In addition, downstream surveys of fish do not show the massive injury to those communities that would occur if the modeled concentrations actually occurred. Although, the benthic macroinvertebrate survey suggests that the population has been impacted, the probable causes could include thermal discharges, nutrient enrichment, residual chlorine or other toxicants, increased sediment loading, and/or changes in major ion chemistry (Southworth et. al. 1994). Therefore, the weight of evidence suggests that leachate from SIOU is not likely causing significant effects on the fish and invertebrate communities of White Oak Creek. However, studies of White Oak Creek in Waste

Table C5.17. Summary of weight of evidence of ecological risks experienced by fish and benthic macroinvertebrate communities in White Oak Creek adjacent to SIOU (WCK 3.9), at White Oak Dam, and in Clinch River, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Species	Evidence	Result	Rationale
White Oak Creek (WCK 3.9)	Literature toxicity data	±	Modeled concentrations of Cd, Hg, and Ag in water are sufficient to adversely affect the fish and benthic invertebrate communities in White Oak Creek
	Biological surveys	±	Fish surveys at WCK 3.9, downstream of SIOU, indicate improvement of the fish population. Surveys of benthic macroinvertebrate community indicate impacts, however, SIOU can not be clearly identified as the source of impacts
	Media toxicity tests	—	No toxicity was observed in fathead minnow and *Ceriodaphnia* toxicity tests
	Weight of evidence	—	Modeled concentrations suggest severe impacts are possible in White Oak Creek due to SIOU contamination. However, the low mercury concentrations measured in White Oak Creek, the low levels of effects found in downstream fish surveys, the ambiguous benthic survey results, and the lack of toxicity observed in the toxicity tests suggests the fish and benthic communities may not be adversely affected by SIOU. A more complete evaluation of White Oak Creek in Waste Area Grouping 1 and Waste Area Grouping 2 is necessary to determine potential risks to these communities
White Oak Dam	Literature toxicity data	±	Modeled concentrations of mercury and silver in water are sufficient to adversely affect the fish and benthic invertebrate communities in White Oak Creek
	Biological surveys	NA	Surveys were not performed
	Media toxicity tests	NA	Toxicity tests were not performed at White Oak Dam
	Weight of evidence	—	Modeled concentrations suggest severe impacts are possible at White Oak Dam due to SIOU contamination. However, based on the toxicity test results for White Oak Creek near SIOU, a more complete evaluation of White Oak Creek would be necessary to determine potential risks to the fish and benthic macroinvertebrate communities

Table C5.17 (continued)

Species	Evidence	Result	Rationale
Clinch River	Literature toxicity data	±	Modeled concentrations of mercury may be toxic to fish and benthic invertebrate communities if all mercury in the water column is methyl mercury. Speciation of mercury was not determined
	Biological surveys	NA	Surveys were not performed
	Media toxicity tests	NA	Toxicity tests were not performed at Clinch River
	Weight of evidence	—	Modeled concentrations of mercury suggest a potential impact on the fish and benthic macroinvertebrate communities. However, based on the toxicity tests and water mercury measurements in White Oak Creek adjacent to SIOU, there is no evidence for adverse impacts in Clinch River due to mercury from SIOU

Ag = silver
Cd = cadmium
Hg = mercury
NA = data were not available
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
WCK 3.9 = White Oak Creek kilometer 3.9
— = evidence is inconsistent with the occurrence of the endpoint effect
± = evidence is too ambiguous or provides insufficient data to interpret

Area Grouping 1 are needed to better define exposures and effects due to the numerous CERCLA and National Pollutant Discharge Elimination System sources.

The future risks to fish and benthic invertebrate communities in White Oak Creek should not increase from current conditions.

5.4.2 Piscivorous Wildlife

5.4.2.1 Chemical screening for piscivorous wildlife

The contaminant exposure estimates for wildlife feeding out of SIOU and White Oak Creek were compared to estimated NOAELs and LOAELs to determine if the contaminant exposure experienced by piscivorous wildlife is potentially hazardous. Hazard quotients were calculated to quantify the magnitude of the hazard where:

$$\text{Hazard quotient} = \frac{\text{estimated exposure}}{\text{NOAEL}} \quad \text{or} \qquad \text{(C5.14)}$$

$$\text{Hazard quotient} = \frac{\text{estimatedexposure}}{\text{LOAEL}}$$

Hazard quotients greater than 1 indicate that individuals may be experiencing exposures that are in excess of NOAEL, and may suggest that adverse effects may be occurring. The comparison of estimated exposure and the NOAEL acts as a screening tool to identify COCs that will be further evaluated for possible estimated effects. Exceedence of the estimated LOAEL evaluates the significance and potential for adverse effects (Table C5.18) which may occur from contaminant exposure.

The toxicological benchmarks and exposure models used in this assessment focus on exposure and effects experienced by individual organisms, however, all endpoints are for population level effects. The use of organism-level exposures and effects is appropriate because of the need to integrate exposure estimates with exposure-response information, which is expressed as organism-level responses. However, the conversion of individual exposure and effects to population levels must occur in the risk characterization.

Since mink and kingfishers have large home ranges and are mobile, a distinct population would not exist in each location that is assessed (i.e., SIOU, WCK 3.9, White Oak Dam and Clinch River). In fact, it is unlikely that the entire Waste Area Grouping 1 area supports a distinct population of these endpoint species. In addition, as a result of their mobility and large home ranges, they may be exposed to contaminants from multiple locations within a watershed.

Table C5.18. Estimated LOAELs for mink and kingfishers, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Experimental Information							Estimated LOAEL (mg/kg-day)
Analyte	Form	Test species	LOAEL (mg/kg-day)	LOAEL duration	Endpoint/effect	Citation	
Mink							
Mercury	Methyl	Mink	0.0247[a]	93 days	Mortality	Wobeser et al. 1976	0.025
PCB	Aroclor-1254	Mink	0.685	Through gestation	Reduced number of young born alive	Aulerich and Ringer 1977	0.685
Kingfisher							
Mercury	Methyl	Mallard duck	0.064	Three generations	Reduced egg production and hatching success	Heinz 1979	0.12
PCB	Aroclor-1254	Ring-necked pheasant	1.8	17 weeks	Reduced egg hatchability	Dahlgren et al. 1972	3.38

[a]Effect severe and study subchronic in duration, therefore a subchronic-chronic uncertainty factor of 10 was applied.

kg = kilogram
LOAEL = lowest observed adverse effect level
mg = milligram
ORNL = Oak Ridge National Laboratory
PCB = polychlorinated biphenyl
SIOU = Surface Impoundments Operable Unit

For the purposes of this assessment, individual mink and kingfishers were assumed to be found at SIOU, WCK 3.9, White Oak Dam, and Clinch River. Risks for each feeding location in White Oak Creek were evaluated by comparing the mean and maximum exposure estimates (using the mean and maximum bioconcentration factors) from each location and the LOAEL. For any given contaminant, if exposure estimates for all sampling locations were below LOAELs, regardless if exposure exceeded NOAELs, adverse effects were assumed to be absent for "populations." Although, exposures exceeding the NOAELs could potentially cause effects to individuals. In contrast, if any exposure for a given contaminant within a location exceeded the estimated LOAEL, it was assumed that populations using that location were potentially experiencing adverse effects from that contaminant.

SIOU. Exposure estimates, NOAELs, LOAELs, and hazard quotients for kingfishers and mink are presented in Tables C5.3 and C5.4. Concentrations of mercury and PCBs (Aroclor-1254 and Aroclor-1260) in fish from SIOU exceeded NOAELs for mink and kingfishers. Drinking water does not make a significant contribution to exposure and will not be discussed further.

The internal dose from ^{137}Cs beta and gamma radiation to a kingfisher was 5.85 and 1.38 μGy/hour, respectively. Therefore, the total internal dose from ^{137}Cs is 7.23 μGy/hour. The internal dose to the kingfisher from ^{90}Sr for beta and gamma radiation was 31.6 and 4.5×10^{-5} μGy/hour, respectively. Therefore, the total internal dose to a kingfisher is 31.6 μGy/hour. The total radiation dose to a kingfisher at the surface impoundments is $7.23 + 31.6 = 38.8$ μGy/hour which is below the International Atomic Energy Agency benchmark of 42 μGy/hour (100 mrad/day) dose considered to be protective of populations (IAEA 1992). For mink, the internal doses from Cs-137 beta and gamma radiation were 5.85 and 1.38 μGy/hour, respectively, for a total dose of 7.23 μGy/hour. The internal dose to mink from ^{90}Sr for beta and gamma radiation was 31.6 and 4.5×10^{-5} μGy/hour, respectively. The external dose to mink was estimated to be 6 μGy/hour. Therefore, the total radiation dose to a mink at SIOU is 44.8 μGy/hour, which exceeds the International Atomic Energy Agency benchmark of 42 μGy/hour (100 mrad/day) dose considered to be protective of populations (IAEA 1992).

White Oak Creek. Hazard quotients for kingfishers at WCK 3.9, White Oak Dam, and Clinch River are presented in Tables C5.6 through C5.8. The total exposure to Ag, Be, Cd, Cr, Ag, Aroclor-1254 and Aroclor-1260 for kingfishers at each location were less than the estimated NOAELs. The mercury exposure, using fish collected downstream of SIOU, exceeded the NOAEL by 8 times at WCK 3.9.

Hazard quotients for mink at WCK 3.9, White Oak Dam, and Clinch River are presented in Tables C5.9 through C5.11. The total exposure to Ag, Be, Cd, Cr, Ag, Aroclor-1254 and Aroclor-1260 for mink at each location were less than the estimated NOAELs. The most conservative exposure calculation, using the maximum concentration potentially found in fish, resulted in cadmium exposures that exceed the NOAEL at WCK 3.9 and White Oak Dam by 2.4 and 1.2 times, respectively (Table C5.10). The total mercury exposure calculated from fish collected at WCK 3.9 was equal to the methyl mercury NOAEL (Table C5.11).

5.4.2.2 Effects estimation for piscivorous wildlife feeding from SIOU

Mercury. Mercury concentrations in the fish in the surface impoundments resulted in a significant risk to mink. Fish from SIOU would have to constitute less than 50 percent of the fish portion of the mink diet for exposure estimates to fall below the LOAEL. Exposure of mink to mercury (0.05 mg/kg•day) is below the dose that is lethal to sensitive mammals (0.1–0.5 mg/kg•day). Paralysis and mortality have been observed in mink consuming diets of 1.8–15 mg/kg methyl mercury. Therefore, acute effects are not expected in mink feeding from SIOU. However, exposures may be high enough to produce chronic reproductive effects.

Mercury concentrations in the fish in SIOU also resulted in a significant risk to kingfishers. Exposure of kingfishers to mercury exceeded the NOAEL (hazard quotient = 33.6) and the LOAEL (hazard quotient = 3.4). Fish from SIOU would have to constitute less than 30 percent of the fish portion of the kingfisher diet for exposure estimates to fall below the LOAEL. Therefore, adverse effects are expected to occur to the kingfisher population or individuals feeding from SIOU.

Aroclor-1254. Aroclor-1254 concentrations in fish resulted in significant risks to mink and kingfishers. Exposures from Aroclor-1254 exceeded the LOAELs (hazard quotient = 3, kingfishers; hazard quotient = 2 mink). For Aroclor-1254 exposures to fall below LOAEL values, fish from SIOU would have to constitute less than 46 percent and 34 percent of the fish eaten daily by mink and kingfishers, respectively. Mink are one of the most susceptible mammals; dietary levels as low as 0.1 mg/kg fresh weight have caused death and reproductive toxicity (Eisler 1986).

Aroclor-1260. Adverse effects from Aroclor-1260 are unlikely to impact the mink or kingfisher populations feeding from SIOU. However, there is a potential for adverse chronic effects to occur on individuals feeding from the impoundments. Exposures of mink and kingfishers to Aroclor-1260 exceeded the NOAELs, but were only 47 percent and 69 percent of the respective LOAELs.

Radionuclides. Reproduction is the population attribute most sensitive to damage from chronic irradiation. The total radiation dose to a mink at SIOU is 44.8 μGy/hour, which exceeds the International Atomic Energy Agency chronic dose benchmark of 42 μGy/hour (100 mrad/day) considered to be protective of populations (IAEA 1992). Also, a mink feeding at SIOU would obtain an annual dose of 0.387 Gy/year. Most mammalian studies indicated that a dose rate of 420 μGy/hour represented an approximate threshold at which effects became apparent in irradiated populations. Tentative conclusions also suggest annual doses of several grays would be required to bring about the extinction of the most sensitive populations. However, pigs and donkeys exposed to a dose rate of 4 μGy/hour showed deterioration in a few weeks and died following a few months of continuous exposure (IAEA 1992). Therefore, there is a potential (although unlikely) for chronic effects to occur for mink feeding from SIOU. The total dose to a kingfisher (39 μGy/hour) was similar to the chronic dose benchmark of 42 μGy/hour (IAEA 1992).

5.4.2.3 Effects estimation for piscivorous wildlife feeding from White Oak Creek

Cadmium. The maximum modeled exposure to mink resulted in cadmium exposure in excess of NOAELs at WCK 3.9 and White Oak Dam. However, the maximum exposure was only 18 percent and 10 percent of the estimated LOAEL at WCK 3.9 and White Oak Dam, respectively. Therefore, adverse effects from cadmium are possible but not expected for mink feeding at these locations.

Mercury. The use of mercury concentrations found in fish downstream of WCK 3.9 enabled determination of current mercury exposures to kingfishers and mink in White Oak Creek. The use of these data assumes that 100 percent of the mercury found in the fish was contributed from the impoundments with no additional sources. Since this is unlikely to be true, calculated exposures to kingfishers and mink are conservative.

Estimated mercury exposures for kingfishers and mink were compared to the estimated NOAEL and LOAEL for methyl mercury. Methyl mercury has been shown to be the predominant form within fish, comprising more than 95 percent of the mercury present (Bloom 1992).

Estimated mercury exposure for kingfishers exceeded the NOAEL at WCK 3.9, however, the exposure estimate was 82 percent of the estimated LOAEL. Because estimated exposure is less than the LOAEL, adverse effects from mercury are not expected among the kingfisher population feeding in White Oak Creek. However, the exceedence of the NOAEL suggests a potential for adverse effects to occur to individuals feeding from the stream.

The mercury exposure for mink estimated from measured concentrations was equivalent to the NOAEL and was 58 percent the estimated LOAEL for methyl mercury. Therefore, it is unlikely that the mink population is at risk due to mercury in White Oak Creek as a result or contributions from SIOU. However, exceedence of the NOAEL suggests a potential for adverse effects to occur to individuals feeding from the stream.

Mercury exposures were not calculated at White Oak Dam and Clinch River since there was minimal risk to the kingfisher or mink found in White Oak Creek adjacent to SIOU (WCK 3.9). Also, total exposures could not be determined based on concentrations found in fish at these downstream locations. The concentrations currently found in fish at White Oak Dam and Clinch River may have accumulated mercury from multiple sources on the reservation. Therefore, the contribution of SIOU to mercury exposure at White Oak Dam and Clinch River cannot be assessed.

5.4.2.4 Weight of evidence

SIOU. Only one line of evidence, literature toxicity data, was available to evaluate ecological risk to piscivorous wildlife (Table C5.19). Those data suggest that belted kingfishers and mink may be adversely affected by mercury and Aroclor-1254 concentrations in the fish in SIOU. It is important to note, however, that mink and kingfisher home ranges were not factored into the exposure estimate. Therefore, less than one third of the aquatic portion of these species' diets would have to come from SIOU for there to be no adverse impacts expected.

White Oak Creek. Only one line of evidence, literature toxicity data, was available to evaluate ecological risk to piscivorous wildlife (Table C5.20). The data suggest that belted kingfisher and mink populations are not being adversely affected by contamination in White Oak Creek (WCK 3.9), White Oak Dam, or Clinch River, that may be attributed to SIOU. However, individual kingfishers feeding from WCK 3.9 may be adversely affected by measured mercury concentrations in fish.

5.4.3 Preliminary Remediation Goals

5.4.3.1 SIOU: piscivorous wildlife

Mercury. The concentration of mercury in SIOU fish (0.795 mg/kg) would have to be decreased to less than 30 percent of the current levels for there to be insignificant risks to piscivorous wildlife.

Table C5.19. Summary of weight of evidence of ecological risks experienced by piscivorous wildlife feeding from SIOU, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Species	Evidence	Result	Rationale
Belted kingfisher	Literature toxicity data	+	Levels of mercury and Aroclor-1254 in SIOU fish exceed LOAELs
	Biological surveys	NA	Surveys not performed
	Media toxicity tests	NA	These tests are generally not performed for wildlife and are therefore unavailable
	Weight of evidence	+	Survival and reproduction of belted kingfishers may be adversely affected by mercury and Aroclor-1254 concentrations in the fish in SIOU
Mink	Literature toxicity data	+	Levels of mercury and Aroclor-1254 in SIOU fish exceed LOAELs
	Biological surveys	NA	Surveys not performed
	Media toxicity tests	NA	These tests are generally not performed for wildlife and are therefore unavailable
	Weight of evidence	+	Survival and reproduction of mink may be adversely affected by mercury and Aroclor-1254 concentrations in the fish in SIOU

LOAEL = lowest observed adverse effect level
NA = data were not available
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
+ = evidence is consistent with the occurrence of the endpoint effect

Table C5.20. Summary of weight of evidence of ecological risks experienced by piscivorous wildlife in White Oak Creek adjacent to SIOU (WCK 3.9), at White Oak Dam, and in Clinch River, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Species	Evidence	Result[a]	Rationale
Belted kingfisher	Literature toxicity data	—	Contaminant exposure from food or water are not sufficient to adversely affect the belted kingfisher population or individuals in the White Oak Creek watershed due to contributions from SIOU
	Biological surveys	NA	Surveys not performed
	Media toxicity tests	NA	These tests are generally not performed for wildlife and are therefore unavailable
	Weight of evidence	—	Survival and reproduction of belted kingfishers is not likely to have been adversely affected by contamination within the White Oak Creek watershed as a result of contributions from SIOU
Mink	Literature toxicity data	—	Contaminant exposure from food or water not sufficient to adversely affect the mink population or individuals in the White Oak Creek watershed due to contributions from SIOU
	Biological surveys	NA	Surveys not performed
	Media toxicity tests	NA	These tests are generally not performed for wildlife and are therefore unavailable
	Weight of evidence	—	Survival and reproduction of mink is not likely to have been adversely affected by contamination within the White Oak Creek watershed as a result of contributions from SIOU

NA = data were not available
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
WCK 3.9 = White Oak Creek kilometer 3.9
— = evidence is inconsistent with the occurrence of the endpoint effect

Aroclor-1254. The concentration of Aroclor-1254 in fish in SIOU (23.8 mg/kg) would have to be decreased to less than one third of the current levels for there to be insignificant risks to piscivorous wildlife.

5.4.3.2 White Oak Creek

Fish and Benthic Macroinvertebrate Communities. The risk characterization (Sect. 5.4.1.2) for fish and benthic macroinvertebrate communities in White Oak Creek suggested no unacceptable risks from contaminants leaching from SIOU. However, silver concentrations (0.0024 mg/L) in surface water at White Oak Creek (WCK 3.9) and White Oak Dam are considered a contaminant of ecological concern for aquatic biota due to exceedence of the secondary chronic value and the lowest chronic value for fish. These modeled surface water concentrations appear to be conservative and may not truly be representative of the current surface water concentrations at WCK 3.9 or White Oak Dam. However, if modeled concentrations are accurate, a preliminary remediation goal would be established. Therefore, surface water concentrations in White Oak Creek should not exceed 0.00012 mg/L, which is the lowest chronic value for fish.

The measured mercury (< 0.00002 mg/L) concentration at WCK 3.9 exceeded the secondary chronic value if methyl mercury is assumed. This value is considered an appropriate preliminary remedial goal, however, the value is below the Practical Quantitation Limit for the analytical method. Therefore, the surface water concentrations in White Oak Creek should not exceed 0.000003 mg/L.

Piscivorous Wildlife. The risk characterization for piscivorous wildlife feeding out of White Oak Creek (WCK 3.9) (Sect. 5.4.1.2) suggested no unacceptable risks for either piscivorous bird or mammal populations. Therefore, no preliminary remediation goals are set for these endpoints.

5.4.4 Uncertainties

1. No reference site was available for comparisons of water or fish concentrations.

2. Ingestion of SIOU surface water by piscivorous wildlife was estimated using historical data from Impoundment 3513 (Stansfield and Francis 1986). These concentrations do not represent the current contaminant concentrations present in SIOU. Exposure estimates may vary minimally since water ingestion is a minor pathway in comparison to fish consumption.

3. Home range of the piscivorous wildlife species was not used as a modifying factor in the exposure assessment. Because wildlife are mobile, they may travel off the site to drink or forage, thereby reducing their exposure. Therefore, the exposure estimates are conservative.

4. There are no published NOAELs for kingfishers. To estimate toxicity, it was necessary to extrapolate from a NOAEL for mallard ducks. While it was assumed that toxicity could be estimated as a function of body size, the accuracy of the estimate is not known. Kingfishers may be more or less sensitive than mallard ducks.

5. While food consumption by wildlife was assumed to be similar to that reported for the same species in other locations (EPA 1993a), the validity of this assumption cannot be determined. Food consumption at SIOU may be greater or less than that reported in the literature, resulting in either an increase or decrease in contaminant exposure. Similarly, water consumption was estimated according to the allometric equations of Calder and Braun (1983). The accuracy with which the estimated water consumption represents actual water consumption is unknown.

6. Modeled surface water concentrations in White Oak Creek appear to be highly conservative. For example, mercury concentrations measured in White Oak Creek (Hicks, personal communication) were three orders of magnitude below the modeled mercury concentrations. Therefore, the exposure estimates, based on the modeled data, to aquatic communities in White Oak Creek and piscivorous wildlife feeding on fish from White Oak Creek are apparently highly conservative.

7. Modeled surface water concentrations in White Oak Creek were assumed to be total concentrations in the water. The model did not factor in potential adsorption of metals to sediments, or other particulates. Also, for the aquatic communities, it is the dissolved fraction of the metal, not the total concentration, that is bioavailable. This will result in a conservative risk estimate.

8. Several contaminants do not have toxicity benchmarks. Wildlife exposure estimates for Aroclor-1260 used the benchmark for Aroclor-1254.

9. Speciation of contaminants such as Hg, As, and Cr was not done. For screening levels in water, the methyl mercury benchmark was exceeded, but the inorganic benchmark was not. Because metal speciation/form was not determined in the fish tissues, and to be conservative, the benchmarks for mink assume Cr VI as opposed

to Cr III, and methyl mercury as opposed to inorganic mercury. For kingfishers, the chromium benchmark is for Cr III because there is no benchmark for Cr VI, and the mercury benchmark assumes methyl mercury.

10. There is some uncertainty, based on the use of the literature bioconcentration factors and the modeled White Oak Creek surface water concentrations for the calculation of potential fish concentrations in White Oak Creek. The maximum bioconcentration factors and the modeled surface water data were used. The conservative evaluation resulted in unacceptable risks to piscivorous wildlife.

11. The radionuclide levels (^{137}Cs and ^{90}Sr) in fish from Impoundment 3513 were labeled "R-unusable" by the data validators, due to QC problems (including a lack of chain of custody forms). However, these data were used in the assessment.

12. The evaluation of radiation exposures for mink and kingfishers through external exposure and ingestion of contaminated prey was based on methodology in Blaylock (1993). This methodology was developed for freshwater biota, not terrestrial organisms. Therefore, use of this methodology propagates uncertainties in the exposure estimates. These uncertainties include:

    - assumption of no bioaccumulation in mink or kingfisher,
    - absorbed fraction of beta and gamma doses to mink and kingfisher assumed to be equal to large fish, and
    - external exposure to mink based on average measurements at the impoundment bank.

13. Floodplain soils and sediments in White Oak Creek within Waste Area Grouping 1 will be evaluated in a later Waste Area Grouping 1 integrated assessment.

6. MODELING PARAMETERS AND RESULTS

Tables C6.1-C6.7 present the modeling parameters used for SIOU and the results.

Table C6.1. Radionuclide emissions during the year 1994, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Nuclide	Class	Size	Source No. 1 Ci/y	Total Ci/y
Americium-241	W	1.00	$1.0 \times 10^{-2}2$	1.0×10^{-2}
Cobalt-60	Y	1.00	2.0×10^{-2}	2.0×10^{-2}
Europium-154	W	1.00	1.0×10^{-2}	1.0×10^{-2}
Plutonium-241	Y	1.00	1.0×10^{-1}	1.0×10^{-1}
Uranium-235	Y	1.00	1.0×10^{-2}	1.0×10^{-2}
Cesium-137	D	1.00	6.5×10^{-1}	6.5×10^{-1}
Strontium-90	D	1.00	1.4×10^{-1}	1.4×10^{-1}

Site information:
- Temperature: 10°C
- Precipitation: 100 cm/y
- Mixing height: 1,000 m

cm = centimeter
°C = degree Celsius
m = meter
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
y = year

Table C6.2. Organ dose and pathway effective dose equivalent summaries, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Organ dose equivalent summary	
Organ	Selected individual (mrem/y)
Gonads	2.02×10^3
Breast	5.87×10^2
R mar	1.12×10^4
Lungs	1.43×10^4
Thyroid	5.97×10^2
Endost	1.26×10^5
Rmndr	5.90×10^3
Effec	9.22×10^3

Pathway effective dose equivalent summary	
Pathway	Selected individual (mrem/y)
Ingestion	3.58×10^2
Inhalation	8.65×10^3
Air immersion	4.93×10^{-2}
Ground surface	2.17×10^2
Internal	9.01×10^3
External	2.17×10^2
Total	9.22×10^3

mrem = millirem
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
y = year

Table C6.3. Nuclide effective dose equivalent summary, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Nuclide	Selected individual (mrem/y)
Americium-241	6.57×10^3
Cobalt-60	1.35×10^2
Europium-154	5.59×10^1
Plutonium-241	6.36×10^2
Uranium-235	1.51×10^3
Cesium-137	1.72×10^2
Strontium-90	1.43×10^2
Total	9.22×10^3

mrem = millirem
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
y = year

Table C6.4. Cancer and pathway risk summaries, Waste Area Grouping 1
SIOU, ORNL, Oak Ridge, Tennessee

Cancer risk summary	
Cancer	Selected individual total lifetime fatal cancer risk
Leukemia	1.16×10^{-2}
Bone	5.69×10^{-3}
Thyroid	2.17×10^{-4}
Breast	1.79×10^{-3}
Lung	2.48×10^{-2}
Stomach	1.12×10^{-3}
Bowel	5.72×10^{-4}
Liver	1.99×10^{-2}
Pancreas	8.75×10^{-4}
Urinary	5.77×10^{-4}
Other	1.07×10^{-3}
Total	6.81×10^{-2}

Pathway risk summary	
Pathway	Selected individual total lifetime fatal cancer risk
Ingestion	6.18×10^{-3}
Inhalation	5.67×10^{-2}
Air immersion	1.19×10^{-6}
Ground surface	5.18×10^{-3}
Internal	6.29×10^{-2}
External	5.18×10^{-3}
Total	6.81×10^{-2}

ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

Table C6.5. Nuclide risk summary, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Nuclide	Selected individual total lifetime fatal cancer risk
Americium-241	3.36×10^{-2}
Cobalt-60	3.38×10^{-3}
Europium-154	1.37×10^{-3}
Plutonium-241	2.43×10^{-3}
Uranium-235	2.04×10^{-2}
Cesium-137	4.51×10^{-3}
Strontium-90	2.41×10^{-3}
Total	6.81×10^{-2}

ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

Table C6.6. Individual effective dose equivalent rate, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(mrem/year) (all radionuclides and pathways)

Distance (m)		
White Oak Creek 10	White Oak Dam 2590	Clinch River 3505
9.2×10^3	2.5×10^2	2.5×10^2

mrem = millirem
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

Table C6.7. Individual lifetime risk (deaths), Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

(all radionuclides and pathways)

Distance (m)		
White Oak Creek 10	White Oak Dam 2590	Clinch River 3505
6.8×10^{-2}	4.5×10^{-3}	4.5×10^{-3}

ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

Using Equation (C6.1), the E_{10} factor calculated, the contaminant concentrations (α), and the area of the surface impoundment (A), the emission rate may be calculated.

For Impoundment 3524,

$A = 295 \text{ ft} \cdot 95 \text{ ft}$
$A = 28{,}025 \text{ ft}^2 = 2{,}605 \text{ m}^2$

$$R_{10} = \left[36.8 \frac{\text{mg}}{\text{m}^2\text{hour}}\right] \left[2{,}605 \text{ m}^2\right] \left[\alpha_i \frac{\text{pCi}}{\text{g}}\right] \left[\frac{1\text{g}}{1{,}000 \text{ mg}}\right] \left[\frac{8{,}760}{\text{year}}\right]$$

$$R_{10} = 8.4 \times 10^5 \cdot \alpha \frac{\text{pCi}}{\text{year}}$$

$$^{241}Am: \quad R_{10} = \left[8.4 \times 10^5\right] \left[106{,}669 \ \frac{pCi}{g}\right] \left[\frac{Ci}{10^{12} \ pCi}\right] = 0.09 \ Ci/year$$

$$^{60}Co: \quad R_{10} = \left[8.4 \times 10^5\right] \left[28{,}457\right] \left[\frac{1}{10^{12}}\right] = 0.02 \ Ci/year$$

$$^{90}Sr: \quad R_{10} = \left[8.4 \times 10^5\right] \left[172{,}148\right] \left[\frac{1}{10^{12}}\right] = 0.14 \ Ci/year$$

$$^{137}Cs: \quad R_{10} = \left[8.4 \times 10^5\right] \left[768{,}087\right] \left[\frac{1}{10^{12}}\right] = 0.65 \ Ci/year$$

$$^{154}Eu: \quad R_{10} = \left[8.4 \times 10^5\right] \left[12{,}392\right] \left[\frac{1}{10^{12}}\right] = 0.01 \ Ci/year$$

Assumptions:

1. Assume the average particle size is 0.5 mm.

2. Assume the ratio of the area of the nonerodible elements to the total area of the soil is 0.1. Therefore, Lc = 0.1 and:

$$\frac{U*_t \text{ corrected}}{U*_t \text{ uncorrected}} = 5$$

Calculation:

Using Assumption 1, the uncorrected threshold friction velocity is 50 cm/second. The corrected threshold friction velocity can be found using Assumption 2.

$$\frac{U*_t \text{ corrected}}{U*_t \text{ uncorrected}} = 5$$

$U*_t$ corrected $= 5 \cdot 50$ cm/second
$= 250$ cm/second

Because the threshold friction velocity is >75 cm/second, a limited erosion model will be used.

The emission rate from surface contamination can be estimated by the following equation:

$$R_{10} = \alpha \cdot E_{10} \cdot A \qquad \text{(C6.1)}$$

R_{10} = emission rate of contaminant (mass/time)
α = contaminant concentration (mass/mass)
E_{10} = annual average respirable emission factor (mass/source extent)
A = source extent

For limited erosion potential, E_{10} may be found from:

$$E_{10} = 0.83 \frac{f \cdot P(u^{+}) \cdot (1-v)}{(PE/50)^2} \qquad \text{(C6.2)}$$

E_{10} = emission factor, mg/m^2 hour
f = frequency of disturbance per month
$P(u^t)$ = erosion potential, where u^t is the fastest mile of wind

V = fraction of contaminated surface covered by continuous vegetation, assume V = 0
PE = Thornthwaites Precipitation Evaporation Index used as a measure of average soil moisture content

The erosion potential, $P(u^t)$, is calculated from:

$$P(u^+) = 6.7\ (u^+ - u_t),\ u^+ \geq u_t$$
$$P(u^+) = 0\ (u^+ - u_t),\ u^+ < u_t$$

u_t = erosion threshold wind speed at a height of 7 m.

The corrected threshold friction velocity, 250 cm/second, can be converted to u_t from the following:

$$\frac{u(Z)}{u*_t} = \frac{1}{0.4} \ln (Z/Zo)$$

u = wind speed at height Z
Z = height above surface, 7 m
U* = corrected threshold friction velocity, 250 cm/second
Zo = roughness height, 70 cm for institutional buildings

Therefore:

$$u(Z) = \left[2.5\ \frac{m}{s}\right]\left[\frac{1}{0.4}\right] \ln \left[\frac{700\ cm}{70\ cm}\right]$$

$$u(Z) = 14.4\ m/second$$

The fastest mile observed is assumed to be 21.8 m/second for the Knoxville area.

$$P(u^+) = 6.7\ (21.8 - 14.4)$$
$$P(u^+) = 49.6 \text{ m/second}$$

The PE index for the region is 116. Assume an average of 5 disturbances per month.

Therefore, E_{10} is calculated to be:

$$E_{10} = 0.83\ \frac{\left[5\right]\left[49.6\ \frac{m}{second}\right]\left[1 - 0\right]}{(116/50)^2}$$

$$E_{10} = 36.8 \text{ mg/m}^2 \cdot \text{hour}$$

Using Equation (C6.1), the E_{10} factor calculated, the contaminant concentrations (α), and the area of the surface impoundment (A), the emission rate may be calculated.

For Impoundment 3524,

$$A = 295 \text{ ft} \cdot 95 \text{ ft}$$
$$A = 28{,}025 \text{ ft}^2 \simeq 2{,}605 \text{ m}^2$$

$$R_{10} = \left[36.8\frac{mg}{m^2\ hour}\right]\left[2{,}605\ m^2\right]\left[\alpha_i\frac{pCi}{g}\right]\left[\frac{1g}{1{,}000\ mg}\right]\left[\frac{8{,}760}{year}\right]$$

$$R_{10} = 8.4 \times 10^5 \cdot \alpha\ \frac{pCi}{year}$$

^{241}Am: $R_{10} = \left[8.4 \times 10^5\right]\left[106{,}669\ \frac{pCi}{g}\right]\left[\frac{Ci}{10^{12}\ pCi}\right] = \frac{0.09\ Ci}{year}$

^{60}Co: $R_{10} = \left[8.4 \times 10^5\right]\left[28{,}457\right]\left[\frac{1}{10^{12}}\right] = \frac{0.02\ Ci}{year}$

^{90}Sr: $R_{10} = \left[8.4 \times 10^5\right]\left[172{,}148\right]\left[\frac{1}{10^{12}}\right] = \frac{0.14\ Ci}{year}$

^{137}Cs: $R_{10} = \left[8.4 \times 10^5\right]\left[768{,}087\right]\left[\frac{1}{10^{12}}\right] = \frac{0.65\ Ci}{year}$

$$^{154}Eu: \quad R_{10} = \left[8.4 \times 10^5\right] \left[12{,}392\right] \left[\frac{1}{10^{12}}\right] = \frac{0.01 \text{ Ci}}{\text{year}}$$

7. GROUNDWATER MODELING PARAMETERS, ASSUMPTIONS, AND RESULTS

7.1 OBJECTIVE OF MODELING STUDY

The objective of the groundwater modeling analysis conducted for the Waste Area Grouping 1/Surface Impoundments was to support ecological- and human health risk assessments aimed at quantitatively evaluating proposed remedial alternatives. As part of this study, groundwater flow and solute transport models were employed to predict constituent concentrations in White Oak Creek originating from the contaminated sediment beneath the impoundments. Predictive simulations were performed for Alternatives 1, 2, and 3. Modeling was not required for the evaluation of Alternatives 4, 5, and 6 (see Sections 3.4 and 3.5). A thorough description of the six remedial alternatives can be found in Sections 4 and 5 of the RI/FS document.

Because of the uncertainties associated with the hydrogeologic system underlying the surface impoundments and the leaching characteristics of the contaminated sediment, conservative assumptions were applied when possible to ensure that the predicted constituent concentrations were not underestimated. These assumptions are documented in the following text.

7.2 MODELING APPROACH

A previously developed groundwater model developed by Ketelle (1995) provided the framework for the recent modeling analysis conducted for Waste Area Grouping 1. This model was developed using FTWORK, a numerical groundwater flow and solute transport code. Originally, the model was constructed to simulate saturated groundwater flow in the ORNL region to refine and quantify the hydrogeologic conceptual model.

As part of the current FS, the model developed by Ketelle (1995) was modified to simulate the migration of radioactive and chemical constituents in the saturated zone. Using the FTWORK model, predictive model runs were conducted to simulate the migration of constituents from the sediment underlying the surface impoundments to potential groundwater outfalls (i.e., White Oak Creek and the storm sewer adjacent to the impoundments). This allowed the calculation of constituent mass-loading rates at these outfalls to support the quantitative evaluation of the proposed remedial alternatives.

For several of the alternatives, the contaminated sediment beneath Impoundment 3524 is expected to be above the water table. Because the FTWORK groundwater modeling code is limited to the simulation of fully saturated conditions (i.e., below the water table), other

groundwater modeling codes capable of simulating unsaturated conditions were employed during the evaluation of these alternatives.

For those alternatives in which Impoundment 3524 is expected to be above the water table, the Hydrologic Evaluation of Landfill Performance (HELP) model was used to predict the groundwater infiltration rate through the caps proposed for Alternatives 2 and 3. Based upon these predicted infiltration rates, the Disposal Unit Source Term (DUST) model was used to simulate the leaching of contaminants from the consolidated sediments and the migration of the dissolved constituents to the water table. This process was conducted for each of the COC. Using time-dependant concentrations calculated using the DUST model, the FTWORK model was used to simulate the transport of the constituent in the saturated zone.

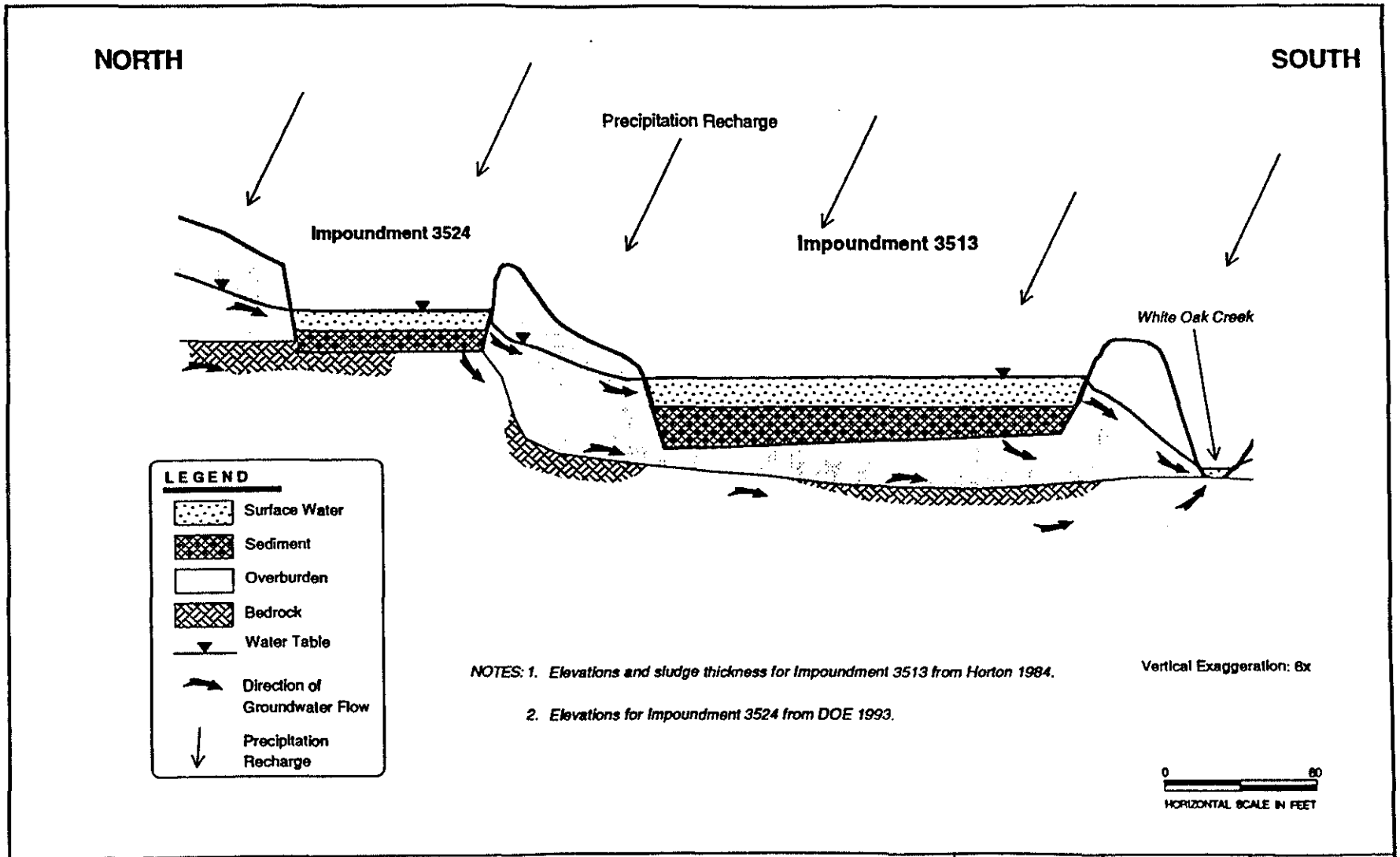
A more detailed description of the modeling approach and the three modeling codes employed in the analysis is provided below.

7.2.1 Saturated Flow and Transport Model (FTWORK)

The computer modeling code, FTWORK, is a block-centered finite difference model developed by Faust et al. (1993) for the Savannah River Laboratory. The code simulates one-, two-, and three-dimensional steady-state and transient groundwater flow and transient, single-species solute transport in saturated media. This code allows the simulation of heterogeneous and anisotropic conditions. In addition, the code is designed to simulate the following transport processes: advective transport, hydrodynamic dispersion, first order decay (chemical, biological, or radioactive), and linear and non-linear equilibrium adsorption.

The FTWORK model developed by Ketelle (1995) simulates groundwater flow in the stratigraphic units underlying the ORNL facility. The model is discretized into a series of finite-difference cells consisting of 66 rows, 81 columns, and 5 layers. Hydraulic head is calculated at the center of each of these cells. Boundary conditions were specified in the model to represent precipitation recharge, White Oak Creek, First Creek, subsurface storm sewers, and groundwater divides. Further details concerning the actual development of the groundwater flow model may be found in Ketelle (1995).

Figure C7.1 illustrates the conceptual model that is simulated in the impoundments region by the Ketelle (1995) groundwater flow model. As shown in the figure, water enters the localized groundwater flow system near the impoundments through precipitation recharge and upgradient groundwater sources. Water is also added to the system through periodic discharge of water into Impoundment 3524. This water is added during dry periods to keep a column of water above the contaminated sediment for the purpose of radioactive shielding. The injection



JE Fig. C7.1	**Cross-section illustrating the hydrogeologic conceptual model** DOE — ORNL, WAG 1 Surface Impoundments — Oak Ridge, Tennessee	DOCUMENT ID 35H830 4003-15 / RI/FS	DRAWING ID 94-10364 PD3-B	DRAWING DATE: FEBRUARY 27, 1995 Ba

of water into Impoundment 3524 may cause mounding of the groundwater in the region. As shown in Figure C7.1, most of the groundwater that flows through the impoundments eventually discharges into White Oak Creek. Additional groundwater is discharged to a subsurface storm sewer that is located along the western edge of Impoundment 3524. This storm sewer is not represented in Figure C7.1.

The flow model developed by Ketelle (1995) was modified to simulate solute transport at the Waste Area Grouping 1 Surface Impoundments. This was accomplished by initializing a source concentration representing each constituent at the impoundments and by assigning solute transport parameters in the model. These transport parameters represent properties characterizing the constituent and/or the geologic media including: (1) dispersivity; (2) porosity; (3) adsorption (i.e., soil/water distribution coefficient); (4) bulk density; and (5) first order radioactive decay.

The source concentrations at the impoundments were simulated using two different methods. For cases where the water table is predicted to be above the base of an individual surface impoundment (e.g., baseline), a source concentration was initialized in the model based upon measured sediment concentrations. Based upon these concentrations and the distribution coefficient assigned in the model, dissolved constituent concentration were calculated using Equation (C7.1). These dissolved concentrations were then assigned in the FTWORK model at the finite-difference cells corresponding to the sediment directly below the impoundment. Using these prescribed solute concentrations, the FTWORK code partitions mass into the solid phase (i.e., sediment) using Equation (C7.1).

$$S = K_d C \qquad \text{(C7.1)}$$

where:

S = concentration of adsorbed species (M/M);
K_d = distribution coefficient (L^3/M); and
C = concentration of dissolved species (M/L^3).

This method of initializing the source concentrations into the FTWORK model provides a mechanism for the source concentration to decay with time. In addition, it also allows the source concentration to decrease with time as mass is leached from the sediment. This allows the model to more accurately simulate actual site conditions.

To ensure conservative estimates of mass-loading rates into White Oak Creek and the storm sewer, source concentrations were initialized in the model based upon the upper 95% confidence interval of the sediment concentrations measured below the individual impoundments (see Sect. 3.1 in the RI). These estimated concentrations are probably much higher than the

average concentration observed in the impoundments. To further ensure that the model calculates conservative contaminant concentrations, the source concentrations assigned to the model were not adjusted to account for differences in volume between the sediment layer and the finite-difference cells. Because the finite-difference cells represent a larger volume, the mass represented in the model is greater than the actual contaminant mass at the base of each impoundment.

For two of the remedial alternatives that were simulated, the sediment in Impoundment 3524 is expected to be desaturated. Because FTWORK is limited to the simulation of saturated flow and transport, the HELP and DUST models were needed to simulate unsaturated groundwater flow and solute transport, respectively. After these models were applied to predict the mass leaching from the source units, FTWORK was used to simulate the transport of contaminants within the saturated zone. This was accomplished by assigning time-dependant concentrations predicted by the DUST model.

7.2.2 Infiltration Model (HELP)

The Hydrologic Evaluation of Landfill Performance (HELP) (EPA 1983) model is a public domain computer code developed by the Waterways Experiment Station for the EPA in 1983. It is a water balance model that simulates precipitation, runoff, evapotranspiration, and changes in water storage to determine infiltration. The HELP model was selected for this study because it is widely used, thoroughly tested, publicly available, and accepted by regulatory agencies. In addition, it typically overestimates the infiltration rate of water in the unsaturated zone thus providing conservative estimates of the infiltration rate through the unsaturated zone.

The HELP model contains default climatic data for various cities in the United States, including Knoxville, Tennessee, located approximately 20 miles from ORR. While the model contains only five years of historic precipitation data, it is capable of synthetically generating up to 20 years of data. Alternatively, actual measured data can be used.

Before applying the HELP model to predict infiltration through an engineered cap, the natural and man-made components of the system must be subdivided into a vertical sequence of distinct units. Each of these units must be classified as either a vertical percolation layer, a hydraulic barrier layer, or a lateral drainage. The vertical percolation layers can be used to represent soils and shot rock, the lateral drainage layers can be used to represent drains, and the hydraulic barrier layers can be used to represent synthetic liners. Hydraulic properties describing these units must be specified in the HELP model including: (1) soil classification; (2) porosity; (3) field capacity; (4) wilting point; and (5) hydraulic conductivity. The HELP model allows the user to use default values for each of these properties or to specify site-specific values. During

the current modeling analysis, site specific data were used in the HELP modeling analysis when available.

7.2.3 Mass-Leaching Model (DUST)

The Disposal Unit Source Term (DUST) (Sullivan 1993) model, developed at the Brookhaven National Laboratory, was used to estimate the rate and concentration of leachate released from desaturated waste material. The DUST simulates the leaching of constituents from a disposal unit, and the transport of these constituents vertically through the unsaturated zone. DUST was developed to assess the transport of radioactive nuclides; however, the code works equally well in describing the transport of chemical constituents. The DUST code incorporates options to model the rate of leachate generation through either a one-dimensional numerical model (finite difference) or a simpler analytical approach. The numerical option was applied for this effort, as this provided increased flexibility needed to adequately represent site-specific conditions. The input requirements associated with the application of the DUST numerical model option include:

- Material parameters - This includes partitioning coefficient (distribution coefficient) and bulk density values for each material represented in the model. Diffusion and dispersion coefficients may also be assigned in the model.

- Facility Coordinate Data - This data details the model vertical discretization and facilities surface area.

- Initial and Boundary Conditions - Initial constituent concentrations are required the establish the starting conditions for solute transport. In order to maximize the mass-loading rate at the water table, initial conditions were established at zero.

- Water Flow Parameters - The rate of water infiltration and the soil moisture conditions for distinct model layers was incorporated. This data was determined through the application of the EPA HELP model.

- Container Parameters - For this modeling effort the waste was considered to be one distinct container allowing for immediate constituent release.

- Wasteform Leaching Parameters - This portion of model input requires the selection of constituent release mechanisms, and the rate of the constituent available for release.

In each Waste Area Grouping 1 modeling application, the entire constituent source was assumed available for release and the release mechanism was assumed to be entirely dominated by the surface rinse method. No other release mechanisms or methods were considered as the surface rinse method in conjunction with the total constituent fraction is known to generate the highest and therefore most conservative estimates of leachate generation. By applying the surface rinse model, the modeler assumes that the total sum of constituents within the wasteform is available for release as soon as water contact occurs. Following container failure the constituents may be held on the wastes by adsorption, chemisorption, adhesion, and ion exchange among other factors. To account for these factors a partition factor was applied. A partition factor or waste distribution coefficient is an equilibrium ratio relating the amount on the wasteform to that in solution. The partition factor is a lumped parameter that covers many physical processes.

The initial mass of each constituent (source) considered was determined from Equation (C7.2) in conjunction with the upper 95% confidence interval of the measured soil concentrations.

$$M = CB_dV \tag{C7.2}$$

where

M = Mass of constituent (g);
C = Constituent concentration in the soil (g/g);
B_d = Bulk density of soil (g/cm^3); and
V = Volume of each waste container (cm^3).

The unsaturated flow modeling (i.e., DUST modeling) required the specification of constituent specific distribution coefficients for both the waste material and the underlying geologic material. Table C7.1 summarizes the distribution coefficients used for the predictive simulations. Site specific values were used when possible. Other K_d values were determined from a literature review (Looney, Grant, and King 1988; Sheppard and Thibault 1990). Distribution coefficients were determined for the organic constituents through the application of the following two equations (Looney, Grant, and King 1988):

$$K_d = K_{oc} \cdot f_{oc} \tag{C7.3}$$

$$\log K_{oc} = 0.79 \log K_{ow} - 1.71 \tag{C7.4}$$

where

K_{ow} = octanol-water partition factor (dimensionless);
K_{oc} = organic carbon-solution distribution coefficient (l^3/m); and
f_{oc} = fraction of organic carbon (dimensionless).

Table C7.1. Summary of distribution coefficients (K_d) used in predictive simulations, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Constituent	K_d of waste (mL/g)	K_d of aquifer (mL/g)
Arsenic	3[a]	3[a]
Beryllium	670[a]	670[a]
Mercury	$1.0 \times 10^{+4}$[b]	$1.0 \times 10^{+4}$[b]
Aroclor-1260	$2.63 \times 10^{+4}$[c]	$2.63 \times 10^{+4}$[c]
N-Nitroso-di-n-propylamine	1.71×10^{-2}[c]	1.71×10^{-2}[b]
Strontium	89[a]	15[d]

[a]Calculated based upon site-specific data summarized in Stansfield and Francis (1986) using Equation 1
[b]Looney, Grant, and King (1988)
[c]Calculated using Equation (C7.4) (assuming $f_{oc} = 0.005$)
[d]Sheppard and Thibault (1990)

g = gram
mL = milliliter
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

The specific model parameters considered in each remedial alternative and the resulting output will be presented in following sections.

7.3 PREDICTIVE SIMULATIONS

7.3.1 Alternative 1 (No Action)

Alternative 1 corresponds to the "no action" alternative. Alternative 1 was simulated based upon present conditions observed at the site. Because all four of the surface impoundments are currently saturated, the HELP and DUST models were not needed for the Alternative 1 analysis. Instead, the leaching and migration of contaminants were simulated by initializing a dissolved constituent concentration using the approach outlined in Section 2.1. Table C7.2 lists the concentrations that were initialized in the FTWORK model for Alternative 1.

Table C7.3 summarizes the results of the FTWORK simulations. Maximum mass-loading rates were recorded for White Oak Creek, the storm sewer adjacent to Impoundment 3524, and the combined total of the creek and the storm sewer. These rates were calculated by multiplying the predicted concentrations by the predicted groundwater flux rate into the creek. The maximum concentrations in White Oak Creek were calculated based on the following two assumptions: (1) all of the contaminant mass that enters the storm sewer will be discharged into the creek; and (2) the average flow rate in White Oak Creek is 5 ft^3/second.

Table C7.2. Summary of source terms initialized in the FTWORK model for Alternative 1, Waste Area Grouping I SIOU, ORNL, Oak Ridge, Tennessee

	UCL_{95} sediment concentration			Kd of sediment (mL/g)	Pore water concentration[a]		
	3524 (mg/kg)	3513 (mg/kg)	3539/40 (mg/kg)		3524 (μg/L)	3513 (μg/L)	3539/40 (μg/L)
Arsenic	1.10×10^1	ND	ND	3.16×10^0	3.48×10^3	ND	ND
Beryllium	6.10×10^2	4.00×10^1	1.10×10^1	6.70×10^2	9.10×10^2	5.97×10^1	1.64×10^1
Mercury	5.90×10^2	4.10×10^2	8.00×10^2	1.00×10^4	5.90×10^1	4.10×10^1	8.00×10^1
Aroclor-1260	ND	2.88×10^1	1.20×10^2	2.63×10^4	0.00	1.09×10^0	4.56×10^0
N-nitroso-di-n-Propylamine	2.30×10^1	2.60×10^1	3.40×10^0	7.10×10^{-2}	3.24×10^5	3.66×10^5	4.79×10^4
Strontium	1.40×10^5 (pCi/kg)	1.40×10^5 (pCi/kg)	1.40×10^2 (pCi/kg)	8.90×10^1	1.12×10^{-2}	1.12×10^{-2}	1.12×10^{-5}

[a]Calculated from the measured sediment concentrations using Equation (C7.1).

g = gram
Kd =
kg = kilogram
μg = microgram
mg = milligram
ND = nondetectable
ORNL = Oak Ridge National Laboratory
pCi = picocurie
SIOU = Surface Impoundments Operable Unit
UCL_{95} = 95th percentile upper confidence limit

Table C7.3. Summary of mass-loading rates predicted for Alternative 1, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Constituent	Predicted maximum mass-loading rate to White Oak Creek (μg/day)	Predicted maximum mass-loading rate to storm sewer (μg/day)	Predicted maximum total mass-loading rate (μg/day)	Predicted maximum concentration in White Oak Creek[a] (μg/L)
Arsenic	2.9×10^4	3.1×10^4	6.0×10^5	4.9×10^{-2}
Beryllium	4.1×10^4	4.5×10^4	8.3×10^4	6.8×10^{-4}
Mercury	3.4×10^3	3.3×10^0	3.4×10^3	2.8×10^{-4}
Aroclor-1260	1.4×10^1	8.6×10^{-4}	1.4×10^1	1.1×10^{-6}
N-nitroso-di-n-Propylamine	2.6×10^8	4.2×10^7	2.7×10^8	2.2×10^1
Strontium	4.5	1.5×10^{-1}	4.7	3.8×10^{-7}

[a]Calculations based upon the assumption that the flow in White Oak Creek is 5 ft^3/second.

ft = foot
L = liter
μg = microgram
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

Figure C7.2 illustrates the combined strontium 90 mass-loading rate in White Oak Creek and the storm sewer as a function of time. Note that the maximum concentration is obtained at the RME. After this time, the mass loading rate slowly decreases as the amount of strontium 90 is reduced due to mass leaching at the source and radioactive decay. Figure C7.3 illustrates a similar mass-leaching curve for mercury. Note that the maximum mass-loading rate is still not obtained after 5000 years. The large difference in the strontium 90 and mercury mass-loading curves is attributed to the difference in partitioning coefficients. The partitioning coefficient representing mercury in the sediment (i.e., 1,000 mL/g) is much higher than the value prescribed for strontium 90 (i.e., 89 mL/g). Consequently, strontium 90 is dissolved and is transported at much higher rates.

7.3.2 Alternative 2 (Simple Cap)

The remedial solution proposed in Alternative 2 consists of constructing multilayered caps over the four surface impoundments. The configuration of these caps is shown in Figure C7.4. The major components of the cap include a vegetative layer of soil underlain by shot rock. These two layers would overlie the contaminated sediment (see Sect. 5 of the RI/FS report).

Before predictive transport simulations were performed, the FTWORK groundwater flow model was used to evaluate whether the waste in Impoundment 3524 would be dewatered once water was no longer pumped into Impoundment 3524 and with the installation of the caps. To evaluate this scenario, constant head cells representing the impoundments in the original model (Ketelle 1995) were removed. The model predicted that the water table would drop approximately 5 feet below the base of Impoundment 3524; consequently, a vadose zone would be developed under this impoundment. The model predicted that the sediment beneath the other three impoundments would remain below the water table.

To evaluate the effectiveness of the multilayered caps, the HELP model was used to estimate the infiltration rate in the unsaturated zone. Figure C7.5 illustrates the vertical distribution of soil, shot rock, and contaminated sediment. These three material types were assigned in the model using vertical flow layers with different hydraulic properties. The parameters that describe these materials are listed in Table C7.4.

The results of the HELP modeling indicate that approximately 10 in./year of precipitation recharge would vertically infiltrate through the capped areas. This is higher than is expected for the capped areas given the nature of the proposed caps and previous estimates of the precipitation recharge rate in the area. In general, the HELP model overestimates groundwater infiltration rates thus producing a conservative estimate of cap effectiveness and groundwater infiltration rate. Although it is expected that 10 inches/year is much higher than the precipitation recharge rate for

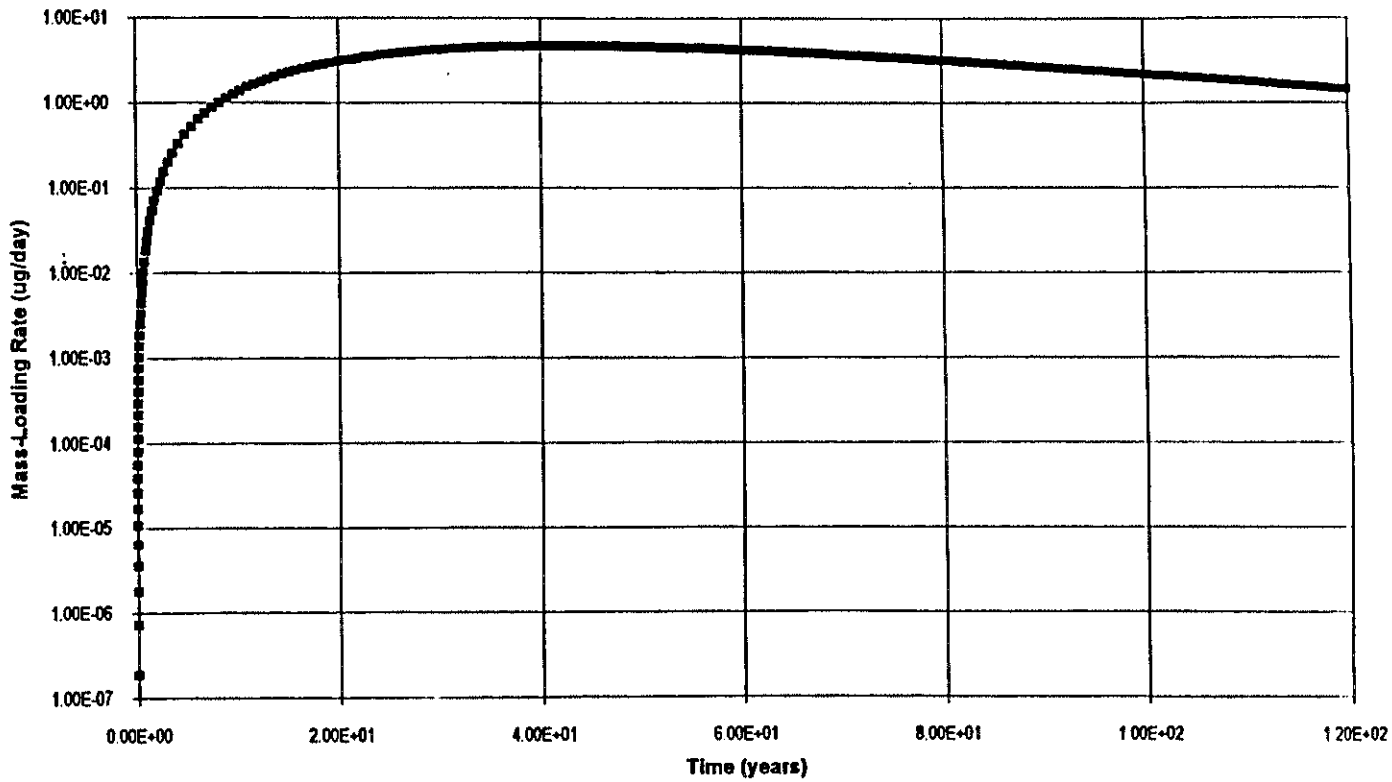


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Fig. C7.2

Total strontium-90 mass-loading rate - Alternative 1

DOE - ORNL, WAG 1, Surface Impoundments - Oak Ridge, Tennessee

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FEBRUARY 24, 1995

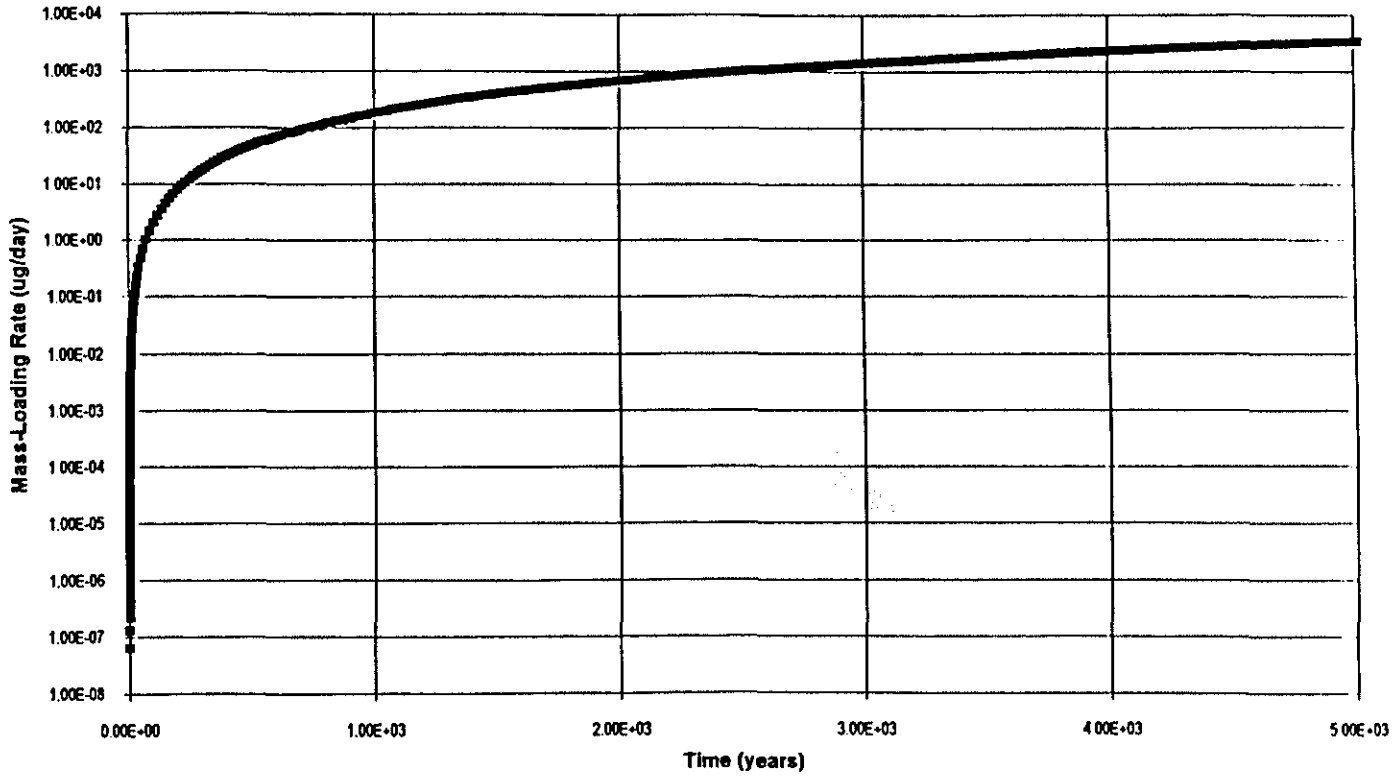

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Fig. C7.3

Total mercury mass-loading rate - Alternative 1

DOE - ORNL, WAG 1, Surface Impoundments - Oak Ridge, Tennessee

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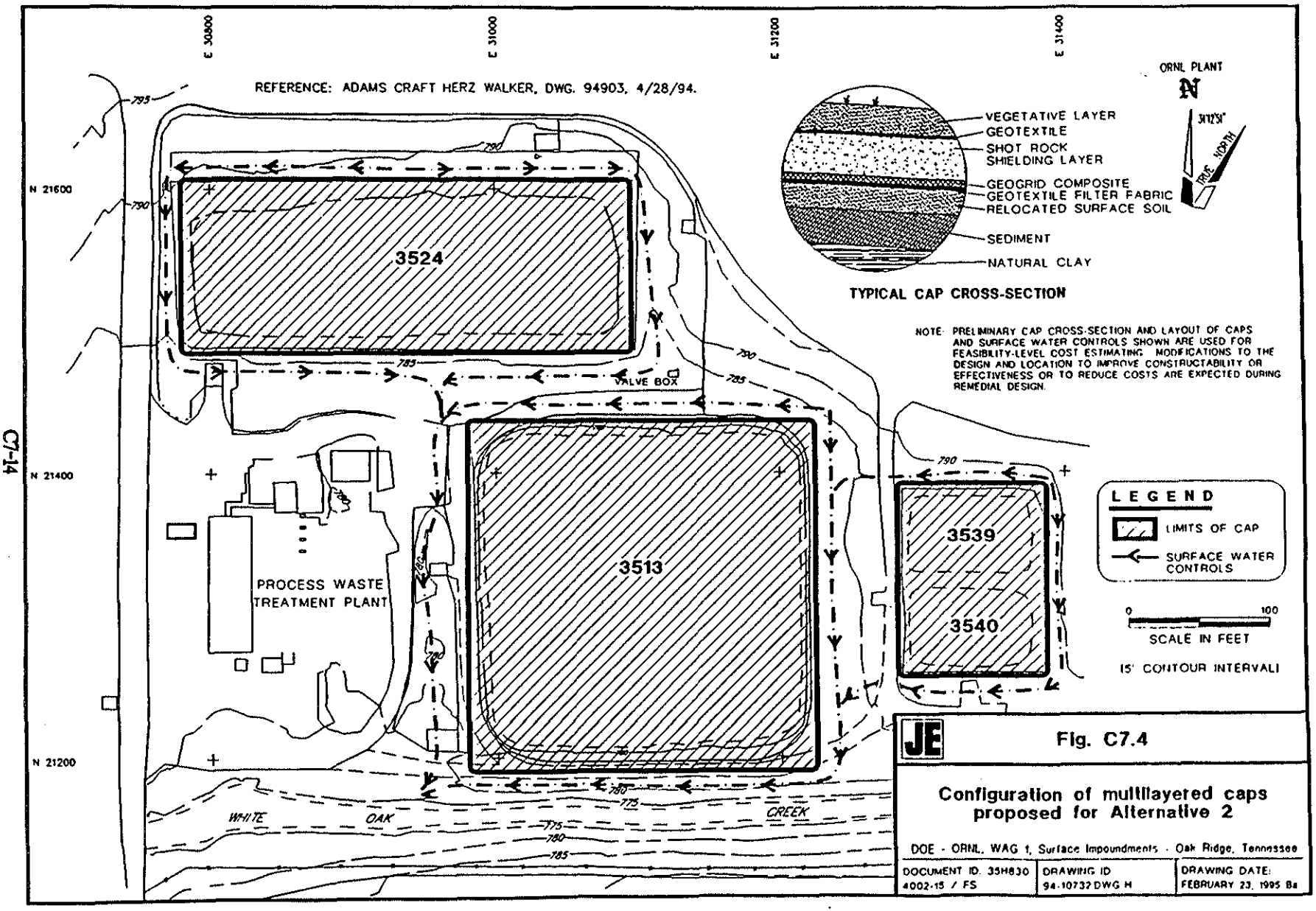

Fig. C7.4

Configuration of multilayered caps proposed for Alternative 2

DOE - ORNL, WAG 1, Surface Impoundments - Oak Ridge, Tennessee

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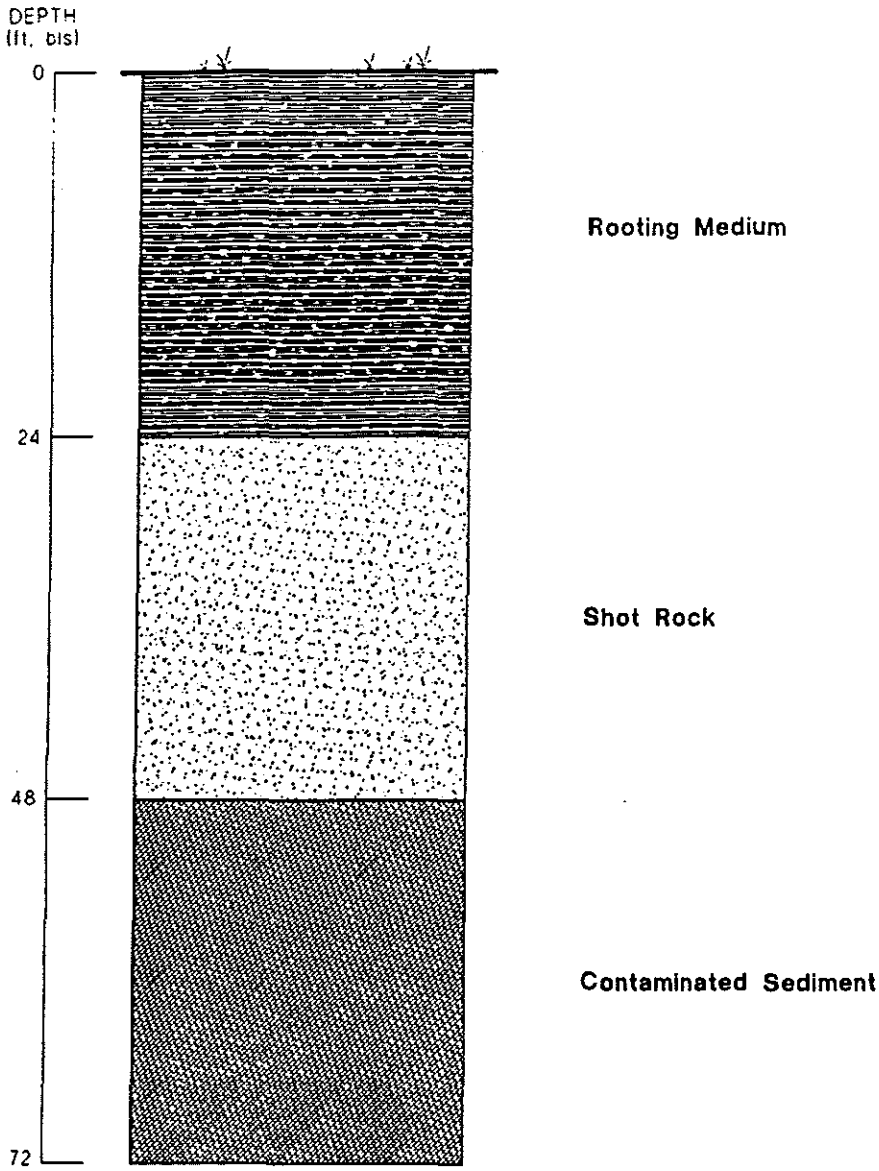

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C7.5

Layers assigned in the HELP model to represent the consolidation cell (Alternative 2)

DOE - ORNL, WAG 1, Surface Impoundments - Oak Ridge, Tennessee

DOCUMENT ID 35H830 4002-15 / FS	DRAWING ID. 95-11405.DWG	DRAWING DATE FEBRUARY 23, 1995 8:

Table C7.4. List of input parameters assigned in the HELP Model for Alternatives 2 and 3, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Description	Layer type	USCS	Porosity	Field capacity	Wilting point	Hydraulic conductivity (cm/second)
Rooting medium	Vertical percolation	CL	0.4640	0.3104	0.1875	2.69×10^{-4}
Drain	Lateral drainage	SP	0.4170	0.0454	0.0200	1.00×10^{-2}
Shot rock	Vertical percolation	GP	0.3500	0.0454	0.0200	1.00×10^{-1}
Infiltration barrier	Barrier soil liner	CL-CH	0.4300	0.3663	0.2802	1.00×10^{-7}
Contaminated soil	Vertical percolation	CL	0.3949	0.2797	0.1885	3.20×10^{-6}
Contaminated sediment	Vertical percolation	Waste	0.5200	0.2942	0.1400	2.00×10^{-4}

CH = fat clay
CL = clay
cm = centimeter
GP = poorly graded clay
HELP = Hydrologic Evaluation of Land Performance
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
SP = poorly graded sand
USCS = Unified Soil Classificaiton System

the capped areas, this value was used in the modeling analysis because it provides a conservative estimate of the amount of mass that is leached from the unsaturated sediment.

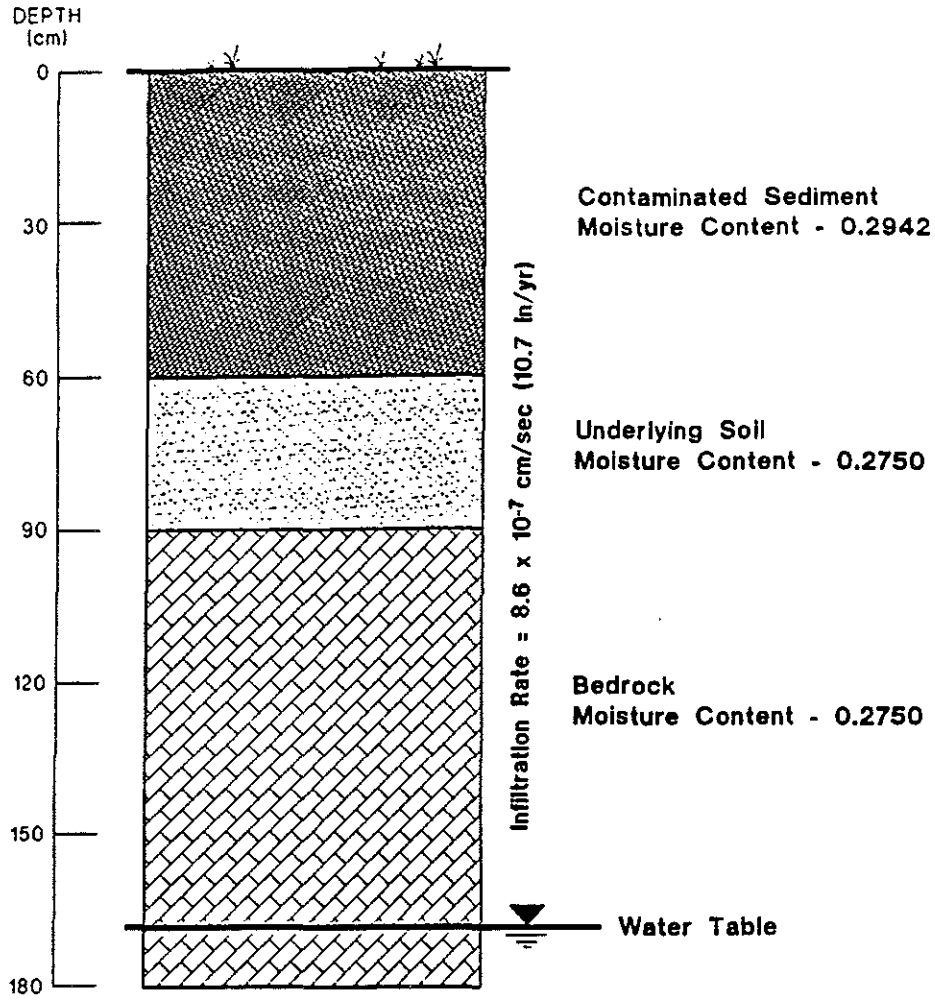
Using the infiltration rate of 10 in./year predicted by the HELP model, the DUST model was used to simulate contaminant mass-leaching from Impoundment 3524 to the water table. To perform these simulations, the DUST model was divided into layers representing the contaminated waste, underlying soil, and unsaturated bedrock (Fig. C7.6). For Impoundment 3524, the DUST model simulations provided estimates of the contaminant loading rates and leachate concentration at the water table.

The FTWORK model was employed to simulate the migration of dissolved constituents in the groundwater and to predict mass-loading rates into White Oak Creek and the storm sewer adjacent to Impoundment 3524. Because the sediment in Impoundments 3513, 3539, and 3540 is expected to be below the water table, the constituent source at these impoundments was initialized using the same methodology and initial concentrations as discussed in Section 3.1. Because a vadose zone is predicted to exist beneath Impoundment 3524 for Alternative 3, the results of the DUST simulations were was used to specify the time-dependant leaching of contaminants from the unsaturated zone.

Table C7.5 illustrates the maximum mass-loading rates to White Oak Creek and the storm sewer adjacent to the impoundments. In addition, the table lists the maximum concentration that is expected in White Oak Creek. Note that for most of the constituents, the predicted concentrations are much lower than for Alternative 1. This is because the unsaturated sediments underlying Impoundment 3524 retard the migration of constituents. If Impoundment 3524 were actually saturated during some periods after the multilayered caps were installed, the predicted constituent concentrations would be higher than those shown on Table C7.5 and lower than those shown on Table C7.6.

7.3.3 Alternative 3 (Consolidation Cell)

As described in Section 5 (RI/FS Report), the remedial solution proposed in Alternative 3 consists of designing a consolidation cell at the present location of Impoundment 3524. A cross section illustrating the proposed design of the consolidation cell is shown in Figure C7.7. This disposal cell would be used to contain the contaminated sediment that currently exists in all four of the impoundments. The cell would be designed in a manner which ensured that the sediment would be above the water table at all times. Consequently, the only mechanism for the leaching of mass from the source zone is through vertical percolation of water in the unsaturated zone.



NOTE: DUST model was discretized vertically into individual nodes 1 cm in height.

Fig. C7.6

Layers assigned in the DUST model to represent mass-leaching from Impoundment 3524 (Alternative 2)

DOE - ORNL, WAG 1, Surface Impoundments - Oak Ridge, Tennessee

DOCUMENT ID 35H830 4002-15 / FS	DRAWING ID. 95-11425.DWG	DRAWING DATE: FEBRUARY 24, 1995 B4

Table C7.5. Summary of mass-loading rates predicted for Alternative 2, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Constituent	Predicted maximum mass-loading rate to White Oak Creek (μg/day)	Predicted maximum mass-loading rate to storm sewer (μg/day)	Predicted maximum total mass-loading rate (μg/day)	Predicted maximum concentration in White Oak Creek[a] (μg/L)
Arsenic	1.7×10^{4}	3.6×10^{4}	4.8×10^{4}	3.9×10^{-3}
Beryllium	5.6×10^{3}	4.6×10^{0}	5.6×10^{3}	4.6×10^{-4}
Mercury	9.4×10^{3}	3.2×10^{1}	9.5×10^{3}	7.8×10^{-4}
Aroclor-1260	1.3×10^{0}	1.2×10^{-3}	1.3×10^{0}	1.1×10^{-7}
N-nitroso-di-n-Propylamine	2.7×10^{8}	1.6×10^{7}	2.8×10^{8}	2.3×10^{1}
Strontium	8.2×10^{-1}	2.7×10^{-1}	7.6×10^{-1}	6.2×10^{-8}

[a]Calculations based upon the assumption that the flow in White Oak Creek is 5 ft^3/second.

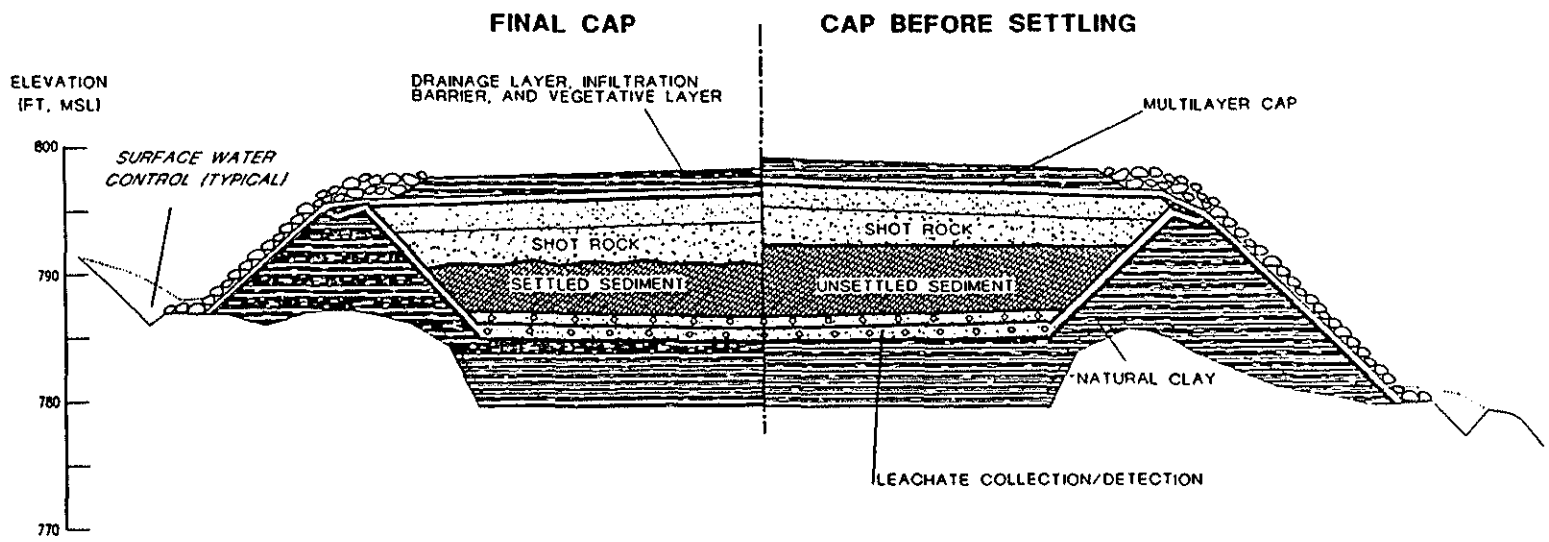
ft = foot
L = liter
μg = microgram
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

Table C7.6. Summary of mass-loading rates predicted for Alternative 3, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Constituent	Predicted maximum mass-loading rate to White Oak Creek (μg/day)	Predicted maximum mass-loading rate to storm sewer (μg/day)	Predicted maximum total mass-loading rate (μg/day)	Predicted maximum concentration in White Oak Creek[a] (μg/L)
Arsenic	1.2×10^3	2.8×10^3	3.8×10^3	3.1×10^{-4}
Beryllium	ND	ND	ND	ND
Mercury	ND	ND	ND	ND
Aroclor-1260	ND	ND	ND	ND
N-nitroso-di-n-propylamine	1.2×10^6	2.8×10^6	3.8×10^6	3.1×10^{-1}
Strontium	ND	ND	ND	ND

[a]Calculations based upon the assumption that the flow in White Oak Creek is 5 ft^3/second.

ft = foot
L = liter
μg = microgram
ND = predicted to be nondetectable by model
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit



PROCESS WASTE POND 3524 - CONSOLIDATION CELL

NOTE. PRELIMINARY CAP CROSS-SECTION SHOWN IS USED FOR FEASIBILITY-LEVEL COST ESTIMATING MODIFICATIONS TO THE DESIGN TO IMPROVE CONSTRUCTABILITY OR EFFECTIVENESS OR REDUCE COSTS ARE EXPECTED DURING REMEDIAL DESIGN

0 30
HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION. 2X

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Fig. C7.7

Cross-section illustrating the construction details for the consolidation cell proposed in Alternative 3

DOE - ORNL, WAG 1, Surface Impoundments - Oak Ridge, Tennessee

DOCUMENT ID 35H830 4002-15 / FS	DRAWING ID 94-10999 DWG D	DRAWING DATE FEBRUARY 23, 1995 Bs

The HELP model was used to predict the groundwater infiltration rate through the consolidation cell. To perform this simulation, the engineered cell was divided into layers corresponding to the various components of the cap such as geomembranes, shot rock, and sediment (Fig. C7.8). To ensure that conservative estimates of the infiltration rate were predicted, it was assumed that the leachate detection layer at the base of the consolidation cell failed. For Alternative 3, an infiltration rate of 0.89 in./year was predicted by the model.

Using the infiltration rate predicted by the HELP model, the DUST model was used to simulate contaminant mass-leaching from the consolidation cell to the water table. To perform these simulations, the DUST model was divided into layers representing different material properties (Fig. C7.9).

The DUST model simulations provided estimates of the contaminant loading rates and leachate concentrations at the water table for different times. The simulations were conducted for 5000 yrs into the future. With the exception of arsenic and n-nitroso-di-n-propylamine the maximum leachate concentration predicted by the DUST model for individual constituents was lower than 2×10^{-27} μg/L. Constituent concentrations of this magnitude are not detectable. These concentrations would be lower in the groundwater entering White Oak Creek due to dilution. The maximum leachate concentrations predicted for arsenic and n-nitroso-di-n-propylamine are 6,500 and 102,000 μg/L, respectively. These constituent concentrations are relatively high because both arsenic and n-nitroso-di-n-propylamine are characterized by low K_d values (Table C7.1).

Because arsenic and n-nitroso-di-n-propylamine are predicted to be the only constituents that are detectable in the groundwater, FTWORK simulations were only conducted for these two constituents. The constituent source was initialized in the model by specifying leachate concentrations predicted using the DUST model and the infiltration rate estimated using the HELP model. As with the DUST simulations, the FTWORK simulations were used to make predictions up to 5000 years into the future.

Table C7.6 illustrates the maximum mass-loading rates to White Oak Creek and the storm sewer adjacent to the impoundments. In addition, the table lists the maximum concentration that is expected in White Oak Creek. As expected, the predicted concentrations are lower for Alternative 3 than Alternatives 1 and 2. Even though both arsenic and n-nitroso-di-n-propylamine are characterized by low distribution coefficients, the clay liner that will be emplaced for Alternative 3 is predicted to significantly retard both constituents.

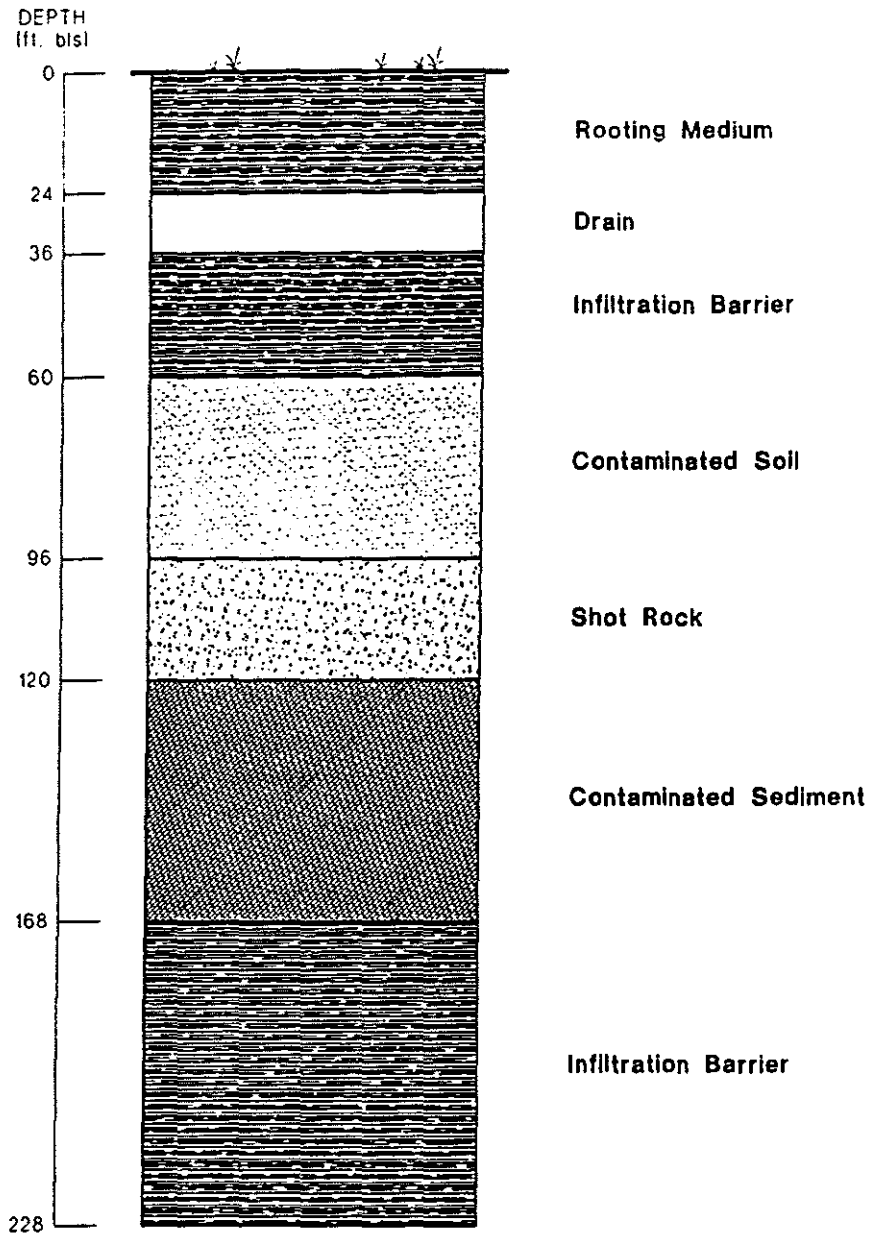

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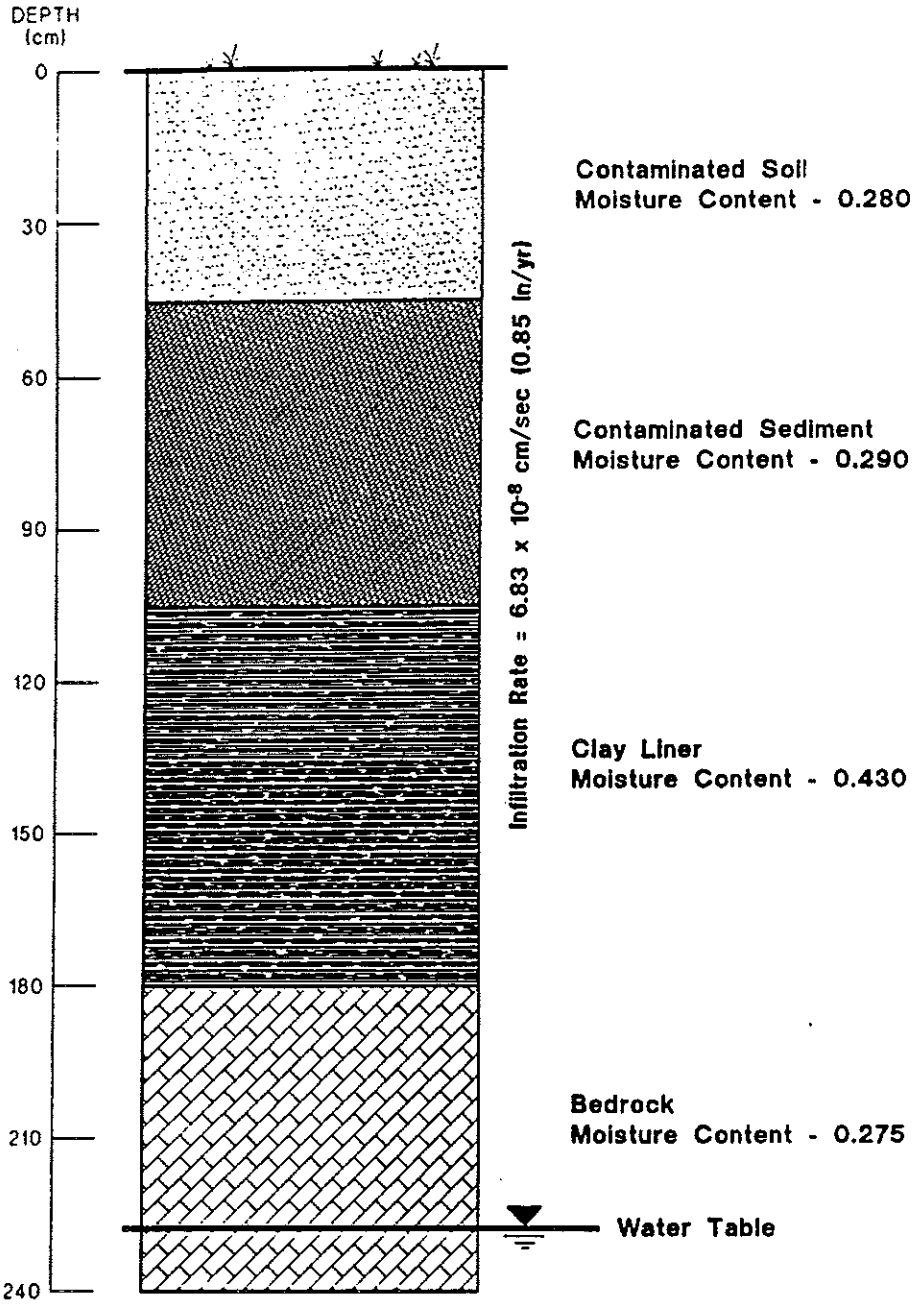
Fig. C7.8

Layers assigned in the HELP model to represent the consolidation cell (Alternative 3)

DOE - ORNL, WAG 1, Surface Impoundments - Oak Ridge, Tennessee

DOCUMENT ID. 35H830 4002-15 / FS	DRAWING ID. 95-11406.DWG	DRAWING DATE- FEBRUARY 24, 1995 B1



NOTE: DUST model was discretized vertically into individual nodes 2 cm in height.

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Fig. C7.9

Layers assigned in the DUST model to represent mass-leaching from the consolidation cell (Alternative 3)

DOE - ORNL, WAG 1, Surface Impoundments - Oak Ridge, Tennessee

DOCUMENT ID 35H830 4002-15 / FS	DRAWING ID. 95-11426.DWG	DRAWING DATE FEBRUARY 23, 1995 Ba

7.3.4 Alternative 4 (Consolidation Cell with Waste Stabilization)

Alternative 4 is identical to Alternative 3, with the exception that for Alternative 4 the consolidated, contaminated sediment will be mixed with cement and fly ash to stabilize the waste. The proposed stabilization will reduce the leachability of the waste, thus lowering the future contaminant concentrations in the groundwater.

Compared to Alternative 3, the stabilization of the waste will enhance the overall effectiveness of the consolidation cell. However, because the leaching characteristics (i.e., partitioning coefficient) of the stabilized waste is unknown, it is difficult to quantify the increase in effectiveness. At worst, the stabilization will provide a marginal decrease in contaminant mass-leaching rates compared to Alternative 3. Because the simulated contaminant mass-loading rates to White Oak Creek and the storm sewer are low for Alternative 3, predictive simulations were deemed unnecessary Alternative 4.

7.3.5 Alternative 5 and 6 (Waste Removal)

Alternatives 5 and 6 consist of removing the contaminated sediment from all four surface impoundments and disposing of this waste in an off-site (Alternative 5) or on-site (Alternative 6) disposal cell. Because the waste will be completely removed from its current location, it is assumed that additional contaminant mass will not migrate from the impoundments to the groundwater system. Consequently, the future mass-loading rate to White Oak Creek is predicted to be zero; therefore, groundwater modeling was not performed for Alternatives 5 and 6.

7.4 SUMMARY AND CONCLUSIONS

Table C7.7 summarizes the results of the predictive solute transport simulations performed for the Waste Area Grouping 1/Surface Impoundments. As expected, the results of these simulations indicate that Alternative 3 provides the greatest protection to White Oak Creek. Furthermore, the model predicts that, with the exception of arsenic and N-nitroso-di-n-propylamine, constituent concentrations at White Oak Creek will be reduced to non-detectable levels for Alternative 3. Arsenic and N-nitroso-di-n-propylamine are predicted to be present at higher concentrations because of the relatively low distributions coefficients associated with these constituents. It is expected that Alternative 4 will be even more protective of the creek than Alternative 3.

The modeling analysis described in this document is appropriate for the purpose of evaluating and comparing remedial alternatives. Groundwater modeling provides the only tool for quantitatively evaluating the future effectiveness of the proposed remedial alternatives.

Table C7.7. Summary of model simulations performed for remedial Alternatives 1, 2, and 3, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Constituent	Alternative 1		Alternative 2		Alternative 3	
	Predicted maximum mass-loading rate (μg/day)	Predicted concentration in White Oak Creek (μg/L)	Predicted maximum mass-loading rate (μg/day)	Predicted concentration in White Oak Creek[a] (μg/L)	Predicted maximum mass-loading rate (μg/day)	Predicted concentration in White Oak Creek (μg/L)
Arsenic	6.0×10^{5}	4.9×10^{-2}	4.8×10^{4}	3.9×10^{-3}	3.8×10^{3}	3.1×10^{-4}
Beryllium	8.3×10^{4}	6.8×10^{-3}	5.6×10^{3}	4.6×10^{-4}	ND	ND
Mercury	3.4×10^{3}	2.8×10^{-4}	9.5×10^{3}	7.8×10^{-4}	ND	ND
Aroclor-1260	1.4×10^{1}	1.1×10^{-6}	1.3×10^{0}	1.1×10^{-7}	ND	ND
N-nitroso-di-n-propylamine	2.7×10^{8}	2.2×10^{1}	2.8×10^{8}	2.3×10^{1}	3.8×10^{6}	3.1×10^{-1}
Strontium	4.7×10^{0}	3.8×10^{-7}	7.6×10^{-1}	6.2×10^{-8}	ND	ND

[a]Calculations based upon the assumption that the flow in White Oak Creek is 5 ft^3/second.

ft = foot
L = liter
μg = microgram
ND = predicted to be nondetectable by model
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit

However, the uncertainties associated with the modeling analysis should be kept in mind when integrating the modeling results into the decision making process.

The largest uncertainties associated with this modeling analysis are twofold: (1) uncertainties associated with distribution coefficients assigned to represent the sediment and the aquifer materials; and (2) uncertainties concerning the role of fractures in the transport of contaminants. Because the distribution coefficient associated with a given constituent is a function of the properties of the constituent and the media in which the constituent is migrating, it is best to use site-specific distribution coefficients. In the current modeling analysis, site specific values were used when possible. Although distribution coefficients were available for many of the constituents in the sediment, measurements were not made in the unconsolidated or bedrock aquifers.

The role of fractures on the subsurface transport of constituents is uncertain in the vicinity of the impoundments. The modeling analysis conducted for the Waste Area Grouping 1/Surface Impoundments was conducted based on the assumption that the aquifer system responds like an equivalent porous media. To date, there is no evidence that individual fractures act as conduits for the direct discharge of constituents from the impoundments to White Oak Creek. If these fractures exist, actual constituent concentrations may be higher than those predicted by the model.

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APPENDIX D

TECHNOLOGY SCREENING

1. SELECTION OF REPRESENTATIVE PROCESS OPTIONS

Following is a discussion of the selection of representative process options for use at SIOU. The results of this screening process are also presented in Figure 4.1 of the RI/FS.

1.1 NO ACTION

The no action general response action is required by the National Contingency Plan and serves as a baseline comparison for the other alternatives. No process options are provided for no action.

Although risk is acceptable under current conditions, the baseline risk assessment for the RME for future conditions indicates that this option would not be effective in protecting human health. There are also continuing releases of contamination from the operable unit to the environment. There are no cost or implementability considerations for this option. As required by the National Contingency Plan, this general response action is carried forward for detailed analysis.

1.2 INSTITUTIONAL CONTROLS

Institutional controls may be used independently or with other technologies or process options. The applicable technology groups include access and use restrictions and maintenance and monitoring. In this document, "federal institutional controls" implies continued ownership of the ORR by DOE and implementation of existing and possible future orders, procedures, and other federal requirements. "Institutional controls" includes controls specified by state and local authorities and industries. Federal institutional controls are usually considered more stringent and more restrictive on land use.

1.2.1 Access and Use Restrictions

Access and use restrictions reduce the likelihood that present and future workers and future residents would be exposed to contaminants. Retained process options include:

- Physical barriers—Fences, signs, or additional access barriers erected at the operable unit boundary restrict site access to authorized personnel only. Additional barriers could be installed to limit inadvertent contact and restrict excavation.

- Shielding barriers—Temporary or permanent shielding barriers could be erected around a contamination source to prevent exposure to radiation. The barriers may be needed if, for example, radiation levels increase as the water level in an impoundment is lowered.

- Institutional requirements—Current DOE and Energy Systems institutional requirements include manned guard gates, badges for access, radiation exposure monitoring and limitations, training, standard operating procedures, designated and marked radiological control boundaries, and other controls considered necessary and sufficient to protect ORNL workers and visitors. Adequate institutional requirements for protecting on-site receptors from unacceptable exposure to contamination will be maintained as long as the site is federally owned and controlled. A buffer zone would be established to permit monitoring after completion of remedial actions and to allow for mitigative actions, if necessary. Similar requirements could be instituted by future industrial owners or managers of the site.

- Deed restrictions—If the federal government released control of a site with residual contamination (an illegal and unlikely scenario), restrictive covenants in the deed would prohibit certain activities on the site such as drilling of drinking water wells; excavation for building foundations; and residential, recreational, or agricultural land use. Deed restrictions could apply to the SIOU site only or could be extended as far as the limits of ORNL property, as necessary, to be protective of human health and the environment.

All access and use restriction process options are carried forward as representative process options. They are considered very effective in preventing exposure to contamination for certain potential receptors in the short and intermediate term, and fairly effective in the long term. They are readily implementable and costs are low.

1.2.2 Maintenance and Monitoring

Site maintenance and monitoring activities (groundwater and radiation monitoring and surveillance and maintenance) will be conducted regardless of the remedial activities selected at this site. For actions that include removal and off-site storage or disposal of contaminated materials, the level of maintenance and monitoring activities would be significantly reduced. Retained process options include:

- Surveillance and maintenance—Routine surveillance and maintenance activities would include physical site surveys and maintenance, as needed, to verify and ensure the integrity of any engineered remedial controls.

- Monitoring—During remediation, monitoring activities would include sampling of removed surface water, groundwater, soil, and sediment to ensure compliance with the waste acceptance criteria of the receiving treatment, storage, or disposal facility. This sampling would also be used to verify removal of all media contaminated above remediation levels. Sampling of the final waste form would be used to verify the effectiveness of any treatment process. Monitoring during remediation activities would also be designed to verify the probable site conditions so that any deviations detected could be identified and managed. Postremediation monitoring would be used either to verify clean closure of the site or to verify the effectiveness of the engineering controls in meeting the remedial action objectives. Normal site monitoring activities would take place as long as the site remains under DOE control. For actions that do not include clean closure of the site, the site would be evaluated every 5 years to assess whether the implemented remedial action meets the requirements in the ROD.

These process options are used to ensure or verify that the objectives have been and continue to be met. They are all readily implementable. The cost of maintenance and monitoring activities depends on their scope, frequency, and duration which, in turn, depends on the remedial action alternative selected. These are all retained as representative process options to support other general response actions.

1.3 CONTAINMENT

Containment of the low-level waste in the impoundments may be used independently or with other technologies or process options. Containment can minimize migration of contaminants or isolate wastes from storms, surface water, and/or groundwater infiltration. The purpose of containment is to reduce or eliminate contaminant migration and exposure pathways. Applicable technology groups include surface controls, capping, horizontal subsurface barriers, vertical subsurface barriers, and groundwater suppression.

1.3.1 Surface Controls

Surface controls are used to minimize erosion and infiltration by controlling surface water run-on and runoff from storms. Retained process options include:

- Grading—Modifications of the surface topography could control surface run-on, ponding, runoff, and infiltration.

- Revegetation—After grading or other civil construction activities at the site, vegetation would be used to stabilize the site surface, decrease wind and water erosion, and help develop a stable environment. Revegetation uses suitable plant species, grasses, plant and seedbed preparation, seeding, planting, mulching, fertilization, and maintenance to establish a suitable ground cover.

- Diversion and collection systems—Diversion methods could be used to collect/divert surface water around the impoundments to reduce the potential for erosion. Dikes and berms are well-compacted earthen ridges constructed to divert run-on. Ditches, trenches, shallow barriers, and culverts collect and/or convey water around, through, or away from a site.

These options are effective, readily implementable, and low in cost. All three process options are carried forward to improve the effectiveness of other options such as capping.

1.3.2 Capping

Caps are horizontal surface barriers that prevent airborne contamination, minimize biointrusion, and/or minimize infiltration from storms and surface water. Caps also provide shielding from radiation. Unless the area to be covered by a cap includes the recharge area, the water table in SIOU would not be significantly lowered. After the initial screening, the only retained process option is:

- Multilayered cap—A multilayered cap would use a combination of materials to provide, for example, a surface protection layer, a drainage layer, and a barrier layer. The surface protection layer, normally topsoil with grass, provides erosion protection, increases evapotranspiration to reduce infiltration, and prevents damage to the drainage and barrier layers from frost and traffic. The drainage layer, typically graded stone, diverts infiltration from storms and surface water away from the barrier layer, which is typically a low-permeability clay and/or geotechnical membrane. An intrusion barrier of stone or other material could be added above the barrier layer to discourage burrowing animals, deep-rooted vegetation, or inadvertent human intrusion.

A cap could be installed at the existing locations of the surface impoundments or could be used to contain wastes that have been removed and treated. In addition to isolating the surface impoundment sediments and reducing the likelihood of contaminant migration into groundwater,

a cap would serve as an effective radiation shield. A cap could only be used if the waste is in a relatively stable, adequately dewatered form. If the waste, as deposited, emits hazardous levels of radiation, placement of the cap materials would require adequate shielding and may require remotely handled equipment. Otherwise, materials and technology for constructing a cap are readily available. A moderate cost is expected for installation of a multilayer cap. The cap is retained as a representative process option.

1.3.3 Horizontal Subsurface Barriers

Under normal conditions for Impoundment 3513, and during heavy rainfall for 3524, groundwater can rise through the bottom of the impoundments and into contaminated sediments. When the groundwater table subsides, contamination within the sediments can be washed into the subsurface soils and fractured bedrock below. Horizontal subsurface barriers would reduce movement of groundwater and contaminants between the surface impoundments and the fractured bedrock. These barriers must be used with vertical barriers and/or caps to be successful. Retained process options include:

- Injected grout sheet barrier—This technology would use augured holes and injection pipes to transport a low-viscosity chemical or cement grout under high pressure that would permeate subsurface soil. The injection pattern must be drilled in a uniform, overlapping pattern either horizontally or at an angle to form an impermeable barrier under the impoundments. The grout must remain fluid until the fissures are sealed.

- Injected grout and clay mixture sheet barrier—A flowable grout and clay mixture could be injected in a manner similar to the grout sheet barrier. Clay and other additives included with the injection mixture are intended to retard solidification and allow the mixture to remain fluid until the fissures in the bedrock are sealed.

- Liner—A compacted clay, geomembrane, or other type bottom liner could be installed in an excavated area. The liner could include multiple barriers and a leachate collection system, if necessary. A geochemical barrier could be designed to adsorb specific contaminants from water passing through the barrier. A liner would retard migration of contamination from the waste material placed over the liner.

A grout and clay mixture sheet barrier is more effective than an injected grout sheet barrier. The mixture is expected to permeate the subsurface soils and fractured bedrock more thoroughly due to lower viscosity and would not harden prematurely. Proper installation of either of the horizontal sheet barriers is difficult to implement. Significant space is required to perform the drilling activities, injection of the grout or the grout and clay mixture is difficult to control,

and verification that there are no major openings in the installed barrier is uncertain. A decrease in the effectiveness of the barrier over time would be expected as the grout deteriorates.

A liner is expected to be more effective than the other subsurface barriers since design and installation are straightforward and quality can be readily controlled. Liner installation in an uncontaminated excavated area is readily implementable using standard construction equipment and techniques. A liner costs much less than an injected horizontal barrier.

The process options retained to represent the subsurface horizontal barrier technology include the grout and clay mixture sheet barrier and the liner. The sheet barrier could be used in combination with in situ treatment, storage, or disposal technologies. A liner would be used as part of a containment system for relocated waste.

1.3.4 Vertical Subsurface Barriers

Vertical subsurface barriers isolate the impoundments from horizontal infiltration of shallow subsurface water in the storm flow zone and groundwater in the unconsolidated zone (i.e., the overburden above bedrock). To completely isolate the impoundments, the vertical barrier needs to be keyed into an impervious subsurface layer. Bedrock may not be impervious, and horizontal barriers, in conjunction with vertical barriers, could be required for complete isolation. The process options evaluated are:

- Soil-bentonite slurry wall—A trench could be excavated above one or more of the impoundments. Bentonite would be mixed with the excavated soil and the mixture would be returned to the trench. The hydraulic conductivity of the resulting slurry wall would be much lower than the surrounding soil, thus retarding infiltration.

- Composite sheet pile and injected grout wall—A pair of parallel, interlocking, steel sheet panel walls could be vibrated or driven until refusal or top of the bedrock to form a retaining wall around the impoundments. To reduce leakage and provide a seal with the underlying bedrock, grout or a grout and clay mixture would be injected under high pressure into the void spaces in the soil between the panels. This type of wall can also serve as a retaining wall, permitting excavation adjacent to one side of the wall.

- Grout sheet curtain—Grout sheets could be injected through vertically drilled holes similar to the horizontal injected grout sheet barrier described in Section 4.2.3.3. Water or air injection is typically used to improve the soil and grout mixture. The low permeability of the barrier can minimize, but not eliminate, infiltration.

- Grout and clay mixture sheet curtain—A mixture of grout, clay, and other additives would be installed similar to the grout sheet curtain previously described.

The effectiveness of the grout and clay mixture sheet curtain is considered better than the grout sheet curtain for the reasons described previously for horizontal barriers. The slurry wall and the composite sheet pile and grout wall would be equally or slightly more effective than the grout and clay curtain, but more difficult to implement. Excavation for the slurry wall would be in somewhat confined quarters and the excavated material may be contaminated and could require special handling. There are some active and abandoned underground pipes near some of the impoundments. Excavating a slurry wall or driving sheet piles at those locations may be difficult. The cost of the composite wall would be the highest, while the other options would be similar in cost.

Because of better implementability, cost factors, and good effectiveness characteristics, the injected grout and clay mixture sheet curtain is retained as the representative process option for permanent vertical subsurface barriers.

1.3.5 Groundwater Suppression

Suppressing the groundwater table around the impoundments would reduce potential migration from the contaminated sediments and soils and reduce infiltration. Because the region near the impoundments is a discharge point for the 3000 Area watershed and is adjacent to White Oak Creek, water table suppression would likely entail recovery and treatment of significant quantities of groundwater. The process options for groundwater suppression are:

- Recovery well network—A series of wells and pumps upgradient and downgradient from the impoundments could lower the water table in the vicinity and capture any contaminated water leaching out of the impoundments.

- Interceptor trench (French drain)—A narrow, vertical trench filled with graded, porous stone could be used upgradient of one or more of the ponds to intercept groundwater flow into the operable unit and to suppress the water table. A network of perforated drainage pipes within the stone-filled trench could enhance performance. Provision of a geotextile filter fabric to line the trench and reduce clogging of the stone with soil fines could increase the useful life of the trench. Recovered groundwater would be pumped from a sump to a storage, treatment, or discharge facility, as appropriate. An interceptor trench could also be used downgradient from a contamination source to capture any leachate released to the groundwater.

Because groundwater in the vicinity of the impoundments is contaminated and contamination from other sources will remain even after remediation of the operable unit, any groundwater removed would have to be monitored and probably treated before discharge. In addition, lowering the groundwater table would affect the hydraulic gradient for some distance away from the operable unit and could increase the rate of migration of other contaminant plumes toward White Oak Creek at this location. Recovery wells, because they could be located in numerous places and drilled to greater depths, might be more effective at suppressing the groundwater table at a greater risk of attracting other contaminant plumes than an interceptor trench. An upgradient trench would be effective in intercepting shallow subsurface flow during storms and would have less effect on normal groundwater elevations. For the lower impoundment, either process option could affect the direction of groundwater flow depicted in the conceptual model and draw water from White Oak Creek rather than discharge water to the creek. This would entail removal and treatment of significant volumes of water and would reduce flow in the creek and subsequent dilution of contamination from other sources. Installation of the trench would require removal of significant quantities of contaminated soil. A small volume of contaminated soil would be removed during well installation. Both process options would require O&M of pumps for groundwater removal. The cost of either option would depend on the scope and duration of the suppression activities and is not considered a differentiating factor.

For a long-term component of a remedial action, groundwater suppression is not considered an appropriate technology. During implementation of some remedial activities, groundwater suppression could be used on a short-term basis to enhance the effectiveness or implementability of removal or in situ treatment technologies. Because of its relative ease of implementation, a recovery well network is selected as the representative process option for short-term groundwater suppression during remedial activities. Although not selected as representative, a downgradient interceptor trench could be used as a contingency action to capture contaminated groundwater if other remedial actions were not successful. An upgradient trench could be used as a contingency to lower groundwater at Impoundment 3524 for approximately 30 years.

1.4 IN SITU TREATMENT

In situ treatment of sediments in the impoundments and underlying soils may be possible if the remedial alternative can reduce the risks to acceptable levels by immobilizing contaminants or reducing contaminant migration in sediments and surrounding soils. Physicochemical treatment is the technology type addressed below. No thermal in situ treatment options are retained after the initial screening.

1.4.1 Physicochemical Treatment

Physicochemical treatment includes chemical processes, such as stabilization, that reduces the solubility of contaminants, and solidification, which alters the waste form by incorporating the contaminants into a solid heterogeneous matrix or homogeneous monolith. Physicochemical treatment also includes physical processes such as dewatering for volume reduction and structural stability. In addition to these technologies, which can be performed in situ or ex situ, permeable treatment beds with high cation exchange capacity can be used in situ to remove contaminants such as metals and radionuclides. The remaining process options after initial screening are:

- Chemical treatment—The potential hazard of waste can be reduced by adding stabilization agents to convert contaminants into their least soluble form. Stabilization can also dehalogenate chlorinated hydrocarbons and volatilize organic compounds. An example of the technology is the stabilization of mercury using readily available sulfide compounds and pH control, which can create highly insoluble mercuric sulfide. Stabilization, when used properly, can significantly reduce the rate of subsurface transport of certain environmental contaminants.

- In situ stabilization/solidification—Commercially available treatment processes and equipment systems have demonstrated the ability to mix liquids, sediments, and soils with chemical stabilization and solidification agents. Inorganic solidification agents include solid silicates (e.g., fly ash, kiln dust, and furnace slag), liquid silicates (e.g., sodium silicate), portland cement, and lime. Because the contaminants may not interact with the solidification reagents, wastes may also require chemical stabilization before solidification. This process, also known as microencapsulation, mechanically locks contaminants within a solidified matrix. Because organic polymers degrade during radiation exposure, their use would be limited. Mixing equipment typically consists of a backhoe-mounted auger and chemical injection system to mix the reagents with contaminated soil or other media.

- Permeable treatment beds—A trench excavated downgradient of a contaminant plume and backfilled with a permeable substance with high cation exchange capacity can form a vertical contaminant interception barrier. Permeable treatment beds using zeolite can effectively remove strontium from contaminated groundwater passing through the bed. Other exchange agents can be effective on other contaminants.

- Drainage beds—Dewatering waste for volume reduction and structural stability can be accomplished in a variety of ways. In situ drainage beds use a geotextile filter fabric,

leachate collection system, and liner to dewater sediment or sludge placed in a cell. Overburden placed above the waste gradually forces water from the sediment into the leachate collection system for discharge to an appropriate treatment facility.

1.4.1.1 Effectiveness

Chemical treatment through simple addition of stabilization agents to the waste in the impoundments would have limited effectiveness. Soluble contaminants in the surface water could be immobilized, but limited contact between stabilization agents and contaminants in the sediments would occur. Any method of mixing the stabilization agents with the waste would improve effectiveness. In situ stabilization and solidification with mixing equipment is one method of adding both stabilization and solidification agents to the waste. An engineering support study would be required to determine the proper formula of stabilization and solidification reagents for effective treatment of the specific media. Because of difficulties in QC under field conditions, the effectiveness of the in situ stabilization process may not be as high as predicted based on laboratory studies. Addition of stabilization or solidification agents would increase the volume of contaminated material and could hinder additional remediation efforts.

Drainage beds can be moderately effective to very effective in reducing water content of sediments and soils. Engineering support studies are necessary to determine settling, dewatering, and pumping characteristics of the waste. The effectiveness of drainage beds can be enhanced by using wicks or more permeable geocomposite layers within the waste to provide preferential flow paths to the leachate collection system. Permeable treatment beds can effectively remove from groundwater the contaminants for which they are designed. Again, studies would be required to determine the effectiveness in removing the COC, the effect of competition of other cations for adsorption sites, and the volume of media required to treat the expected waste stream. The treatment beds can become saturated with contamination, and the contaminated media would have to be removed, stored, or disposed of, and replaced with fresh media.

1.4.1.2 Implementability

Installation of a drainage bed and operation of the leachate collection system are readily implementable. The permeable treatment bed is also straightforward to implement with standard construction equipment; however, the excavation required for the trench would likely yield contaminated soil requiring special handling and disposal procedures. Implementing the chemical treatment or the stabilization and solidification processes would be more difficult. Construction equipment and techniques are available. However, the presence of radioactive contamination at the site may add shielding, containment, and personnel protection requirements that inhibit implementability at the site.

1.4.1.3 Costs

Costs for the drainage beds and permeable treatment beds are considered moderate, but these processes cannot stand alone and would only be part of a more robust remedial alternative. The cost for adding solidification agents would vary significantly, depending on the equipment used to add and mix the agents with the waste. In situ solidification would be much more costly than the other process options; radiation protection requirements could increase the cost significantly.

1.4.1.4 Selection of representative process option(s)

Because in situ stabilization and solidification is the process that deals with the waste most effectively, it is retained as a representative process option and carried forward for assembly and screening of alternatives. The drainage beds process option is also carried forward as a key element of a more robust alternative. Addition of stabilization agents and installation of permeable treatment beds are limited in scope and applicability and are not carried forward for alternative development. They are considered as possible process modifications to support developed alternatives or contingency actions that could be taken if an alternative does not perform as expected.

1.4.2 Thermal Treatment

The only process option for in situ thermal treatment is in situ vitrification, which was screened out in the initial screening as not applicable to the site conditions. If the waste is dewatered and isolated from groundwater in a storage or disposal cell, in situ vitrification could be used as a contingency action in the event that the cell does not sufficiently contain the waste.

1.5 REMOVAL

Waste removal would be required for any alternative that includes ex situ treatment, waste relocation, or off-site disposal or storage actions. Waste removal technologies and systems are developed and adaptable using existing equipment. They have been demonstrated at DOE sites and throughout the waste disposal industry. Because of radiation protection requirements, adequate shielding or remote operation must be addressed during waste removal operations. Technologies for removal of contaminated sediment, soil, surface water, and groundwater are discussed here. Extraction of contaminated groundwater or surface water for the remedial alternative will be performed, if necessary, using conventional pumping equipment.

1.5.1 Solids Removal

Waste removal equipment could be operated from the bank of the impoundments or submerged to limit worker exposure as needed. Waste handling, transportation, and/or treatment systems are required for the retrieved wastes.

Retained process options are:

- Mechanical excavation—Standard commercial excavating equipment (e.g., an hydraulic backhoe with an extended reach or a crane-mounted clamshell or dragline) is capable of removing sediments and soils with or without removing the surface water. Other standard equipment (i.e., loaders, graders, and bulldozers) can be used for removal of surface soils. A limiting factor would be potential exposure of the operator to radiation from the excavated material. Remotely operated systems are available.

- Hydraulic or pneumatic dredge—Dredging is the removal of solids from the bottom of a body of water without removing the surface water. Hydraulic dredging can remove bulk materials, sediments, granular materials, and liquids using a cutter head to mobilize sediments or soils and a hydraulic pump to transport the mobilized solids mixed with water in a slurry through a pipeline. Pneumatic dredging uses the injection of compressed air near the intake of a submerged pipe to create a vacuum that transports a solids-water slurry through a pipeline. Either type of dredge can be operated from a floating barge or from the banks of the impoundments.

- Remotely controlled mobile dredge—A small, track-mounted or floating dredge with a cutter head and a hydraulic slurry pump can remove sediments from the impoundments while operating from a remote location. Hydraulic or electric lines between the mobile dredge and the remote power unit (and operator station) provide power for the cutter head, the pump, and the positioning equipment. The excavated slurry can be pumped through pipelines to a treatment or storage location.

1.5.1.1 Effectiveness

Mechanical excavation is the only option that can remove both submerged and surface soils or sediments. If the sediment has a high liquid content, mechanical excavation equipment would have to be carefully selected to limit spills, leaks, and radiation exposure. Dredging process options are only effective on submerged materials. By moving the contaminated sediments in a slurry through pipelines, dredging provides a much greater degree of control and limits possible exposure to the removed material. The remotely operated mobile dredge best

reduces the likelihood of exposure. This type would effectively remove subsurface sediments, but it may not be powerful enough to remove contaminated subsurface native clay soils. The hydraulic or pneumatic dredges could possibly excavate those soils, but mechanical excavation of the soils would be most effective. Pneumatic dredges are most effective in deep water and would not be useful at this site.

1.5.1.2 Implementability

Mechanical excavation would be readily implementable, provided that (1) adequate protection of the operators from exposure to radiation and (2) prevention of excavated materials from becoming airborne could be assured. It is unlikely that excavation equipment could be adequately decontaminated, so it would have to be packaged and disposed of or transported to other contaminated sites. Hydraulic or pneumatic dredges would have to be operated from the banks of the impoundments, rather than from floating barges at this site. The ponds are too small to adequately maneuver barges. The barge would become contaminated and require appropriate decontamination or packaging, transport, and disposal. Shore-mounted dredges are more difficult to control and cannot easily gain access to all areas of the ponds. Because of its small size, the remotely controlled hydraulic dredge would be relatively simple to install, operate, remove, and package for disposal or use at another contaminated site.

1.5.1.3 Cost

The remotely controlled dredge would be the least expensive process option by far. Because of the large size of the mechanical excavation equipment and the other types of dredges and because of the likelihood that they could not be decontaminated, their usefulness after the SIOU remedial actions would be limited. Most or all of the large excavation equipment cost would be applied to this site. The contaminated portions of the remotely controlled mobile dredging system could either be scrapped and disposed of with the rest of the material from the site or packaged and moved to another contaminated site. The cost for either of these options is negligible relative to the cost for the other equipment.

1.5.1.4 Selection of representative process option(s)

The remotely controlled mobile dredge is retained as a representative process option for removing the most highly contaminated medium (i.e., the sediment) because it is highly effective, implementable, and low in cost. Mechanical excavation is also retained for excavation of the lesser contaminated soils.

1.5.2 Liquids Removal and Pretreatment

Debris-free contaminated surface water or groundwater can be removed by a variety of pumps. It may be necessary to remove liquids to improve the efficiency of an in situ treatment technology or to simplify the excavation of solid wastes. Once liquid has been extracted, pretreatment may be needed before discharge to a treatment facility.

- Pumping—Properly sized pumps and hoses can be used to transport surface water or groundwater. The peristaltic and the centrifugal pumps are two commonly used pumps. Each has relative strengths and weaknesses. The peristaltic pump has the advantage of making only indirect contact with contaminants; however, it has a low pumping capacity. The centrifugal pump has a higher pumping capacity, yet its internal components come into direct contact with the waste stream.

- Pretreatment—Among contaminants that may need to be removed before sending a liquid waste stream to a treatment facility are metals, radionuclides, and particulates. Engineering support studies need to be performed on the liquid of concern to properly design the system. Many technological options used in pretreatment schemes result in contamination of more materials, which will increase disposal or treatment costs.

Pumping is a proven, inexpensive method to remove and transport bulk liquid and is especially efficient in removing water contained in engineered holding facilities such as surface impoundments. Implementability of pumping is good and the technology is widely used. Removing liquids always presents a risk that spills, leaks, splashing, and hose failures will occur, necessitating provisions for spill containment. Liquid removal would be mandatory in cases where caps are included in the remedial design.

The need for pretreatment would be dictated by the characteristics of the liquid waste stream and the waste acceptance criteria of the receiving treatment facility (see Sect. 4.2.8.1 of the RI/FS). Pretreatment can be accomplished with a variety of proven technologies, including particulate settling, filtration, carbon adsorption, and ion exchange. Any of these technologies could be implemented as part of the overall treatment scheme. Each required unit operation would cause a dramatic cost increase in comparison to the pumping option. Because there are multiple COCs, chemical effects such as competitive adsorption and solubility of several constituents in the same solvent would make engineering support studies necessary. Even with adequate waste characterization, it could take multiple stages and technologies used in series to properly treat the waste.

Due to the ease of implementation, low cost, and the lack of other options, pumping will be retained as a process option. Since pretreatment is potentially cost-prohibitive, it will be considered only as part of a contingency should the liquid waste streams produced from remedial actions not meet the waste acceptance criteria for the final liquid treatment facility.

1.6 EX SITU TREATMENT

For remedial alternatives that require removal of contaminated media, treatment may be required to meet applicable regulations or waste acceptance criteria at a storage or disposal site. The applicable ex situ treatment technology types are physicochemical treatment and thermal treatment.

1.6.1 Physicochemical Treatment

Ex situ physicochemical treatment incorporates physical and/or chemical processes to treat the COCs as required. The process options retained after initial screening are:

- Mechanical dewatering—Equipment types including filter presses, rotary drum filters, vacuum and pressure belt filters, and centrifuges can reduce the water content of sediment, sludge, soil, or slurry to as low as 40 percent by weight. Both the volume and the weight of the final solid product are reduced. The total contamination in the solid phase can be reduced, but a contaminated liquid waste stream that requires treatment is produced. Free liquids are essentially eliminated from the solid phase, which makes the latter more acceptable for storage or disposal. Depending on the filterability of the material, a filter aid may need to be added; this increases costs and at least partially offsets the volume decrease achieved in the solid phase.

- Stabilization and solidification—Ex situ stabilization and solidification, also known as microencapsulation, involves adding stabilization materials that limit the solubility or mobility of contaminants and solidification agents that incorporate the contaminants into a solid heterogeneous matrix. The ex situ process requires removal and transfer of the waste to a treatment tank, addition of the stabilization and solidification materials under controlled conditions, thorough mixing of the waste with the reagents, and transfer of the waste mixture to an appropriate storage container or disposal facility before it hardens. Reagents such as those described for the in situ stabilization and solidification processes (see Sect. 4.2.4.1 of the RI/FS) could be used. An engineering support study would be required to determine the proper stabilization and solidification formula for effective treatment of the specific media.

- PCB treatment—Because the concentration of PCBs in all sediments and possibly some of the soils is greater than 50 ppm, treatment to remove or destroy some of the PCBs may be required. The demonstrated technology of incineration is not applicable to the highly radioactive waste. Base-catalyzed destruction, described in *EPA Engineering Issue, Technology Alternatives for Remediation of PCB-Contaminated Soil and Sediment* (Dávila 1993), appears to have the best chance of being effective on this waste when compared to other established, demonstrated, or emerging technologies for PCB treatment.

1.6.1.1 Effectiveness

Mechanical dewatering of the sediments and soils is fairly effective and can provide a significant reduction of the volume of sediments and soils removed in a slurry. A volume reduction of up to 30 percent compared to the in situ volume is possible. The final waste form is a filter cake that appears solid and dry with a water content of perhaps 30 percent. Note that the terms "filter cake" and "filtrate" apply only to filters. If a centrifuge is selected, the proper terms are "centrifuge cake" and "centrate," respectively. For simplicity, the former set of terms will be used throughout this document. The cake may need to be ground into a powder or granular form for handling purposes before packaging or transport to a storage or disposal facility. Engineering support studies would need to be performed to determine the leachability of contaminants from the waste.

Ex situ solidification can be very effective in reducing the leachability of ^{137}Cs, ^{124}Am, and Pu and its daughter products, but is less effective in reducing the leachability of ^{90}Sr, which is the COC for groundwater migration. The solidification process would result in an increase of as much as 100 percent in the volume of waste.

If treatment of PCB-contaminated waste is required for a remedial alternative, an appropriate and effective treatment would have to be developed during engineering support studies. For analysis purposes, base-catalyzed destruction is assumed to be effective.

1.6.1.2 Implementability

Mechanical dewatering equipment is commercially available; however, it could require modification to meet radiation protection requirements. After use, the equipment would be difficult or impossible to decontaminate and would need to be packaged and disposed of or shipped to another radioactively contaminated site. Handling the highly radioactive filter cake to prevent exposure of operators and to eliminate the possibility of airborne contamination would require special equipment and techniques. The solidification process is readily implementable using available construction equipment and techniques. Remotely operated solidification

equipment is available that can meet the necessary shielding, containment, and personnel protection requirements. Contaminated portions of the solidification equipment would need appropriate packaging and disposal or reuse.

For the dewatering process, neither criticality nor transuranic waste is likely to result from increases in concentration due to volume reduction of the sediment from the surface impoundments. Composite sediment samples show a maximum concentration of approximately 21 nCi/g of transuranic when dried. Compaction or dewatering will not result in a totally dry material, resulting in lower concentrations. Therefore, the generation of transuranic waste (which by definition is 100 nCi/g or greater of alpha-emitting transuranic elements with half-lives greater than 20 years) is extremely unlikely. For ^{239}Pu, the minimum concentration required to produce criticality in water, a worse case than in partially saturated sediment, is 6.9 g/L, or approximately 0.42 Ci/L. This is roughly 0.0004 Ci/g, orders of magnitude above the concentrations detected in the surface impoundment sediments. Criticality is not a credible concern.

The implementability of a PCB treatment process would be determined during engineering support studies.

1.6.1.3 Cost

Mechanical dewatering costs less than stabilization and solidification. The cost for PCB treatment is not comparable because it is used for a different purpose.

1.6.1.4 Selection of representative process option(s)

Stabilization and solidification is retained as a representative ex situ physicochemical treatment process option. Stabilization and solidification is more effective than mechanical dewatering in reducing leachability of the waste, although ^{90}Sr is not bound into the solidified matrix as well as other contaminants, and waste volume is increased. Mechanical dewatering would reduce the volume of waste to be disposed of or stored and could be used as a contingency action if in situ dewatering in drainage beds is not effective (see Sect. 4.2.4.1 of the RI/FS). PCB treatment is also retained as a supplementary treatment process for alternatives that require elimination of PCB contamination.

1.6.2 Thermal Treatment

Thermal treatment uses heat to solidify or dewater the waste. The process options retained after initial screening are:

- Vitrification—After removal and placement of the waste in a melter vessel, high voltage electric current passed through electrodes, a plasma arc, or another heat source is used to melt soil, waste solids, and additives into a glass-like waste form. The molten material can be poured into containers where it solidifies in a monolith, or molten slag can be collected and cooled in a quenching tank to yield a granular vitrified waste. The process destroys organic constituents and releases volatile constituents that are typically treated in an off-gas system. A 20–40 percent reduction in the volume of the waste is possible. An engineering support study would be required before design of the system.

- Sediment/soil drying—After removal, waste is placed in a treatment vessel and heated thermally or with microwave or radio frequency energy to volatilize the interstitial water in the sediments and drive it off as a vapor. Drying improves handling and aids in preparation for disposal. A 50–70 percent reduction in the volume of the waste is possible in the case of sediments, while 25–40 percent is a typical range for soil volume reduction. The vapor may require additional treatment.

1.6.2.1 Effectiveness

Vitrification of sediments and soils provides a stable, leach-resistant waste form significantly smaller in volume than the original waste. Some cesium is volatilized during the vitrification process and must be collected in the off-gas system. Since a significant percentage of the sediment contains cesium, a large secondary waste stream would be created, thus reducing the effectiveness of vitrification. Sediment and soil drying also effectively reduces volume, but reduces leachability less effectively (i.e., similar to mechanical dewatering). As discussed in Section 4.2.6.1 of the RI/FS, neither generation of transuranic waste nor criticality concerns would result from the expected volume reduction.

1.6.2.2 Implementability

Most potentially applicable vitrification technologies have been performed only on a pilot basis using simulated (rather than actual) radioactive waste. The process consumes significant amounts of energy. Most soil-drying technologies are also innovative, although thermal heating has been used in some full-scale applications. These technologies are also energy intensive, although less so than the vitrification technologies. The equipment for both process options would be contaminated after use and would need to be packaged and shipped to another contaminated site or to a disposal facility.

1.6.2.3 Cost

Initial mobilization of a vitrification process is very costly and probably not cost effective for the small volumes of waste at this operable unit. Operating costs, particularly for energy requirements, are also high. The capital and operating costs for sediment and soil drying are moderately high.

1.6.2.4 Selection of representative process option(s)

Neither of the ex situ thermal treatment process options is retained for development and screening of alternatives. Although vitrification is potentially more effective at reducing leachability of most constituents, the physicochemical treatment process option of stabilization and solidification is selected as representative of all ex situ treatment technologies. Vitrification has cost and implementability concerns, reduced effectiveness for cesium-contaminated waste, and is an innovative technology for this application. These concerns justify the decision to represent vitrification rather than use it as the representative option. Sediment and soil drying is similar in effectiveness and greater in cost than mechanical dewatering and less effective than stabilization and solidification.

1.7 SOLIDS DISPOSAL OR STORAGE

Any wastes removed from the site must be transported and disposed of or stored in a manner that protects human health and the environment. The two technology types for this general response action are the engineered facility and temporary storage. The soils and sediments could be segregated if appropriate, treated as necessary, and transported to one or more storage or disposal facilities designed and permitted to accept the applicable waste types (i.e., mixed waste or low-level waste).

1.7.1 Engineered Facility

Appropriate engineered facilities could be used or constructed to manage the wastes either on site or off site. The facility's waste acceptance criteria would have to be compatible with the solid waste streams resulting from the selected removal or treatment process. The process options retained are:

- Consolidation cell—Consolidating wastes within an area of contamination is acceptable under CERCLA without invoking RCRA land disposal restrictions and permitting requirements. A consolidation cell is a combination of engineered containment barriers (including liners and caps) into which wastes in the same area of contamination are placed.

- Off-site disposal facility—Wastes would be processed to meet the waste acceptance criteria for the off-site disposal facility and packaged to meet shipping regulations for hazardous, low-level radioactive, or mixed waste.

1.7.1.1 Effectiveness

Once wastes are removed, the effectiveness of protection of human health and the environment at the SIOU site would be similar for both options. The effectiveness of an engineered facility would depend, in part, on site-dependent considerations as well as engineering design, particularly for long-term effectiveness. Short-term effectiveness during remedial actions would depend on the waste handling requirements for transport of the waste to the consolidation cell or disposal site. Transport to an on-site consolidation cell would be simpler and offer less opportunity for exposure of workers or the public to the waste than would transport to an off-site facility.

1.7.1.2 Implementability

Construction of new facility for managing mixed waste is implementable on or off site. For a location within ORNL, certain regulatory requirements such as minimum depth to groundwater would have to be waived, or regulatory agencies would have to approve engineered elements that are protective to the same degree as required by regulations. Administrative implementability for the consolidation cell may therefore be difficult, but regulatory agencies are likely to accept a sufficiently robust design.

Permitting, regulatory, and public perception problems would make construction of a new, off-site, mixed-waste landfill administratively impractical in the time frame appropriate for remediation of this site. For existing disposal facilities, there are major technical and administrative implementability concerns. First, the waste would have to meet the waste acceptance criteria for the receiving facility. No existing facility will accept waste from the SIOU without treatment (e.g., removing hazardous constituents to reduce the waste to low-level waste rather than to mixed waste). Second, removal of the waste from the site will invoke land disposal restrictions requiring specific treatment technologies for each hazardous constituent, equivalent treatment technologies to those prescribed, or waivers from the land disposal restriction requirements. The treatment technologies for the hazardous constituents would be difficult to implement because of the high levels of radioactivity associated with the waste.

Very few existing facilities have waste acceptance criteria that match waste streams resulting from remedial actions at this operable unit. Following is a summary of the available facilities and their pertinent waste acceptance criteria.

1. Envirocare, Salt Lake City, Utah. Accepts mixed waste, but radiation levels must not require shielding, and PCB levels must be less than 50 ppm. Disposal cost is $85/ft^3$. Surface impoundments waste cannot meet these criteria with or without treatment.

2. Chem-Nuclear, Barnwell, South Carolina. Accepts radioactive waste only. No hazardous waste, no liquids, and no PCB waste above detectable levels are accepted. Disposal cost is $152/ft^3$. Surface impoundments waste can possibly meet these criteria with rigorous treatment to remove or immobilize hazardous constituents such that the waste is classified as low-level waste rather than mixed waste.

3. DOE Radioactive Solid Waste Disposal Site, Hanford, Washington. Accepts radioactive waste only for disposal. No hazardous waste and no PCB waste above 50 ppm is accepted. Disposal cost is $63/ft^3$. Surface impoundments waste can possibly meet these criteria with rigorous treatment to remove or immobilize hazardous constituents to classify the waste as low-level waste rather than mixed waste. Hanford will also accept mixed wastes for storage and is applying for permits necessary to dispose of mixed waste. Future treatment and disposal costs are not available.

4. US Ecology Waste Disposal Facility, Hanford, Washington. Accepts radioactive waste only for disposal. No hazardous waste and no PCB waste above 50 ppm is accepted. Disposal cost is $57/ft^3$. Surface impoundments waste can possibly meet these criteria with rigorous treatment to remove or immobilize hazardous constituents to classify the waste as low-level waste rather than mixed waste.

5. DOE Nevada Test Site, near Las Vegas, Nevada. Accepts radioactive waste only for disposal. No hazardous waste, no liquids, and no PCB waste above 50 ppm are accepted. Disposal cost is $5-10/ft^3$. Surface impoundments waste can possibly meet these criteria with rigorous treatment to remove or immobilize hazardous constituents to classify the waste as low-level waste rather than mixed waste. Nevada Test Site is applying for permits necessary to dispose of mixed waste. Future disposal costs are not available.

1.7.1.3 Cost

The cost to construct and operate a new, on-site consolidation cell would be moderate. The costs to package and transport waste to an off-site facility and for the disposal fees would be extremely high.

1.7.1.4 Selection of representative process option(s)

The consolidation cell is retained for development of alternatives because it is very effective, reasonably implementable, and less costly than disposal at an off-site facility.

Disposal at an off-site facility is equally effective, but difficult to implement and high in cost. Construction of a new, off-site disposal facility is rejected as administratively impractical. Of the existing off-site facilities, Nevada Test Site is the most attractive option due to its lower disposal fee. Although significant administrative difficulties are expected in implementing contractual arrangements with Nevada Test Site and the transportation and disposal permits with federal and state regulatory agencies, these difficulties are perceived to be less than at other facilities. Despite the significant technical (i.e., treatment, packaging, and transport) and administrative difficulties, off-site disposal at Nevada Test Site is retained as a representative process option in the event that on-site management of the waste is rejected by regulators or the public.

1.7.2 Storage

If no on- or off-site engineered facility can accept the waste, storage may be the only viable option until a disposal site can be developed. The waste would have to be treated to meet the waste acceptance criteria of the storage area. Long-term storage of the sediments and/or soil at ORR is the only process option retained.

- Long-term storage at ORR—There are various storage locations at ORR used specifically for low-level waste storage. Additional locations could be developed into a new storage facility that meets the containment and other regulatory requirements for SIOU waste. Waste would be transported and stored at an appropriate new or existing permitted facility after treatment and packaging. The facility would be operated pursuant to permit requirements for the period of time required for the following actions: (1) identify a disposal facility and enter into a contract; (2) (optional) design, permit, and construct a treatment facility to meet the disposal facility's waste acceptance criteria; (3) (optional) remove wastes from containers and treat; (4) (optional) containerize treated wastes; and (5) transport wastes to disposal facility.

Effective operation of appropriate storage facilities could be readily implemented. The cost for development of such a facility; treatment (if necessary), packaging, and transport of the waste to the facility; and operating the facility for a long time would be very high. Eventually the waste would have to be relocated to a permanent disposal facility at additional cost and risk and potentially with additional treatment required to meet the disposal facility's waste acceptance

criteria. Storage at ORR is retained as a representative process option to address the possibility that no disposal options may be available.

1.8 LIQUIDS TREATMENT AND DISCHARGE

The surface water in the impoundments, groundwater removed during the remedial actions, and any liquids removed during treatment processes will require treatment before discharge.

1.8.1 Treatment/Discharge

Available process options for treating these liquids include use of the existing treatment systems at ORNL or development of new treatment systems.

- ORNL process waste treatment system—The Process Waste Treatment Plant immediately adjacent to the surface impoundment site uses conventional solids and liquids separation and settling equipment to remove metals and solids and ion exchange columns to remove low levels of radioactivity (primarily ^{90}Sr and ^{137}Cs). After treatment at Process Waste Treatment Plant, water is transferred to the Nonradiological Wastewater Treatment Plant for further treatment. Nonradiological Wastewater Treatment Plant is divided into two processes: a metals treatment unit operation to remove heavy metals and a nonmetal treatment unit operation to remove volatile and nonvolatile organics. The treated water from the Nonradiological Wastewater Treatment Plant is collected in the final effluent tank. The pH of the water is then adjusted before discharge to White Oak Creek through the National Pollutant Discharge Elimination System permitted outfall.

- New treatment facility—A new temporary treatment facility using treatment processes similar to the existing system and designed specifically for the expected liquid waste streams could be built on the site.

Both the existing treatment systems and a new facility could effectively remove the expected contamination from the liquid wastes resulting from the remedial actions. The existing system has a limited capacity used to treat waste from ongoing research or production processes at ORNL and to draw down excess volumes of liquids in the impoundments during high runoff periods. For implementation of an alternative that requires liquid treatment at the existing systems, the volume and rate of liquid discharge could not exceed the available storage and treatment capacity of the system. In addition, some pretreatment (e.g., filtering of solids) may be required to meet the waste acceptance criteria of Process Waste Treatment Plant. A new

treatment facility would be designed with adequate treatment and storage capacity. Commercially available package treatment plants could be brought to the site. Providing an adequate site for locating the facility and obtaining a discharge permit for the effluent would be difficult and time-consuming. The cost for the new facility would be much greater than the fees for using the existing systems.

Use of the existing ORNL systems for treating and discharging liquids is carried forward as the representative process option because the effectiveness would be similar, sufficient capacity is presumed to be available, implementation is much easier, and cost is much less.

APPENDIX E

APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

1. INTRODUCTION

Section 121 of CERCLA specifies that remedial actions for cleanup of hazardous substances must comply with requirements or standards under federal or more stringent state environmental laws that are applicable or relevant and appropriate to the hazardous substances or particular circumstances at a site. Inherent in the interpretation of ARARs is the assumption that protection of human health and the environment is ensured.

This appendix describes the potential ARARs for remedial actions under consideration for storage options at the Waste Area Grouping 1 SIOU. The introduction is followed by a discussion of chemical-specific ARARs and then radiation protection standards. The location-specific ARARs are then discussed, followed by action-specific ARARs, which are discussed for each alternative in the FS. The text discussions focus on those potential ARARs with the potential to impact the project's compliance with ARARs. The surface impoundment sediments contain low-level waste, RCRA characteristic waste, and PCBs. The surrounding soils contain low-level waste and RCRA characteristic waste. A complete description of the SIOU and the nature and extent of contamination is found in Section 3.2 of this RI/FS. Summary Tables E.1 through E.9 include all potential ARARs identified thus far.

Federal construction activities are covered by the OSHA standards in 29 CFR 1926, "Construction Standards," and 29 CFR 1910, "General Industry." The final regulations for "Hazardous Waste Operations and Emergency Response" (29 CFR 1910.120) appeared in 54 FR 9294 (Final Rule, March 6, 1989). DOE also addresses occupational safety in 10 CFR 835, "Radiation Protection for Occupational Workers," DOE Order 5480.11, "Radiation Protection for Occupational Workers," DOE Order 5480.4, "Environmental Protection, Safety, and Health Protection Standards," DOE Order 5483.1A, Occupational Safety and Health Program for Contractors at GOCO Facilities," DOE Order 5480.9, "Construction Safety and Health Program," and DOE Order 5480.10, "Contractor Industrial Hygiene Program."

ARARs apply to those federal and state regulations that are designed to protect the environment and do not generally apply to occupational safety regulations. EPA requires compliance with the OSHA standards in 40 CFR 300.150 of the National Contingency Plan, not through the ARARs process. Therefore, neither the regulations promulgated by OSHA nor the DOE Orders related to occupational safety are addressed as ARARs.

Table E.1. Summary of chemical- and location-specific ARARs for the Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

	Requirement	Applicability	Citation
	Chemical-specific		
Radionuclides	DOE must comply with all legally applicable requirements of National Emission Standards for Hazardous Air Pollutants for DOE facilities (10 mrem/year)	Public exposure, airborne emissions from all sources -Applicable	40 CFR 61.92
	Exposures to members of the public from all radiation sources shall not cause an effective dose equivalent to be greater than 100 mrem per year	Public exposure, all sources -TBC	DOE Order 5400.5(II.1a)
	DOE will carry out all DOE activities to ensure that radiation doses to individuals will be ALARA	Planning and performance of all DOE activities -TBC	DOE Order 5400.5(I.4)
	Use RESRAD or an alternative approved method to develop specific guidelines for allowable levels of residual radioactivity left in place. The generic guidelines for ^{230}Th and ^{232}Th are 5 pCi/g averaged over the first 15 cm of soil or 15 pCi/g averaged over 15-cm-thick layers of soil below the first 15 cm	Long-term management of radioactivity left in place -TBC	DOE Order 5400.5 (IV)
Chemical	Reduce exposure with a 10-in. cover of clean soil for each order of magnitude necessary to reduce concentrations within appropriate risk levels. The Toxic Substances Control Act anti-dilution provisions are only applicable after a remedial response begins and are not appropriate to dilution which has occurred due to the introduction of PCBs into the environment under prior activities at Superfund sites	PCBs left in place at concentrations greater than 50 ppm -TBC	OSWER 9355.4-01, "Guidance on Remedial Actions for Superfund Sites with PCB Contamination"
	Based on a new lead uptake/biokinetic model, 400 ppm is recommended as a screening level for lead in soil	Cleanup of lead in soils and sediments -TBC	OSWER 9355.4-12, "Interim Guidance on Establishing Soil Lead Cleanup Levels at Superfund Sites

Table E.1 (continued)

Requirement	Applicability	Citation
Location-specific		
Action(s) that will affect such resources must adhere to the DOE-ORO Programmatic Agreement (May 9, 1994). When alteration or destruction of the resource is unavoidable, steps must be taken to minimize or mitigate the impacts and to preserve data and records of the resource	Any action that will impact historic or archaeologic resources -**Applicable**	NHPA (16 USC 470*a*–*w*) EO 11593; 36 CFR 800 DOE-ORO Programmatic Agreement (May 9, 1994)

ALARA = as low as reasonably achievable
ARAR = applicable or relevant and appropriate requirement
CFR = *Code of Federal Regulations*
cm = centimeter
DOE = U.S. Department of Energy
EO = Executive Order
g = gram
in. inch
mrem = millirem
NHPA = National Historic Preservation Act
ORNL = Oak Ridge National Laboratory
ORO = Oak Ridge Operations
OSWER = Office of Solid Waste and Emergency Response
PCB = polychlorinated biphenyl
pCi = picocurie
ppm = part per million
SIOU = Surface Impoundments Operable Unit
TBC = to be considered
Th = thorium
USC = *United States Code*

Table E.2. Summary of action-specific ARARs for Alternative 2, the multilayer cap, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Action	Requirement	Prerequisites	Citation
Institutional controls	Controls recommended include restrictions on land use, deed restrictions, well-drilling prohibitions, well-use advisories, and deed notices	Long term management of contamination left in place - **TBC**	40 CFR 300.430(e)(3)(ii)
	Controls include, but are not limited to: periodic monitoring, as appropriate; appropriate shielding; physical barriers (i.e., fences, warning signs) to prevent access; inspection and repair of coverings; temporary dikes; drainage courses; and appropriate radiological safety measures to ensure protection during activities at the site	Interim management of residual radioactive material above guidelines left in inaccessible locations - **TBC**	DOE Order 5400.5(IV)(6)(c)
	Minimize the unauthorized entry of persons or livestock using signs, barriers, security measures, etc.	Closure of a surface impoundment with waste in place - **Relevant and Appropriate**	40 CFR 264.14 TDEC 1200-1-11-.06(11)
Stormwater runoff	Sediment and erosion controls and best management practices must be utilized to control runoff from construction activities	Control of stormwater discharges associated with construction activities at industrial sites that result in a disturbance of greater than 5 acres of total land area - **Applicable** For those sites with less than 5 acres affected - **Relevant and Appropriate**	40 CFR 122 TDEC 1200-4-10-.05
	National Pollutant Discharge Elimination System permit required if stormwater runoff is collected and discharged to a new outfall; monitor to ensure compliance with the state water quality standards	Control of stormwater runoff at industrial sites - **Applicable**	40 CFR 122.26 TDEC 1200-4-10-.04

Table E.2 (continued)

Action	Requirement	Prerequisites	Citation
Fugitive emissions from construction activities	Take reasonable precautions to prevent particulate matter from becoming airborne; no visible emissions are permitted beyond property boundary lines for more than 5 min/hour or 20 min/day. Potential non-point sources of fugitive emissions are included in the plant-wide fugitive emissions plan	Non-point source air emissions - **Applicable**	TDEC 1200-3-8-.010
	Limits emissions of radionuclides to the ambient air from DOE facilities to 10 mrem/year for the total site	Point source air emissions - **Applicable**	40 CFR 61.92
	Requires point source emissions monitoring for any source with the potential to emit in excess of 0.1 mrem/year		40 CFR 61.93
Treatment of surface water from SIOU	Must meet waste acceptance criteria of water treatment facility	Discharge to treatment facility - **TBC**	ORNL Liquid Waste Treatment Systems waste acceptance criteria, WM-WMCO-201, July 1991
	On-site wastewater treatment units that are part of a wastewater treatment facility that is subject to regulation under §402 or §307(b) of the CWA (i.e., are National Pollutant Discharge Elimination System-permitted) are exempt from the requirements of RCRA Subtitle C standards	All tank systems, conveyance systems, and ancillary equipment used to store or transport wastewater to the Process Waste Treatment Plant - **Applicable**	40 CFR 260.10; 40 CFR 270.1(c)(2); 53 FR 34079, September 2, 1988
Closure of SIOU	Eliminate free liquids or solidify remaining waste and waste residues; stabilize remaining wastes to a bearing capacity sufficient to support final cover	Closure with waste in place - **Relevant and Appropriate**	40 CFR 264.228(a)(2)(i-ii) TDEC 1200-1-11-.06(11)

ARAR = applicable or relevant and appropriate requirement
CFR = *Code of Federal Regulations*
CWA = Clean Water Act
DOE = U.S. Department of Energy
FR = *Federal Register*
min = minute
mrem = millirem
ORNL = Oak Ridge National Laboratory
RCRA = Resource Conservation and Recovery Act
SIOU = Surface Impoundments Operable Unit
TBC = to be considered
TDEC = Tennessee Department of Environment and Conservation

Table E.3. Summary of action-specific ARARs for Alternative 3, consolidation cell with simple dewatering, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Action	Requirement	Prerequisites	Citation
Institutional controls			
	See Table E.2		
Stormwater runoff			
	See Table E.2		
Fugitive emissions from construction activities			
	See Table E.2		
Treatment of surface water from SIOU			
	See Table E.2		
Installation of a liner in the consolidation cell			
RCRA	The liner system must consist of two liners and a leachate collection and removal system consisting of: • a top liner (e.g., geomembrane) to prevent the migration of hazardous constituents into the liner during the postclosure period; • a bottom liner with upper component liner (also to prevent migration) and lower component consisting of at least 3 ft of compacted soil with a permeability of 1×10^{-7} cm/second; • leachate collection and removal system between the top and bottom liner capable of detecting, collecting and removing leachate from all areas of the impoundment during the postclosure care period. This requirement can be met by:	Upgrade of an existing surface impoundment -Relevant and Appropriate	40 CFR 264.221(c); TDEC 1200-1-11-.06(11)

Table E.3 (continued)

Action	Requirement	Prerequisites	Citation
	— construction of a bottom slope of 1 percent; and — 12 in. or more granular drainage material with a hydraulic conductivity of 1×10^{-1} or synthetic or geonet drainage materials with a transmissivity of 3×10^{-4} seconds or more		
	Must comply with the requirements of 264.221(a)(1),(2),(3) as follows: • constructed of appropriate materials to prevent failure due to pressure gradients, contact with the waste, climatic conditions, or stress from installation or daily operation; • placed on a base or foundation capable of supporting the liner and resistance to the pressure gradients above and below the liner to prevent failure of the liner; and • installed to cover all areas likely to be in contact with the waste or leachate		40 CFR 264.221(c)(1)(ii); TDEC 1200-1-11-.06(11)
	Constructed of material chemically resistant to the waste and of sufficient strength and thickness to prevent collapse		40 CFR 264.221(c)(2)(iii); TDEC 1200-1-11-.06(11)
	Inspect liners during installation and construction for uniformity, imperfections, or damage		40 CFR 264.226(a); TDEC 1200-1-11-.06(11)
	Monitor and record leachate removed from the leachate collection system during the postclosure period		40 CFR 264.226(d); TDEC 1200-1-11-.06(11);
	Alternative design practices to those in 40 CFR 264.221(c) may be approved by the Regional Administrator if the owner or operator can prove the design will: • prevent migration of the waste to the groundwater or surface water; and • allow detection of leaks through the top liner at least as effectively as a double liner and leachate collection and removal system as required in 40 CFR 264.221(c)		40 CFR 264.221(d); TDEC 1200-1-11-.06(11)

Table E.3 (continued)

Action	Requirement	Prerequisites	Citation
Toxic Substances Control Act	The synthetic membrane liner must have a minimum thickness of 30 mils	Disposal of PCBs in a chemical waste landfill -Applicable	40 CFR 761.75(b)
DOE Orders	Must comply with the prohibition of new or increased discharges of radionuclides in liquid waste to active or virgin soil columns	Discharge of liquid wastes to soil columns -TBC	DOE Order 5400.5(II)(3)(b)
Chemical waste landfill general design requirements			
	Wastes placed in the consolidation cell must be compatible with PCBs or segregated from the PCBs	Disposal of PCBs in a chemical waste landfill -Applicable	40 CFR 761.75(b)
	Provide diversion structures capable of diverting all surface water runoff from a 24-hour, 25-year storm		
	The landfill must be located above the historical high groundwater table. The bottom of the liner shall be at least 50 ft above the historical high water table		
	Must be located in thick relatively impermeable formations (clay pans) or where soil has a high clay content meeting the requirements of 40 CFR 761.75(b)(1)		
	Must be located in an area which minimizes erosion and prevents landsliding or slumping		
	If evidence is provided to the Regional Administrator that the operation of the landfill will not present an unreasonable risk of injury to health or the environment from PCBs, one or more of the requirements of 40 CFR 761.75(b) may be waived at the discretion of the Administrator		40 CFR 761.75(c)
Final closure and capping of the consolidation cell			
RCRA	Eliminate free liquids or solidify remaining waste and waste residues Stabilize remaining wastes to a bearing capacity sufficient to support final cover	Closure with waste in place -Relevant and Appropriate	40 CFR 264.228(a)(2) TDEC 1200-1-11-.06(11)

Table E.3 (continued)

Action	Requirement	Prerequisites	Citation
	Cover the consolidation cell with a final cover designed and constructed to: • provide long-term minimization of migration of liquids; • function with minimum maintenance; • promote drainage and minimize erosion and abrasion to the cover; • accommodate settling and subsidence; and • have a permeability less than or equal to the natural subsoils present		
Toxic Substances Control Act	Capping of a PCB chemical waste landfill does not have specific requirements; however, should parallel a RCRA closure	Closure of chemical landfill - TBC	OSWER 9355.4-01, "Guidance on Remedial Actions for Superfund Sites with PCB Contamination"
DOE Orders	Control and stabilization features shall be designed to provide, to the extent reasonably achievable, an effective life of 50 years and minimum life of 25 years	Interim storage of residual radioactive material which exceeds residual radioactive guidelines - TBC	DOE Order 5400.5(IV)(6)(b)(1)
	Controls may be used for interim management such as fences, warning signs, and restrictions on land use	Interim and long-term management of residual radioactive material above decontamination guidelines - TBC	DOE Order 5400.5(IV)(6)(b)(4)
Postclosure maintenance monitoring			
RCRA	Postclosure care must begin after closure and continue for 30 years after that date	Closure with waste in place -Relevant and Appropriate	40 CFR 264.117; TDEC 1200-1-11-.06(7)
	Maintain the effectiveness and integrity of the final cover including preventing run-on and runoff from damaging the final cover		40 CFR 264.228(b) TDEC 1200-1-11-.06(11)
	Maintain and monitor a groundwater monitoring system in compliance with 40 CFR 264 Subpart F		40 CFR 264.228(b)(3) 40 CFR 264 Subpart F TDEC 1200-1-11-.06(11)

Table E.3 (continued)

Action	Requirement	Prerequisites	Citation
Toxic Substances Control Act	Sample designated watercourses once every 6 months after disposal is completed (monthly during disposal)	Closure of a chemical waste landfill -Applicable	40 CFR 761.75(b)
	Groundwater monitoring of three points in the landfill, frequency determined on a site-specific basis		40 CFR 761.75(b)
	A 6-ft woven mesh fence, wall or similar device shall be placed around the site to prevent unauthorized access		40 CFR 761.75(b)
DOE Orders	Design and implement an environmental monitoring program that conforms to DOE Order 5400.1(IV) and is capable of measuring migration of radionuclides and detecting changing trends in performance to allow sufficient time for corrective action before performance objectives are exceeded	Low-level waste storage facility -TBC	DOE Order 5820.2A DOE Order 5400.1(IV)
Closure of Impoundments 3513, 3539, and 3540			
	Eliminate free liquids or solidify remaining waste and waste residues if any; stabilize remaining wastes to a bearing capacity sufficient to support final cover	Closure with waste in place -Relevant and Appropriate	40 CFR 264.228(a)(2)(i-ii) TDEC 1200-1-11-.06(11)

ARAR = applicable or relevant and appropriate requirement
CFR = *Code of Federal Regulations*
cm = centimeter
DOE = U.S. Department of Energy
ft = foot
in. = inch
ORNL = Oak Ridge National Laboratory
OSWER = Office of Solid Waste and Emergency Response
PCB = polychlorinated biphenyl
RCRA = Resource Conservation and Recovery Act
SIOU = Surface Impoundments Operable Unit
TBC = to be considered
TDEC = Tennessee Department of Environment and Conservation

Table E.4. Summary of action-specific ARARs for Alternative 4, consolidation cell with ex situ on-site treatment, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Action	Requirement	Prerequisites	Citation
Institutional controls			
	See Table E.2		
Stormwater runoff			
	See Table E.2		
Fugitive emissions from construction activities			
	See Table E.2		
Treatment of surface water from SIOU			
	See Table E.2		
Movement of waste from SIOU to the treatment facility and back to the consolidation cell			
	Must treat to meet the LDRs for those RCRA characteristic wastes for which LDRs have been promulgated	Wastes which failed EP toxicity test or current TCLP tests for hazardous wastes **-Applicable**	40 CFR 268
	Where a treatment technology specified in 40 CFR 268 is not appropriate to the waste, the generator may apply for a treatability variance to comply with the LDRs	Hazardous wastes for which the technology specified in 40 CFR 268 is appropriate **-Applicable**	40 CFR 268.44
Tank requirements for treatment or storage (on site)			
	Ensure that existing and new tanks have sufficient structural strength that is compatible with the waste to prevent collapse or rupture	Storage or treatment of RCRA hazardous waste (listed or characteristic) in a tank **-Applicable**	40 CFR 264.191-192; TDEC 1200-1-11-.06(10)(b)-(c)

Table E.4 (continued)

Action	Requirement	Prerequisites	Citation
	Ensure that waste is compatible with the tank material unless the tank is protected by a liner or by other means		40 CFR 264.191; TDEC 1200-1-11-.06(10)(b)
	Provide tanks with secondary containment and controls to prevent overfilling, and maintain sufficient freeboard in open tanks to prevent overtopping by wave action or precipitation		40 CFR 264.193-194; TDEC 1200-1-11-.06(10)(d)-(e)
	Inspect the following: overfilling control, control equipment, monitoring data, waste level (for uncovered tanks), tank condition, aboveground portions of tanks (to assess their structural integrity), and the area surrounding the tank (to identify signs of leakage)		40 CFR 264.195; TDEC 1200-1-11-.06(10)(f)
	Repair any corrosion, crack, or leak		40 CFR 264.196; TDEC 1200-1-11-.06(10)(g)
	At closure, remove all hazardous waste and hazardous waste residues from tanks, discharge control equipment, and discharge confinement structures		40 CFR 264.197(a); TDEC 1200-1-11-.06(10)(h)
	If all contaminated contents cannot be removed, consider the tank system a landfill and close in accordance with the landfill closure requirements of 40 CFR 264.310		40 CFR 264.197(b); TDEC 1200-1-11-.06(10)(h)
	Less stringent minimum technology requirements may be applied to tanks designated as temporary units; protection of human health and the environment must be ensured	Tank units used for management of RCRA or CERCLA remediation wastes and designated as temporary units **-Applicable**	40 CFR 264.553
Chemical waste landfill general design requirements			
	See Table E.3		

Table E.4 (continued)

Action	Requirement	Prerequisites	Citation
Installation of a liner in the consolidation cell			
	See Table E.3		
Final closure and capping of the consolidation cell			
	See Table E.3		
Postclosure maintenance monitoring			
	See Table E.3		
Closure of Impoundments 3513, 3539, and 3540			
	See Table E.3		

ARAR = applicable or relevant and appropriate requirement
CERCLA Comprehensive Environmental Response, Compensation, and Liability Act
CFR = *Code of Federal Regulations*
EP = Extraction Procedure
LDR = land disposal restrictions
ORNL = Oak Ridge National Laboratory
RCRA = Resource Conservation and Recovery Act
SIOU = Surface Impoundments Operable Unit
TCLP = Toxicity Characteristic Leaching Procedure
TDEC = Tennessee Department of Environment and Conservation

Table E.5. Summary of action-specific ARARs for Alternative 5, off-SIOU consolidation cell, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Action	Requirement	Prerequisites	Citation
Institutional controls			
	See Table E.2		
Stormwater runoff			
	See Table E.2		
Fugitive emissions from construction activities			
	See Table E.2		
Treatment of surface water from SIOU			
	See Table E.2		
Chemical waste landfill general design requirements			
	See Table E.3		
Installation of a liner in the consolidation cell			
RCRA	The RCRA landfill regulations found at 40 CFR 264.301 and TDEC 1200-1-11-.06(14) will be relevant and appropriate to the design of the consolidation cell. These regulations mirror those for surface impoundments at 40 CFR 264.221(c) and TDEC 1200-1-11-.06(11), which are listed in Table E.3		
Toxic Substances Control Act	See Table E.3		
DOE orders	See Table E.3		
Final closure and capping of the consolidation cell			

Table E.5 (continued)

Action	Requirement	Prerequisites	Citation
RCRA	The RCRA landfill regulations found at 40 CFR 264.301 and TDEC 1200-1-11-.06(14) will be relevant and appropriate to the capping and closure of the consolidation cell. These regulations mirror those for surface impoundments at 40 CFR 264.221(c) and TDEC 1200-1-11-.06(11), which are listed in Table E.3	Capping and closure of disposal cell — **Relevant and Appropriate**	40 CFR 264.301 TDEC 1200-1-11-.06(14)
Toxic Substances Control Act	See Table E.3		
DOE Orders	See Table E.3		
	Must comply with DOE Order 5820.2A performance objectives	Low-level waste disposal - **TBC**	DOE Order 5820.2A
Postclosure maintenance monitoring			
RCRA	The RCRA landfill regulations found at 40 CFR 264.301 and TDEC 1200-1-11-.06(14) will be relevant and appropriate to the postclosure care of the consolidation cell. These regulations mirror those for surface impoundments at 40 CFR 264.221(c) and TDEC 1200-1-11-.06(11), which are listed in Table E.3	Postclosure monitoring at disposal cell — **Relevant and Appropriate**	40 CFR 264.301 TDEC 1200-1-11-.06(14)
Toxic Substances Control Act	See Table E.3		
DOE Orders	See Table E.3		
Closure of SIOU	See Table E.3 "Closure of Impoundments 3513, 3539, 3524, and 3540"		
Transport of the contaminated sediment and subimpoundment soils			
	Cargo tanks used in the transportation of hazardous waste must meet the qualifications and maintenance requirements as found in 49 CFR 180, Subpart E, and meet the substantive requirements of 40 CFR 171, 172, 173, 177, and 178	Cargo tank used for the transportation of hazardous waste within the CERCLA AOC -**Relevant and Appropriate**	49 CFR 180; 40 CFR 171, 172, 173, 177, and 178

Table E.5 (continued)

Action	Requirement	Prerequisites	Citation
	A pipeline used to transport the contaminated materials to a consolidation cell must meet requirements found in 49 CFR 195	Pipelines used for transportation of hazardous waste within the CERCLA AOC -Relevant and Appropriate	49 CFR 195

AOC = area of concern
ARAR = applicable or relevant and appropriate requirement
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
CFR = *Code of Federal Regulations*
DOE = U.S. Department of Energy
ORNL = Oak Ridge National Laboratory
RCRA = Resource Conservation and Recovery Act
SIOU = Surface Impoundments Operable Unit
TBC = to be considered
TDEC = Tennessee Department of Environment and Conservation

Table E.6. Summary of action-specific ARARs for Alternative 6, removal and disposal, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Action	Requirement	Prerequisites	Citation
Institutional controls			
	See Table E.2		
Stormwater runoff			
	See Table E.2		
Fugitive emissions from construction activities			
	See Table E.2		
Treatment of surface water from SIOU			
	See Table E.2		
Closure of SIOU			
	See Table E.4		
Treatment of the waste to meet the disposal requirements of 40 CFR 761.60(a)(4)			
	The Regional Administrator may approve an alternate disposal method which can achieve a level of performance equivalent to incineration or high efficiency boilers	Disposal of PCB-contaminated soil and sediment -**Applicable**	40 CFR 761.60(e)
			40 CFR 761.60(i)(2)
Movement of waste from SIOU			
	Must treat to meet the land disposal restrictions for those RCRA characteristic wastes for which land disposal restrictions have been promulgated	Wastes that failed EP toxicity test or current TCLP tests for hazardous wastes -**Applicable**	40 CFR 268

Table E.6 (continued)

Action	Requirement	Prerequisites	Citation
	Where a treatment technology specified in 40 CFR 268 is not appropriate to the waste, the generator may apply for a treatability variance to comply with the land disposal restrictions	Hazardous wastes for which the technology specified in 40 CFR 268 is appropriate -**Applicable**	40 CFR 268.44
Tank requirements for treatment or storage (on site)			
	See Table E.4		
Transportation of waste to a disposal facility			
	Generators must certify before the shipment that the waste meets the waste acceptance criteria of the receiving facility	Waste shipped from one field organization to another for disposal -**TBC**	DOE Order 5820.2A(III)
Transportation to a licensed off-site disposal facility			
	The waste must meet packaging, labeling, marking, placarding, manifest and pretransport requirements in accordance with DOT regulations	Transportation of radioactive materials above exempt quantities - **Applicable**	49 CFR Parts 172, 173, 175, 178, and 179; DOE Order 5480.3 (TBC)
	Exemption from the TDEC radiation protection regulations for radioactive material in individual quantities that do not exceed the applicable quantity set forth in Schedule RHS 8-3	Handling of radioactive materials above exempt quantities - **Applicable**	TDEC 1200-2-10-.04(3)
	Transporter and receiving facility must be licensed	Delivery of licensable quantities of radioactive material to a disposal facility within the state - **Applicable**	TDEC 1200-2-10-.32(4)
	Packaging requirements are based on the maximum activity of radioactive material in a package	Packaging of radioactive materials above exempt quantities for public transport -**Applicable**	49 CFR 173.431; 49 CFR 173.433; 49 CFR 173.435; 49 CFR 173.411

Table E.6 (continued)

Action	Requirement	Prerequisites	Citation
	Low-level waste must be disposed of on site; if off-site disposal is required due to lack of capacity, disposal must be to a DOE facility	Shipments of low-level waste - TBC	DOE Moratorium on Low-Level Waste Shipments (May 17, 1991); DOE Order 5820.2A
	Off-site disposal of low-level waste to a commercial facility requires an exemption from the on-site disposal requirements of DOE Order 5820.2A; requests for exemption must be approved by the DOE-Oak Ridge Operations Field Office	Shipments of low-level waste - TBC	Grumbly Memorandum October 12, 1993

ARAR = applicable or relevant and appropriate requirement
CFR = *Code of Federal Regulations*
DOE = U.S. Department of Energy
DOT = U.S. Department of Transportation
EP = extraction procedure
ORNL = Oak Ridge National Laboratory
PCB = polychlorinated biphenyl
RCRA = Resource Conservation and Recovery Act
SIOU = Surface Impoundments Operable Unit
TBC = to be considered
TCLP = Toxicity Characteristic Leaching Procedure
TDEC = Tennessee Department of Environment and Conservation

Table E.7. Summary of action-specific ARARs for Alternatives 2 through 5, contingency actions, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee

Action	Requirement	Prerequisites	Citation
Contingency action for all alternatives: use of zeolite package treatment plant			
Generated wastes	A person who generates solid wastes must determine whether that waste is hazardous using various methods, including application of knowledge of the hazardous characteristics of the waste based on information regarding the materials or processes used. RCRA restricted wastes must be treated to meet the land disposal restrictions	Generation of solid wastes **-Applicable**	40 CFR 262.11 TDEC 1200-1-11-.03(1)(b)
Storage of spent zeolite	Allows storage of mixed wastes at the ORR for periods longer than 1 year pending development of treatment capacity	Storage of mixed waste **-TBC**	EPA/DOE LDR-FFCA
Contingency action for Alternatives 3 and 5, mechanical dewatering			
Movement of waste from SIOU to a RCRA unit and back to the consolidation cell	Must treat to meet the land disposal restrictions for those RCRA characteristic wastes for which land disposal restrictions have been promulgated	Wastes which failed EP toxicity test or current TCLP tests for hazardous wastes **-Applicable**	40 CFR 268
	Where a treatment technology specified in 40 CFR 268 is not appropriate to the waste, the generator may apply for a treatability variance to comply with the land disposal restrictions	Hazardous wastes for which the technology specified in 40 CFR 268 is in appropriate **-Applicable**	40 CFR 268.44
Tank requirements for treatment or storage (on site)		See Table E.4	

ARAR = applicable or relevant and appropriate requirement
CFR = *Code of Federal Regulations*
DOE = U.S. Department of Energy
EP = Extraction Procedure
EPA = U.S. Environmental Protection Agency
FFCA = Federal Facility Compliance Agreement
LDR = land disposal restriction
ORNL = Oak Ridge National Laboratory
ORR = Oak Ridge Reservation
RCRA = Resource Conservation and Recovery Act
SIOU = Surface Impoundments Operable Unit
TBC = to be considered
TCLP = Toxicity Characteristic Leaching Procedure
TDEC = Tennessee Department of Environment and Conservation

Table E.8. Summary of potential TDEC radiation protection standards as relevant and appropriate to the FS storage alternatives, Waste Area Grouping 1 SIOU, ORNL, Oak Ridge, Tennessee[a]

	Relevant and appropriate[d]			
	Alternative 2	Alternative 3	Alternative 4	Alternative 5
TDEC 1200-2-11-.16, Performance Objectives				
(1) Land disposal facilities must be sited, designed, operated, closed and controlled after closure so that reasonable assurance exists that exposure to humans is within limits established in the performance objectives				
(2) Protection of the general population from releases of radioactivity. Concentrations of radioactive material that may be released to the general environment in groundwater, surface water, air, soil, plants or animals must not result in an annual dose exceeding an equivalent of 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ. Reasonable effort shall be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable	yes	yes	yes	yes
TDEC 1200-2-11-.17, Technical Requirements for Land Disposal Facilities				
(1) Disposal site suitability requirements for land disposal				
(a) The purpose of this section is to specify the minimum characteristics a disposal site must have to be acceptable for use as a disposal facility. The primary emphasis in the disposal site suitability is given to isolation of wastes, a matter having long-term impacts, and to disposal site features that ensure that the long-term performance objectives of 1200-2-11-.16 of this part are met, as opposed to short-term convenience or benefits				
(b) Disposal site shall be capable of being characterized, modeled, analyzed, and monitored	yes	yes	yes	yes
(d) Areas must be avoided having known natural resources which, if exploited, would result in failure to meet performance objectives	yes	yes	yes	yes
(e) Disposal site must be generally well-drained and free of areas of flooding and frequent ponding and located outside 100-year floodplains or wetland areas	no	no	no	yes
(f) Minimize the upstream drainage areas to decrease the amount of runoff that could erode or inundate the disposal unit	yes	yes	yes	yes

Table E.8 (continued)

	Relevant and appropriate[a]			
	Alternative 2	Alternative 3	Alternative 4	Alternative 5
(g) The disposal site must provide sufficient depth to the water table that groundwater intrusion, perennial or otherwise, into the waste will not occur. The Department will consider an exception to this requirement to allow disposal below the water table if it can be conclusively shown that disposal site characteristics will result in molecular diffusion being the predominant means of radionuclide movement and the rate of movement will result in the performance objectives of 1200-2-11-.16 being met. In no case will waste disposal be permitted in the zone of fluctuation of the water table	no	no	no	yes
(h) The hydrogeologic unit used for disposal shall not discharge groundwater to the surface within the disposal site	no	no	no	yes
(i)(j) Areas must be avoided where tectonic processes such as faulting, folding, seismic activity or surface geologic processes such as mass wasting, erosion, slumping, landsliding or weathering may occur with such frequency and extent to effect the ability of the disposal site to meet performance objectives or preclude defensible modeling and prediction of long-term impacts	no	no	no	yes
(k) The disposal site must not be located where nearby activities or facilities could impact the site's ability to meet performance objectives or mask environmental monitoring	no	no	no	yes
(2) Disposal site design for land disposal (a) Site design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance after site closure	yes	yes	yes	yes
(d) Covers must be designed to minimize to the extent practicable water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity	yes	yes	yes	yes
(e) Surface features must direct surface water drainage away from disposal units at velocities and gradients that will not result in erosion that will require ongoing active maintenance in the future	yes	yes	yes	yes

Table E.8 (continued)

	Relevant and appropriate[a]			
	Alternative 2	Alternative 3	Alternative 4	Alternative 5
(f) The disposal site must be designed to minimize to the extent practicable the contact of water with waste during storage, the contact of standing water with waste during disposal, and the contact of percolating or standing water with wastes after disposal	yes	yes	yes	yes
(3) Land disposal facility operation and disposal site closure				
(c) All wastes shall be disposed of in accordance with the requirements of (d) through (k)				
(g) The boundaries and locations of each disposal unit (e.g., trenches) must be accurately located and mapped by means of a land survey. Disposal units must be marked in such a way that the boundaries of each unit can be easily defined. Three permanent survey marker control points, referenced to USGS or NGS survey control stations, must be established on the site to facilitate surveys. The USGS or NGS control stations must provide horizontal and vertical controls as checked against USGS or NGS record files	yes	yes	yes	yes
(h) Maintenance of a buffer zone of land between the disposal unit and disposal boundary and beneath the disposed waste	yes	yes	yes	yes
(j) Active waste disposal operations must not have an adverse effect on completed closure and stabilization measures	yes	yes	yes	yes
(k) Only wastes containing or contaminated with radioactive materials shall be disposed of at the disposal site	yes	yes	yes	yes
(4) Environmental Monitoring				
(b) The licensee must have plans for taking corrective measures if migration of radionuclides would indicate that the performance objectives of 1200-2-11-.16 may not be met	yes	yes	yes	yes

Table E.8 (continued)

	Relevant and appropriate[a]			
	Alternative 2	Alternative 3	Alternative 4	Alternative 5
(c) During the land disposal facility site construction and operation, the licensee shall maintain a monitoring program, including a monitoring system. Measurements and observations must be made and recorded to provide data to evaluate the potential health and environmental impacts during both the construction and the operation of the facility and to enable the evaluation of long-term effects and the need for mitigative measures. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal unit before they leave the site boundary	no	no	no	yes
(d) After the disposal site is closed, the licensee responsible for postoperational surveillance of the disposal site shall maintain a monitoring system based on the operating history and the closure and stabilization of the disposal site. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal unit before they leave the site boundary	yes	yes	yes	yes
(5) Alternative requirements for design and operations. The Department may, upon request or on its own initiative authorize provisions other than those set forth in (2), (3), and (4), of this Rule for the segregation and disposal of waste and for the design and operation of a land disposal facility on a specific basis, if it finds the assurance of compliance with the performance objectives of 1200-2-11-.16.	no	no	no	no
(7)(b) The requirements of this section are intended to provide stability of the waste. Stability is intended to ensure that the waste does not structurally degrade and affect overall stability of the site through slumping, collapse, or other failure of the disposal unit and thereby lead to water infiltration. Stability is also a factor in limiting exposure to an inadvertent intruder, since it provides a recognizable and nondispersible waste				
1. Waste must have structural stability. Maintain physical dimensions and form under expected disposal conditions (weight of overburden, weight of compaction equipment, presence of moisture, microbial activity and chemical changes)	yes	yes	yes	yes

Table E.8 (continued)

	Relevant and appropriate[a]			
	Alternative 2	Alternative 3	Alternative 4	Alternative 5
2. Notwithstanding the provisions in 1200-2-11-.17(7)(a) 2 and 3, liquid wastes, or wastes containing liquid, must be converted into a form that contains as little freestanding and noncorrosive liquid as is reasonably achievable, but in no case shall the liquid exceed 1% of the volume of the waste when the waste is in a disposal container designed to ensure stability, or 0.5 percent of the volume of the waste for waste processed to a stable form	no	no	yes	no
3. Void spaces within the waste and between the waste and its package must be reduced to the extent practicable	no	no	yes	no
(10) Institutional requirements				
(b) An institutional control program is required to physically control access to the disposal site. The program must include environmental monitoring, periodic surveillance, and minor custodial care	yes	yes	yes	yes

[a]Requirements of the TDEC regulations are only listed if potentially relevant and appropriate for at least one alternative.

FS = feasibility study
mrem = millirem
NGS = National Geodetic Survey
ORNL = Oak Ridge National Laboratory
SIOU = Surface Impoundments Operable Unit
TDEC = Tennessee Department of Environment and Conservation
USGS = United States Geologic Survey

Table E.9. Summary of DOE Order 5820.2A, Chapter II Substantive Requirements for Management of Low-Level Waste

DOE Order 5820.2A	Requirement
Chapter III(3)(a)	Performance objectives for management of low-level waste disposed of after September 26, 1988
Chapter III(3)(e)	Waste acceptance criteria must be established for each low-level waste TSD facility
Chapter III(3)(f)	Waste treatment requirements
Chapter III(3)(g)	Waste shipment requirements
Chapter III(3)(h)	Long-term storage requirements
Chapter III(3)(e)	Low-level waste disposal requirements
	Disposal site selection
	Disposal facility operations
Chapter III(3)(j)	Disposal site closure/postclosure
Chapter III(3)(k)	Environmental monitoring

DOE = U.S. Department of Energy
TSD = treatment, storage, and disposal

The following is a listing of the definitions of terms used throughout this report:

Applicable requirements are "those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site" (40 CFR 300.5).

Relevant and appropriate requirements are "those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting law that, while not applicable to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site" (40 CFR 300.5).

CERCLA on-site remedial response actions must only comply with the substantive requirements of a regulation and not the administrative requirements to obtain federal, state, or local permits [CERCLA §121(e)]. To ensure that CERCLA response actions proceed as rapidly as possible, EPA has reaffirmed this position in the final National Contingency Plan (55 FR 8756, March 8, 1990). **Substantive requirements** pertain directly to the actions or conditions at a site, while **administrative requirements** facilitate their implementation. EPA recognizes that certain of the administrative requirements, such as consultation with state agencies, reporting, etc., are accomplished through the state involvement and public participation requirements of the National Contingency Plan. These administrative requirements should be observed if they are useful in determining cleanup standards at the site (55 FR 8757).

In the absence of federal- or state-promulgated regulations, there are many criteria, advisories, guidance, and proposed standards that are not legally binding but may serve as useful guidance for setting protective cleanup levels. These are not potential ARARs, but are TBC guidance [40 CFR 300.400(g)(13)].

2. CHEMICAL-SPECIFIC ARARS

"Chemical-specific requirements set health- or risk-based concentration limits or discharge limitations in various environmental media for specific hazardous substances, pollutants, or contaminants" (55 FR 8741, March 8, 1990). These requirements generally set protective cleanup levels for the chemicals of concern in the designated media or else indicate a safe level of discharge that may be incorporated when considering a specific remedial activity. Impoundment waters and soil consisting of the sediment and subimpoundment soils in the surface impoundments and adjacent soils are the only media being addressed in the SIOU FS. Tables 3.3 and 3.4 of the RI report list radionuclide and chemical COCs, respectively.

There are no federal or state regulations governing cleanup for contaminated soils at CERCLA sites. However, regulations found in the Toxic Substances Control Act contain storage, disposal, and cleanup requirements for materials contaminated with PCBs. These regulations require that any soils containing concentrations of PCBs 50 ppm or greater (40 CFR 761.60) be incinerated (40 CFR 761.70) or disposed of in a chemical waste landfill (40 CFR 761.75). No provisions of the Toxic Substances Control Act may be avoided as a result of any dilution under 40 CFR 761.1(b).

However, in the guidance report for remedial actions at Superfund sites containing PCB(s), EPA clarifies that the Toxic Substances Control Act anti-dilution provisions are only applicable after a remedial response begins and are not appropriate to dilution that has occurred due to the introduction of PCBs into the environment under prior activities at Superfund sites (EPA 1990). The form and concentration of PCB contamination should be evaluated "as found" at the site, at which time the anti-dilution prohibition applies. The Toxic Substances Control Act requirement for disposal (40 CFR 761.75) would then be applicable for the disposal of media excavated from the SIOU with concentrations greater than 50 ppm. Preliminary remediation goals are set in the guidance report at 1 ppm for residential land use (a risk of 10^{-5}) and between 10 and 25 ppm for industrial and/or remote areas (a risk of 10^{-4}) (EPA 1990). Alternatives should reduce concentrations to these levels or limit exposures. This guidance indicates that a 26-cm (10-in.) cover of clean soil will reduce the risk by approximately one order of magnitude. These values are considered TBC guidance, not ARARs (Table E.1).

EPA has suggested cleanup values for lead in soils based on studies of levels of lead in the blood of children. The EPA Office of Solid Waste and Emergency Response Directive 9355.4-02 (dated September 7, 1989) recommends a cleanup level for soils of 500–1,000 ppm lead. However, EPA has issued interim soil lead guidance for CERCLA sites (OSWER Directive 9355.4-12, August 1994), recommending a screening level for lead in soil of 400 ppm, based on a new lead uptake/biokinetic model. This guidance discusses development of preliminary remediation goals for CERCLA sites and is considered TBC guidance for SIOU.

In the absence of federally or state-promulgated ARARs, EPA also recommends the development of risk-based goals and states a preference for reference doses or reference concentrations for systemic toxicants and carcinogen slope factors for carcinogens (EPA 1988). These are available through IRIS (EPA 1994a) and the EPA HEAST (EPA 1994b).

3. RADIATION PROTECTION STANDARDS

There are very few standards for the cleanup of radioactively contaminated CERCLA sites. The Atomic Energy Act of 1954 and its amendments delegated authority for control of nuclear energy to DOE, NRC, and EPA. Tennessee is an NRC-agreement state and, as such, has its own authority and licensing regulations found at TDEC 1200-2-4 et seq. The DOE requirements for handling and cleanup of radioactive materials applicable to DOE and its contractors are outlined in a series of internal DOE Orders. Standards in these orders are not considered by EPA to be ARARs, but are TBC guidance if no equivalent regulation exists.

The radiation exposure limit defined in DOE Order 5400.5, "Radiation Protection of the Public and the Environment," (February 8, 1990) is: an effective dose equivalent of 100 mrem/year from all exposure pathways and all DOE sources of radiation. The overriding principle of the DOE Order is that all releases of radioactive material shall be ALARA (Table E.1).

DOE Order 5400.5, Chap. IV, presents guidelines for cleanup of residual radioactive material and management of sites with residual radioactivity above the specified guidelines. Also listed are criteria for interim storage and interim and long-term management of properties where residual radioactivity is left in place above the guidelines (Table E.1). Information on application of the guidelines and requirements presented in the order, including procedures for deriving specific property guidelines for allowable levels of residual radioactive material from basic dose limits, is contained in *Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0*, (Yu et al. 1993). DOE has proposed its radiation protection standards for the public and the environment, as found in DOE Order 5400.5, for codification at 10 CFR 834 (58 FR 16268, March 25, 1993); these rules are expected to be final in May 1995 (Houlberg et al. 1995). These standards may be legally applicable for cleanup at the Waste Area Grouping 1 SIOU if finalized before the ROD is issued; in the interim they are considered TBC guidance.

Per DOE Order 5820.2A ("Radioactive Waste Management," September 9, 1988), the management of low-level radioactive waste must ensure that external exposure to the waste and concentrations of radioactive material that may be released into surface water and soil does not exceed 25 mrem/year to any member of the public. Releases to the atmosphere shall not exceed 10 mrem/year. Reasonable effort should be made to maintain releases to the environment to ALARA levels. Chapter III of DOE Order 5820.2A pertains to the management of low-level radioactive waste and contains siting, design, closure, and postclosure care requirements which may supply TBC guidance for Alternative 5. Chapter III(3)(h) provides for the long-term storage of low-level waste to allow for radionuclides to decay, or storage of wastes until they can be disposed of by approved methods.

4. LOCATION-SPECIFIC ARARS

Location-specific requirements set restrictions upon the concentration of hazardous substances or the conduct of activities solely because they are in special locations (55 FR 8741, March 8, 1990). The current information for the Waste Area Grouping 1 SIOU indicates that

the only location-specific requirement is the location of the surface impoundments in a historic district and their eligibility for listing (Table E.1).

Based on the definitions in the National Historic Preservation Act of 1966, much of ORNL has been identified as a "historic district" [16 USC 470-h-2; National Historic Preservation Act §110 (a)(2)(A)] (Carver and Slater 1994). Any prehistoric or historic district, site, building structure, or object included in, or eligible for inclusion in, the National Register of Historic Places is considered a historic property and a cultural resource. Impoundments 3513 and 3524 are eligible for listing. All undertakings at a property must comply with the requirements of the Historic Sites Act (16 USC §461), the National Historic Preservation Act as amended (16 USC §470), the Archaeological and Historic Preservation Act (16 USC §469), and Executive Order 11593, "Protection and Enhancement of the Cultural Environment" (May 13, 1971). An "undertaking" means any project, activity, or program that can result in changes in the character or use of historic properties, if any such historic properties are located in the area of potential effects.

DOE-Oak Ridge Operations has determined activities such as continued operation, maintenance, research, development, waste management, D&D, and restoration may have an effect upon historic resources included in and eligible for inclusion in the National Register. Therefore, DOE-Oak Ridge Operations has been entered into a Programmatic Agreement (May 9, 1994) with the Advisory Council on Historic Preservation (Council) and the Tennessee State Historical Preservation Officer pursuant to 30 CFR 800.13 of the regulations. All activities shall be administered in accordance with the Programmatic Agreement to satisfy the DOE-Oak Ridge Operation's responsibilities for compliance with National Historic Preservation Act Sections 106 and 110 for all individual undertakings.

National Historic Preservation Act §110(b), implemented by 36 CFR Part 800, requires agencies to document historic properties that may be destroyed or altered as a result of Federal actions or assistance. The documentation may include architectural, engineering, oral or written historical, and archaeological documents. National Historic Preservation Act §106 provides information used in determining what types of documentation need to be provided.

For Alternative 5, a potential site for the new consolidation cell at ORNL is Waste Area Grouping 5. Any consolidation cell located at Waste Area Grouping 5, or another area, would be selected to ensure that it is located outside of any floodplains or wetlands area. An ecological assessment of the Waste Area Grouping 5 (Ashwood, Suter, and Stewart 1992) area indicates there are no federal- or state-listed endangered or threatened species, or state-listed "in need of management" species present on Waste Area Grouping 5. Based on the preliminary findings of

ORNL site-wide surveys for architectural/historical and archaeological resources (DuVall 1994, Carver and Slater 1994), there are no archaeological sites, relics, or structures, or any historic properties included or eligible for inclusion in the National Register of Historic Places that would be impacted by proposed remedial actions at Waste Area Grouping 5.

5. ACTION-SPECIFIC ARARS

Performance, design, or other action-specific requirements set controls or restrictions on particular kinds of activities related to the management of hazardous waste (55 FR 8741, March 8, 1990). Selection of a particular remedial action at a site will invoke the appropriate action-specific ARARs that may specify particular performance standards or technologies, as well as specific environmental levels for discharged or residual chemicals. Although the surface impoundments are not RCRA-regulated units, RCRA characteristic waste has been identified in the sediments and subimpoundment soils. Therefore, although not legally applicable to the closure of the impoundments, certain RCRA regulations may be relevant and appropriate. This FS report discusses six potential remedial alternatives for SIOU, including no action; a multilayer cap over all impoundments; a single consolidation cell at the SIOU with dewatering; a single consolidation cell at SIOU with ex situ treatment; a consolidation cell outside the operable unit at ORNL; and complete excavation, treatment and off-site disposal. In the consolidation cell alternatives and the removal alternative (Alternatives 3–6), all impoundments that are excavated will be remediated to risk-based levels as discussed in Chapter 4 of the RI/FS. See Section 4.4 of the RI/FS for a detailed description of these alternatives. Tables E.2–E.8 summarize the ARARs for the alternatives, as discussed below.

5.1 ALTERNATIVE 1—NO ACTION

Alternative 1 includes continuation of the existing institutional and operational controls for the foreseeable future, assumed to be 30 to 100 years.

5.1.1 Institutional Controls

There are no regulatory requirements specifying monitoring or institutional controls for CERCLA units. However, the National Contingency Plan at 40 CFR 300.430(e)(3)(ii) suggests consideration of one or more alternatives that involve little or no treatment, but provide protection of human health and the environment through the use of institutional controls. The preamble to the National Contingency Plan provides examples of institutional controls, which

include land- and water-use restrictions, deed restrictions, well-drilling prohibitions, building permits, and well-use advisories and deed notices (55 FR 5706).

In DOE Order 5400.5, Chapter IV requires administrative (institutional) controls for long-term management in areas containing residual radioactivity above guidance levels. Active controls specified in the order that may be considered TBC guidance include land restrictions, fences, and warning signs. Table E.2 summarizes requirements for institutional controls for alternatives that leave waste in place.

5.2 ALTERNATIVE 2—MULTILAYER CAP WITH INSTITUTIONAL CONTROLS

Under this alternative, existing surface water would be removed from the surface impoundments, and a simple multilayer cap would be placed over the entire SIOU. Surface water controls and long-term institutional controls would be implemented to increase the effectiveness of this alternative (for a more detailed description of this alternative see Section 4.4 of this FS). The Toxic Substances Control Act disposal requirements do not apply to PCBs placed in a disposal site before February 17, 1978, which remain in place (40 CFR 761, introductory note to Subpart D). Therefore, there are no Toxic Substances Control Act requirements for closure of the surface impoundments under this alternative. ARARs for this alternative are listed in Table E.2 and discussed below.

5.2.1 Institutional Controls

See Section 5.1.1.

5.2.2 Stormwater Runoff

Stormwater discharges from activities at industrial sites involving construction operations that result in the disturbance of 2 ha (5 acres) total land or more require National Pollutant Discharge Elimination System permits for stormwater discharges (40 CFR 122). Consultation with TDEC is required to ensure compliance with the substantive requirements of the National Pollutant Discharge Elimination System permitting process for stormwater discharges during construction activities (Chap. 1200-4-10-.05 of the Rules of the TDEC). In particular, implementation of good site planning and best management practices to control stormwater discharges is required (Table E.2). After remediation, if stormwater runoff is collected and discharged to a new outfall, a modification of the existing National Pollutant Discharge Elimination System permit would be required for that outfall.

5.2.3 Fugitive Emissions

Elevation of airborne particulate concentrations may result from remediation activities. The ORNL fugitive emissions permit incorporates the TDEC requirements for control of fugitive dust by reference. These regulations are promulgated by the TDEC Air Pollution Commission at TDEC Rules, Chap. 1200-5-8-.010 (Table E.2). An operator must take reasonable precautions to prevent particulate matter from becoming airborne. In addition, fugitive dust may not be emitted as a visible emission beyond property boundary lines for more than 5 min/hour or 20 min/day.

The ORNL plant air quality permit lists general plant activities that may emit fugitive dust. The approved permit covers environmental restoration activities including non-point source fugitive emissions from remediation. The ORNL air compliance staff may extend coverage under the fugitive permit for specific activities. To ensure compliance, ambient air monitoring stations may be recommended as a best management approach for activities occurring during remediation of SIOU.

Subpart H of 40 CFR 61 addresses atmospheric radionuclide emissions from DOE facilities and may be applicable to airborne emissions during remedial activities. EPA has issued a final National Emission Standards for Hazardous Air Pollutants rule (54 FR 51654, December 15, 1989) that limits emissions of radionuclides to the ambient air from DOE facilities to amounts that would not cause any member of the public to receive an effective dose equivalent of 10 mrem/year or more (40 CFR 61.92). Title 40 CFR 61.93(b)(4)(i) requires radiological emission measurements at all release points that have a potential to discharge radionuclides into the air in quantities that could cause an effective dose equivalent in excess of 1 percent of the standard (0.1 mrem/year). All radionuclides that could contribute greater than 10 percent of the standard (1 mrem/year) for a release point shall be measured.

5.2.4 Treatment of Surface Water Removed from SIOU

To meet Clean Water Act requirements for discharge to surface water or groundwater removed from the impoundments during dewatering activities will be sent to the Process Waste Treatment Plant, and must meet the waste acceptance criteria for this facility before treatment. Any on-site wastewater treatment units that are part of a wastewater treatment facility that is subject to regulation under §402 or §307(b) of the Clean Water Act (i.e., are National Pollutant Discharge Elimination System-permitted) are exempt from the requirements of RCRA Subtitle C standards for all tank systems, conveyance systems, and ancillary equipment (40 CFR 260.10; 40 CFR 270.1(c)(2); 53 FR 34079, September 2, 1988). The Process Waste Treatment Plant feeds into the Nonradiological Waste Treatment Plant, which is a National Pollutant Discharge

Elimination System-permitted facility operating in compliance; therefore, there are no further ARARs considered for this activity (Table E.2). If the Process Waste Treatment Plant cannot accept some or all of the surface water or groundwater, a contingency is to use a package treatment plant consisting of zeolite ion exchange canisters before transferring the water to the Nonradiological Waste Treatment Plant. In addition to meeting the waste acceptance criteria for the Nonradiological Waste Treatment Plant, all spent zeolite packs must be characterized and, if necessary, managed and disposed of as a hazardous waste in accordance with 40 CFR 261, 262, and 263, or as a mixed waste under the land disposal restriction-Federal Facility Compliance Agreement (1992). As stated above, this package treatment plant, as described in the FS, will also fall within the RCRA exemption for National Pollutant Discharge Elimination System-permitted facilities.

5.2.5 Final Capping and Closure of SIOU

Closure of SIOU will be accomplished with a simple multilayer cap. The cap will be designed to provide radiation shielding, prevent airborne contamination, and protect human and ecological receptors from inadvertent intruders. Portions of the RCRA requirements for closure of a surface impoundment with waste in place will be relevant and appropriate for this action [TDEC 1200-1-11-.06(11); 40 CFR 264.228(a)(2)(i-ii)] (Table E.2). Other requirements of RCRA for closure are not appropriate to this alternative because institutional controls restricting access will be put into place to protect the public from exposure by groundwater and surface water contamination until additional measures are defined in the ROD for the Waste Area Grouping 1 soils and the groundwater OU.

5.3 ALTERNATIVE 3—CONSOLIDATION CELL WITH SIMPLE DEWATERING

This alternative would consolidate all the sediments and contaminated soil from SIOU into a consolidation cell at the current location of Impoundment 3524. Sediment and subimpoundment soil would be temporarily removed from Impoundment 3524, the consolidation cell constructed, and the sediment and soil from the impoundments placed into the consolidation cell and dewatered in place. See Section 4.4 of the FS for a more detailed description of this alternative. Due to the presence of PCBs, radioactivity, and RCRA characteristic waste in the sediment, the requirements of the Toxic Substances Control Act (applicable), RCRA (relevant and appropriate) and DOE Order 5400.5 (TBC guidance) are pertinent to this alternative (see below).

5.3.1 Institutional Controls

See Section 5.1.1.

5.3.2 Stormwater Runoff

See Section 5.2.2.

5.3.3 Fugitive Emissions

See Section 5.2.3.

5.3.4 Treatment of Surface Water Removed from SIOU

In addition to surface water or groundwater removed from the impoundments during dewatering activities, all decontamination fluids and/or collected leachate will also be sent to the Process Waste Treatment Plant and must meet the waste acceptance criteria for this facility before treatment (Sect. 5.2.4).

5.3.5 Installation of Liner in Impoundment 3524

The requirements for upgrading RCRA Subtitle C surface impoundments would be relevant and appropriate to the construction of the liner for the consolidation cell (Table E.3). Design requirements for surface impoundments are found in Subpart K of the RCRA regulations [TDEC 1200-1-11-.06(11); 40 CFR 264.221 et seq.]. A two-liner system is required with a leachate collection and removal system between the liners. The top liner must prevent the migration of hazardous constituents into the liner throughout the postclosure care period. The bottom liner consists of two components. The first component of the bottom liner must be designed to prevent migration of hazardous constituents. The second component must consist of at least 1 m (3 ft) of compacted soil. In between the top and bottom liner must be a leachate detection/collection system. For leachate collection systems not located completely above the seasonal high water mark, the leachate detection system must be able to demonstrate no adverse impact on the functioning of the system due to the presence of groundwater. Throughout the closure period, leachate from the consolidation cell must be monitored and recorded. Alternative designs may be approved by the Regional Administrator under certain conditions (Table E.3).

In addition to the RCRA surface impoundment regulations, the liner must meet the requirements of the Toxic Substances Control Act for a chemical waste landfill. The requirements largely reflect the RCRA requirements and are included in Table E.3. DOE Order 5400.5(II)(3)(b) prohibits the new or increased discharge of radionuclides in the form of liquid wastes into active or virgin soil columns. Therefore, the liner and/or leachate collection system as designed and installed must not allow the leaching of radionuclides in liquid wastes to be discharged into the soil.

5.3.6 Waste Consolidation

Wastes will be consolidated from all the impoundments and placed into the consolidation cell located at Impoundment 3524.

5.3.6.1 Consolidation of RCRA waste within SIOU

Under this alternative, relocation of sediment and soil occurs within the same operable unit (referred to as an "area of contamination" under CERCLA). The waste is remaining within the area of contamination; therefore, no "placement" or land disposal occurs per RCRA 3004(k) and the land disposal restrictions are not triggered (55 FR 8760, March 8, 1990; EPA 1989).

5.3.6.2 Consolidation of PCBs within SIOU

Under this alternative, movement of any sediment containing PCB concentrations of 50 ppm or greater must also comply with the Toxic Substances Control Act requirements for disposal. (See Chapter 2 for a discussion of the Toxic Substances Control Act anti-dilution provision.) PCB contamination in the sediment exceeds 50 ppm; therefore, under the Toxic Substances Control Act, disposal options are limited to incineration or disposal in a chemical waste landfill unless an alternative method is approved per 40 CFR 761.65 (40 CFR 761, Subpart D). Under this alternative, the Toxic Substances Control Act requirements for design of a chemical waste landfill will be applicable (Table E.3).

A chemical waste landfill must be located above the historical high groundwater table and the bottom liner located 15 m (50 ft) from the historical high water table [40 CFR 761.75(b)(3)]. If the consolidation cell cannot meet this requirement or any other requirement in the chemical waste landfill requirements, 40 CFR 761.75(c) allows the Regional Administrator to grant waivers of any requirement in 40 CFR 761.75(b) by evidence showing that the operation of the landfill will not present an unreasonable risk of injury to health or the environment from PCBs (Table E.3).

5.3.7 Final Capping and Closure of Impoundment 3524

If a RCRA-permitted surface impoundment containing hazardous waste is closed with waste in place, the facility owner must close the facility and perform postclosure care in accordance with the RCRA surface impoundment closure requirements [TDEC 1200-1-11-.06(11); 40 CFR 264.228; see Table E.3]. The Waste Area Grouping 1 surface impoundments are not RCRA-permitted; however, the RCRA requirements for closure with waste in place will be relevant and appropriate because RCRA characteristic waste has been identified at SIOU. Tennessee has obtained RCRA authorization for the general RCRA program; therefore, TDEC citations are referenced on Table E.3; the federal citation is also given for general reference. The

owner or operator must eliminate free liquids and stabilize remaining wastes to a bearing capacity sufficient to support a final cover [TDEC 1200-1-11-.06(11); 40 CFR 264.228(a)(2)(i, ii)]. The surface impoundments must be covered with a final cover designed and constructed to provide long-term minimization of migration of liquids through the capped area, function with minimum maintenance, promote drainage and minimize erosion or abrasion of the cover, and accommodate settling and subsidence so that the cover's integrity is maintained. Additionally, to keep water and leachate from collecting in the waste, the cap should have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present [TDEC 1200-1-11-.06(11); 40 CFR 228(a)(2)(iii)].

General postclosure care regulations appear at TDEC 1200-1-11-.06(7) (40 CFR 264.117). The TDEC Commissioner may determine the postclosure care period based on consideration of continued protection of human health and the environment. The security controls of 40 CFR 264.14, which minimize the unauthorized entry of persons or livestock, may also be relevant and appropriate (see "Institutional Controls" on Table E.2).

Postclosure care requirements for surface impoundments [TDEC 1200-1-11-.06(11); 40 CFR 264.228(b)] are also listed in Table E.3 and include long-term maintenance of the cover, run-on and runoff diversion systems, etc.

In addition to the RCRA surface impoundment requirements, which would be relevant and appropriate to this remedial alternative, closure of the surface impoundments must also comply with DOE Order 5400.5(IV)(6) requirements for monitoring and long-term management of radionuclides above residual radioactivity guidelines (see Table E.3). These DOE requirements would be TBC guidance for this action.

The capping of the consolidation cell is not regulated under the Toxic Substances Control Act. However, the Toxic Substances Control Act regulations add additional monitoring and closure requirements for a chemical waste landfill as described in Table E.3.

5.3.8 Closure of Impoundments 3513, 3539, and 3540

During relocation of sediment and subimpoundment soils from Impoundments 3513, 3539, and 3540, all contaminated sediment will be removed from the impoundments. If all contaminated subsoils associated with these surface impoundments cannot be removed, portions of the RCRA requirements for closure with waste in place will also be relevant and appropriate for this action [TDEC 1200-1-11-.06(11); 40 CFR 264.228(a)(2)(i-ii)] (Table E.3). Other requirements of closure with waste in place, (e.g., capping) while relevant, are not appropriate since this is considered an interim action for these particular impoundments. Contaminated

subsoils at these impoundments will be addressed in future CERCLA actions for subsoils in Waste Area Grouping 1.

5.3.9 Mechanical Dewatering Contingency

If engineering support studies indicate the sediment and soil would retain excessive amounts of water so that the structural stability of the consolidation cell would be impacted, a mechanical dewatering process would be used. If tanks are used in the mechanical dewatering process, the RCRA tank requirements must be followed (Table E.7). Movement of the waste from the surface impoundments to a RCRA unit (i.e., tank) at the operable unit and placement back into the operable unit after mechanical dewatering would be considered "placement" under RCRA, triggering the land disposal restrictions for restricted waste, since the waste has left the operable unit and entered the RCRA unit and subsequently been placed back in the operable unit (55 FR 8760, March 8, 1990; EPA 1989; see Sect. 5.4.1 for a discussion on land disposal restrictions and Table E.7).

5.4 ALTERNATIVE 4—CONSOLIDATION CELL WITH EX SITU TREATMENT

This alternative is the same as the previous alternative with one additional component of on-site, ex situ treatment by stabilization/solidification before transferring the waste to the consolidation cell. As mentioned, the movement of wastes for consolidation within an excavated operable unit will not trigger the RCRA land disposal restrictions. However, movement of the waste from the surface impoundments to the ex situ treatment unit at the operable unit and placement back into the unit after treatment would be considered "placement" under RCRA, triggering the land disposal restrictions for restricted waste, since the waste has left the operable unit and entered the treatment unit (55 FR 8760, March 8, 1990; EPA 1989).

5.4.1 RCRA Restricted Waste

The EP toxicity test was run on the sediments of all four impoundments. In these tests, only mercury failed the EP toxicity tests. For those wastes that are generated during remediation, the generator must properly characterize those wastes under 40 CFR 261 to determine if those wastes are hazardous. Analysis of SIOU for all metals indicates that Cr, Cd, Pb, Hg, As, and Se will potentially fail the TCLP test when performed following generation of waste.

For those wastes which fail the EP toxicity test as well as the TCLP (i.e., mercury), the wastes would have to be treated to meet the land disposal restrictions (Table E.4). However, those wastes that pass the EP toxicity test, but fail the TCLP, are considered hazardous, but not restricted wastes since land disposal restrictions have not yet been promulgated for these newly identified toxicity characteristic wastes (58 FR 48116, September 14, 1993). Since those wastes

would be considered hazardous, the consolidation cell receiving those wastes would have to meet the RCRA Subtitle C requirements for surface impoundments as described in Table E.3. The land disposal restrictions for the newly identified toxicity characteristic metal wastes (D004–D011) are currently scheduled to be promulgated in June 1996 (Houlberg et al. 1995) and, when promulgated, would be legally applicable for placement of all restricted waste at the SIOU after that time.

It appears that 2,4-dinitrotoluene, for which land disposal restrictions have been promulgated, may also fail the TCLP. The newly promulgated universal treatment standard for 2,4-dinitrotoluene is 140 mg/kg in nonwastewaters (40 CFR 268.48). The concentration of 2,4-dinitrotoluene at the SIOU is well below the universal treatment standard; therefore it will meet the land disposal restriction upon placement in the consolidation cell (see Chapter 3 of the RI/FS).

The land disposal restriction for the low-mercury subcategory (< 260 mg/kg total mercury) is the TCLP value (0.20 mg/L), with the best developed and available technology acid leaching, followed by chemical precipitation and dewatering [TDEC 1200-1-11-.10 (40 CFR 268)]. To meet the land disposal restriction requirements, a treatability variance can be obtained under TDEC 1200-1-11-.10(3)(e) (40 CFR 268.44). EPA has developed guidance for obtaining and complying with a treatability variance for soil that is contaminated with RCRA hazardous wastes for which treatment standards have already been set (Office of Solid Waste and Emergency Response Directive 9347.3-06FS, July 1989). Alternate treatment levels are presented for mercury based on actual treatment of soil. For mercury, the treatability variance method is immobilization. If the waste is above 0.08 ppm, the waste must be treated using immobilization to achieve 90–99 percent reduction in the waste extract. If the waste is below 0.08 ppm, the waste must be treated within 0.0002–0.008 ppm or treated to pass TCLP. To obtain a treatability variance, the intent to comply with the land disposal restrictions using a treatability variance must be documented in the FS. To document the intent to use the treatability variance the following information must be included in the FS: (1) description of the waste and its source; (2) description of the proposed action; (3) intent to comply with the land disposal restrictions through a treatability variance; and (4) the specific treatment level to be achieved for each alternative utilizing the treatability variance.

5.4.2 Treatment of RCRA Waste

If treatment takes place in a building, the containment building requirements of 40 CFR 264.1101 et seq. will be ARAR for the construction and design of the treatment facility. Tanks associated with the treatment of the wastes must comply with RCRA tank requirements in 40 CFR 264, Subpart J (see Table E.4). Subpart J sets out requirements such as secondary

containment and closure of the tank system. If all of the waste cannot be removed the tank must be closed in accordance with the landfill closure requirements of TDEC 1200-1-11-.06(14)(k) (40 CFR 264.310). If a tank system is designated as a RCRA temporary unit under 40 CFR 264.553, less stringent requirements may be used for those tanks involved in the remediation of CERCLA wastes as long as protection of human health and the environment is ensured.

The remaining ARARs for this alternative are the same as the consolidation cell without ex situ treatment.

5.5 ALTERNATIVE 5—OFF-SIOU CONSOLIDATION CELL

Under this alternative a consolidation cell will be constructed outside of Waste Area Grouping 1. A possible location is on Waste Area Grouping 5. The consolidation cell will be constructed as in Alternative 3 using simple dewatering measures for sediments and subimpoundment soil. For the design of the consolidation cell under RCRA, the requirements will be the same as in Alternative 3; however, Subpart N, "Landfills," TDEC 1200-1-11-.06(14)(b) (40 CFR 264.301) are cited as relevant and appropriate for this alternative (Table E.5). The ARARs for this alternative will reflect those in Alternative 3 with the addition of the following ARARs.

5.5.1 Transport of Waste from Waste Area Grouping 1 to Waste Area Grouping 5

The transport of the sediment and subimpoundment soil to the new consolidation cell must comply with the substantive requirements of the DOT hazardous material transportation regulations (40 CFR 171 et seq.). The DOT regulations govern transportation in commerce of hazardous materials. Government agencies offering hazardous materials for transportation in commerce or transporting hazardous materials in furtherance of commercial enterprise are subject to the regulations. However, the Chief Counsel of the Research and Special Programs Administration under DOT has issued an opinion letter for DOE-Headquarters stating that DOE is not required to comply with the Hazardous Materials Transportation Act when it offers or transports hazardous materials in a government vehicle because those DOE activities are presumed to be for a governmental purpose and thus not in commerce (Kaleta 1991). The DOT requirements would be applicable if DOE does not close off the road to public use during transport, if the transport does not occur in a DOE-operated government vehicle, or if access to the roads is not controlled by the use of gates and guards (Kaleta 1991). However, DOE has stated that it will comply with the substantive DOT transportation requirements. If transported by tanker truck, the requirements of 49 CFR 180 would also be relevant and appropriate. If a pipeline is constructed to convey the waste to the new consolidation cell, the pipeline safety regulations in 49 CFR 195 would be ARARs.

5.6 ALTERNATIVE 6—REMOVAL AND DISPOSAL

Under this alternative the sediment and subimpoundment soils from all surface impoundments will be excavated, treated, and transported off site to the Nevada Test Site for disposal (see Section 4.4 of the FS for a more detailed description of this alternative). As discussed in Section 5.4 of this appendix, any treatment of the mixed waste must meet the applicable land disposal restrictions before final disposal.

5.6.1 Stormwater Runoff during Remedial Activities

See Section 5.2.2.

5.6.2 Fugitive Emissions

See Section 5.2.3.

5.6.3 Treatment of Surface Water Removed from SIOU

See Section 5.2.4.

5.6.4 Closure of SIOU

See Section 5.3.8. This will be relevant and appropriate to Impoundments 3524, 3513, 3539, and 3540.

5.6.5 Treatment of the RCRA Component of the Sediment and Subimpoundment Soil

Sediment and subimpoundment soil would have to be treated to meet the applicable land disposal restrictions as discussed in Section 5.4.1. Treatment must also comply with the requirements for treatment units as discussed in Section 5.4.2.

5.6.6 Treatment of the PCB Component of the Sediment and Subimpoundment Soil

PCBs contaminated above 50 ppm will be treated using an alternative treatment technology to those specified in the Toxic Substances Control Act 40 CFR 761. The Toxic Substances Control Act does allow for the use of alternative treatment methods if it can be demonstrated the alternate disposal method can achieve a level of performance equivalent to incineration or high efficiency boilers [40 CFR 761.60(e); Table E.6]. Approval is required by the EPA Administrator for the research and development of PCB disposal methods using a total of more than 500 lb of PCB material. Requests to use an alternative treatment method must be submitted to the Regional Administrator showing that the method of destroying PCBs will not present an unreasonable risk of injury to health or the environment.

5.6.7 Transportation of Mixed Waste to Off-Site Disposal

DOT Regulations for Hazardous Materials list general requirements for shipping and packaging in 49 CFR 172 and 175 and requirements for carriage by public highway in 49 CFR 177 (Table E.6). General requirements for shipping hazardous materials are defined in 49 CFR 172, with specific marking, labeling, and placarding regulations for radioactive materials in 49 CFR 172.510, 172.405, and 172.556, respectively.

EPA and TDEC regulations governing generators and transporters of hazardous waste are found under 40 CFR 262-263 and TDEC 1200-1-11-.03 to .04, respectively. TDEC 1200-1-11-.03 (40 CFR 262) requires generators to ensure and document that the hazardous waste they generate is properly identified and transported to a treatment, storage, or disposal facility. Specific requirements are given for manifesting (TDEC 1200-1-11-.03(3); 40 CFR 262.20–23), packaging, labeling, marking, and placarding (TDEC 1200-1-11-.03(4); 40 CFR 262.30–33). In addition, there are record keeping and reporting requirements (TDEC 1200-1-11-.03(5); 40 CFR 262.40–43). Pretransport requirements reference the DOT regulations under 49 CFR 172, 173, 178, and 179. In addition, the Toxic Substances Control Act marking requirements of 40 CFR 761.40 and reporting and manifesting requirements of 40 CFR 761.202 et seq. are also applicable.

On May 17, 1991, DOE (EM-50) issued a moratorium on off-site shipments of the Toxic Substances Control Act and RCRA hazardous wastes that are potentially contaminated with radioactivity. To ensure that inappropriate shipments of mixed waste are not occurring, the DOE Office of Environmental Restoration and Waste Management later issued a *Performance Objective for Certification of Non-radioactive Hazardous Waste* (October 16, 1991). The basic premise of the performance objective is that no mixed waste is to be shipped off site to a facility not specifically licensed for the radioactive component of the waste. In accordance with DOE Order 5820.2A, mixed waste is to be disposed of on the site where it is generated, if possible, or if off-site disposal is necessary due to lack of on-site capacity, disposal must be at another DOE facility. An off-site treatment/disposal facility holding both a RCRA permit and an NRC agreement-state permit can be used for disposal if an exemption to DOE Order 5820.2A requirements is approved by EM-50, in consultation with EH-1, and the waste meets acceptance criteria of the off-site treatment/disposal facility (Table E.6). On October 12, 1993, DOE provided an exemption to the on-site storage requirements of DOE Order 5820.2A for mixed waste, with certain conditions applied (Grumbly 1993). The specific exemption for mixed waste is limited to small quantities of such waste, determined on a case-by-case basis. Requests for exemption may be approved by the manager of the DOE-Oak Ridge Operations field office. The fact that the soils are also contaminated with PCBs will not directly impact the off-site shipment

of the waste as long as the radiological release criteria of DOE Order 5400.5 are met and the off-site facility is the Toxic Substances Control Act-permitted (Pelletier 1992).

5.7 ADDITIONAL POTENTIAL ARARS FOR ALTERNATIVES 2-5

DOE is authorized to control all types of nuclear materials at sites under its jurisdiction and is exempt from the TDEC NRC licensing and regulatory requirements for on-site activities (TDEC 1200-2-10-.06). Therefore, the TDEC regulations are not considered to be legally applicable for CERCLA cleanup at DOE facilities. Sections of the TDEC radiation protection regulations, TDEC 1200-2-11-.16 et seq., may be considered relevant and appropriate for some or all of the alternatives discussed in this FS. The TDEC radiation protection regulations mirror the NRC regulations found at 10 CFR 61. DOE Order 5820.2A incorporates all appropriate NRC requirements for design and siting of low-level waste facilities (see Chapter 3). Tables E.8 and E.9 list the TDEC radiation protection regulations that may be potentially relevant and appropriate to each alternative.

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EPA. 1989. *Determining When Land Disposal Restrictions (LDRs) Are Applicable to CERCLA Response Actions*, July 1989. Superfund Publication: 9347.3-O5FS. EPA Office of Solid Waste and Emergency Response, Washington, D.C.

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APPENDIX F

ALTERNATIVE COST ESTIMATES

1. BASIS OF COST ESTIMATE

This appendix presents the basis of estimate for the items that are common to all of the alternatives for Waste Area Grouping 1 SIOU at ORNL in Oak Ridge, Tennessee. A short basis of estimate, a present value estimate (life-cycle cost), and a summary report are included for each of the alternatives. The detailed cost backup is available at the DOE Information Resource Center in Central Records.

1.1 COMMON BASES AND ASSUMPTIONS

The following are common assumptions for all alternatives and are shown here to avoid repetition.

- The estimates have been prepared in the Automated Estimating System format, using the ERAUG94B.val standard value file for labor rates, escalation rates, and indirects.

- The remedial action will be performed by a fixed-price subcontractor and the monitoring and maintenance will be performed by Energy Systems. Work schedule is assumed to be 5 days/week for 8 hours/day.

- Material pricing and labor hours were obtained by vendor quotes, historical data, and cost reference publications such as R. S. Means and Richardson's Construction Estimating Standards.

- Mobilization and demobilization is included at 5 percent of the fixed-price contractor (not total project cost). It is assumed that an out-of-town contractor would set up an office in Oak Ridge to handle the documentation, payroll, security, procurement, staffing, etc. in addition to site-specific requirements. This would also account for loss of productivity due to a learning curve for the methods of operation within ORNL as well as living expenses, transportation and travel costs for fixed-price contractor key personnel.

- An allowance of 5 percent of direct material cost has been included to cover small tools in fixed-price contractor estimates, as required, based on previous experience.

- Fixed-price contractor estimates include clean-up cost at 1 percent of material and 5 percent of labor cost, as required, based on anticipated site requirements and past experience.

- Energy Systems will perform final tie-ins to existing systems.

- A safety engineer and two health physics technicians are included for the fixed-price contractor for the duration of the remedial action. Dust control is included, where appropriate, and allowances are included to cover decontamination of construction equipment and disposal of decontaminated water.

- Soil excavated for support facilities, erosion control, and groundwater monitoring wells is assumed to be contaminated and is therefore placed in concrete boxes. The existing steam piping and insulation are assumed to be contaminated and are therefore placed in B-25 boxes. The protective clothing required for the remedial action is assumed to be placed in 55-gal drums. All of these containers require purchasing, handling and transportation, waste characterization, and storage at the Oak Ridge K-25 Site.

- Surface water control ditches are within the limits of the operable unit and the excavated soil can be placed inside the impoundments. Any additional soil excavated for cell capacity will also be placed inside.

- Track-mounted remote dredge with a production rate of around 757 L/min (200 gal/min) will perform dredging. Twenty-five percent solids is assumed or around 189 L/min (50 gal/min) of in situ sludge, and every hour of dredging will require 2 hours of settling for a total of around 64 L/min (17 gal/min). Assuming 50 percent for down time gives 42 L/min (11 gal/min) or around 2.52 m^3/hour 3.3 yd^3/hour of in situ sludge. Dredging one part of sludge requires three parts of water so the water must be recirculated to maintain shielding. These same rates apply if other dredges are used.

- A crane is included to support the dredging operation.

- Contaminated water will be treated at the existing Process Waste Treatment Plant. Treatment charges are included for the surface water, equipment decontamination water, and personnel decontamination water. 18,927 L/day (5,000 gal/day) of water are required for equipment decontamination operations and 1,893 L/day (500 gal/day) are required for personnel decontamination, but only for the days requiring these activities. Water will be pumped to the Process Waste Treatment Plant by tieing into an existing pipeline.

- Samples taken before design will be taken on a grid of 15 m (50 ft) on center spacing. Sampling costs are based on the Bear Creek Valley Operable Unit 2 project.

- Impoundments that have had the contaminated materials removed shall be backfilled with borrow material. The distance to borrow area is approximately 16,090 m (10 miles).

- All equipment that comes in direct contact with contaminated material (i.e., dredge, pumps, tanker trucks, etc.) will be purchased, decontaminated to the extent possible, and kept for future use on similar projects.

- Concrete boxes are assumed to hold 2.3 m^3 [81 ft^3 (3 yd^3)] of contents. The volume of concrete per box is calculated to be 2.1 m^3 (73.5 ft^3). Storage costs include the total volume of box and contents. Based on a weight limit of around 42,000 lb/truck, one truck can haul two concrete boxes or five B-25 boxes or 45 drums.

1.2 ENGINEERING ESTIMATES

Titles I, II, and III engineering costs, including project management, are estimated as a percentage of the fixed-price construction value based on knowledge acquired through similar projects, historical data, and the appropriate level of effort necessary for this project. The percentages applied to specific tasks are shown below.

1.2.1 Work Breakdown Structure (WBS) 1.03 Remedial Action Integration

Support participant		Percentage
TS01	FS Contractor	*a*
SC01	Characterization Subcontractor	*a*
SC01	Independent Certification	5 percent
C069	Energy Systems Title III Engineer	8 percent
AE01	Architect-Engineer Title III Engineer	3 percent
XO21	Energy Systems Field Maintenance	*a*
C069	Energy Systems Project Management	12 percent
MK66	MK-Ferguson of Oak Ridge Company Indirects on Fixed Price	11 percent
MK67	MK-Ferguson of Oak Ridge Company Directs on Fixed Price	*a*
XO27	Waste Management	*a*

1.2.2 WBS 1.04 Remedial Design Work Plan

Support participant		Percentage
AE01	Remedial Design Architect-Engineer Planning and Coordination	5 percent[b]
MM46	Energy Systems On-Site Subcontractor	*a*
MK67	MK-Ferguson of Oak Ridge Company Planning	*a*
C069	Energy Systems Technical Advisory Group	*a*
C069	Engineer Remedial Management	*a*
XO21	Engineering Support Studies	*a*

1.2.3 WBS 1.05 Remedial Design Report

Support participant		Percentage
TS01	FS Contractor	1 percent[b]
AE01	Architect-Engineer Titles I and II Engineer	15 percent
XO35	Environmental Compliance	0.5 percent[b]
C069	Energy Systems Design and Project Liaison	4 percent
C069	Energy Systems Project Management	3 percent
MK67	MK-Ferguson of Oak Ridge Company Planning	0.5 percent[b]
XO27	Waste Management	0.5 percent[b]
C069	Energy Systems Technical Advisory Group	*a*

1.2.4 WBS 1.06 Remedial Action Work Plan

Support participant		Percentage
AE01	Remedial Design Architect-Engineer Planning and Coordination	0.5 percent[b]
MK67	MK-Ferguson of Oak Ridge Company Planning	0.5 percent[b]
C069	Engineer Remedial Management	0.5 percent[b]

Note: Unless otherwise noted, all values are a percentage of the fixed-price construction (participant MK51).

[a]Percentage is estimated by direct material and/or labor.
[b]Percentage is based on Architect-Engineer Titles I and II engineering (participant AE01) for remedial design report.

1.3 POSTCONSTRUCTION PLANNING/COORDINATION

This activity is assumed to last 6 months and will involve primarily the finalizing of remedial action reporting.

1.4 ENVIRONMENTAL HEALTH AND SAFETY MONITORING DURING REMEDIAL ACTION

A total of 250 hours/year for Energy Systems field maintenance, 400 hours/year for Energy Systems Environmental Restoration Division, plus associated well monitoring costs are assumed for the same duration as construction activities. Only the four new monitoring wells installed by this project are assumed to be analyzed.

1.5 VERIFICATION MONITORING DURING REMEDIAL ACTION

A total of 125 hours/year for Energy Systems field maintenance, 200 hours/year for Energy Systems Environmental Restoration Division, plus associated well monitoring costs have been assumed for the same duration as construction activities. Only the four new monitoring wells installed by this project are assumed to be analyzed.

1.6 CALCULATIONS

Attached are the calculations that are common to all alternatives.

Note: Reference each individual alternative for schedule, WBS title file, and Automated Estimating System reports. Also attached to each are the alternative-specific bases, assumptions, and calculations.

1.7 ALTERNATIVE 2—MULTILAYER CAP AND INSTITUTIONAL CONTROLS

1.7.1 Basis of Estimate and Assumptions

- General and subcontractor trailers, personnel and equipment decontamination facilities, perimeter radiation rope with signs, and perimeter monitoring will be set up in support of this project. These items will require decontamination and/or removal after the remedial action is accomplished.

- Site preparation will include erosion control, contractor's laydown area, relocation of existing power and steam lines, and surface water controls.

- The sludge inside the impoundments will be covered by a geotextile and a geogrid before any other material is placed to keep the solids in place. Approximately 0.3 m (1 ft) of surface soil is excavated from around the impoundments and placed inside

them. A layer of clay borrow will replace the excavated surface soil. Shot rock will be placed inside the impoundments while the water is being drawn off and sent to the Process Waste Treatment Plant. A geotextile filter fabric will be placed over the shot rock and a vegetative layer will be placed on top of those. The vegetative layer will be seeded and benchmark monuments will be put in place. A chain link fence will be constructed around the site.

- Groundwater monitoring wells will be installed to provide monitoring during and after the remedial action. Sediment will also be sampled during the remedial action.

- Mobilization and demobilization is included as described in the common assumptions.

- Training and medical costs are calculated using the Energy Systems cost estimating guidance report.

- Closure verification sampling of surface soil is included, assuming a 15 by 15-m (50- by 50-ft) grid.

- Postremedial action monitoring of groundwater is included for 30 years and is based on the RI/FS for the Bear Creek Operable Unit 2 project.

- Long-term maintenance costs include monthly visual surveillance, mowing, an annual soil patch, and fence maintenance at 5 percent of new fence costs per year. All are for 30 years and are performed by Energy Systems field maintenance.

- A project contingency of 35 percent has been applied to this estimate due to the level of design at the FS stage.

- Postremedial action verification (5-year CERCLA) has been included every 5 years for 30 years. Energy Systems Environmental Restoration Division is calculated at 1,000 hours.

- Deed restrictions include 40 hours for an attorney.

1.7.2 Work Breakdown Structure

WBS	Title
1.1.01.01	Support Facilities
1.1.01.02	Decontamination and Removal of Support Facilities
1.1.02.01	Site Preparation
1.1.02.02	Multilayered Cap
1.1.02.03	Groundwater Monitoring Wells
1.1.02.04	Mobilization and Demobilization
1.1.02.05	Training Contractor Personnel
1.1.03	Remedial Action Integration (Direct)
1.1.11	Deed Restrictions
2.1.03	Remedial Action Integration (Indirect)
2.1.04	Remedial Design Work Plan
2.1.05	Remedial Design Report
2.1.06	Remedial Action Work Plan
2.1.07	Postconstruction Planning and Coordination
2.1.08	Monitoring During Remedial Action
2.1.09	Closure Verification Sampling
3.1.10.1	Postremedial Action O&M (year 1)
4.1.10.2	Postremedial Action O&M (years 2-30)
5.1.10.3.1	Postremedial Action Verification (CERCLA year 5)
5.1.10.3.2	Postremedial Action Verification (CERCLA year 10)
5.1.10.3.3	Postremedial Action Verification (CERCLA year 15)
5.1.10.3.4	Postremedial Action Verification (CERCLA year 20)
5.1.10.3.5	Postremedial Action Verification (CERCLA year 25)
5.1.10.3.6	Postremedial Action Verification (CERCLA year 30)

1.7.3 Project Schedule

The project schedule is based on manhours and assumed crew size. Consideration was also given to each line item for the amount of time required to accomplish a task. The schedule and appropriate application of escalation form the basis for obtaining escalated cost and the fiscal year summary cost information.

1.7.4 Reports

The following Automated Estimating System and Building Life-Cycle Cost reports are attached.

- Summary Report per WBS, Participant
- Life-Cycle Cost Analysis (Present Worth)

1.7.5 Escalated Cost Summary

The escalated cost summary based on these assumptions is:

- present worth, $21,230,000
- capital, $19,028,000,
- O&M, $7,011,000.

1.8 ALTERNATIVE 3—CONSOLIDATION CELL WITH SIMPLE DEWATERING

1.8.1 Basis of Estimate and Assumptions

- General and subcontractor trailers, personnel and equipment decontamination facilities, an on-site laboratory, perimeter radiation rope with signs, and perimeter monitoring will be set up in support of this project. These items will require decontamination and/or removal after the remedial action is accomplished.

- Site preparation will include erosion control, contractor's laydown area, relocation of existing power and steam lines, and surface water controls. Excavated soil shall be stockpiled.

- The sludge and subimpoundment soil is relocated from Impoundment 3524 into Impoundment 3513 by remotely operated dredge. The water must be recirculated to maintain shielding. Some solid material (rock, rebar, etc.) will be encountered and removed with conventional equipment, sprayed off, and stockpiled. Solids are 5 percent of total. The remaining sludge is sprayed down to one point and pumped to Impoundment 3513. A consolidation cell liner is installed inside the now empty Impoundment 3524. Now the sludge and soil from Impoundments 3513, 3539, and 3540 are relocated into the consolidation cell using the process described above. Riprap from Impoundments 3539 and 3540 is removed and stockpiled with the solid items. A geotextile and a geogrid layer are placed over the sludge. Next the stockpiled solids are placed inside. Then shot rock is placed inside until it effectively replaces the water for shielding. The water will be pumped to the Process Waste Treatment Plant as the shot rock is placed. A filter fabric is placed over the rock. Existing piping and valve boxes between the impoundments will be abandoned and new piping routed. Soil excavated for piping is placed inside the consolidation cell. 0.3 m (1 ft) of surface soil from around the impoundments is excavated and placed inside along with stockpiled soil. A daily cover will be maintained, and a temporary cap installed. The emptied impoundments will be backfilled with clean borrow.

The leachate collection system will dewater the consolidation cell in 2 years. The temporary cap shall be maintained for that period.

After 2 years a closure cap will be installed and a chain link fence placed around the site.

- Groundwater monitoring wells will be installed to provide monitoring during and after the remedial action. Sediment will also be sampled during the remedial action.

- Mobilization and demobilization are included as described in the common assumptions.

- Training and medical costs are calculated using the Energy Systems cost estimating guidance report.

- Closure verification sampling of surface soil, subimpoundment soil, and stockpile area soil is included, assuming a 15- by 15-m (50- by 50-ft) grid.

- Postremedial action monitoring of groundwater is included for 30 years and is based on the RI/FS for the Bear Creek Operable Unit 2 project.

- Long-term maintenance costs include monthly visual surveillance, mowing, an annual soil patch, and fence maintenance at 5 percent of new fence costs per year. All are for 30 years, and Energy Systems field maintenance will perform these tests.

- A project contingency of 35 percent has been applied to this estimate due to the level of design at the FS stage.

- Postremedial action verification (5-year CERCLA) has been included every 5 years for 30 years. Energy Systems Environmental Restoration Division is calculated at 1,000 hours.

- Deed restrictions included 40 hours for an attorney.

1.8.2 Work Breakdown Structure

WBS	Title
1.1.01.01	Support Facilities
1.1.01.02	Decontamination and Removal of Support Facilities
1.1.02.01	Site Preparation
1.02.02	Consolidation Cell
1.1.02.03	Dewatering
1.1.02.04	Closure Cap (after 2 years)
1.1.02.05	Groundwater Monitoring Wells
1.1.02.06	Mobilization and Demobilization
1.1.02.07	Training Contractor Personnel
1.1.03	Remedial Action Integration (Direct)
1.1.11	Deed Restrictions
2.1.03	Remedial Action Integration (Indirect)
2.1.04	Remedial Design Work Plan
2.1.05	Remedial Design Report
2.1.06	Remedial Action Work Plan
2.1.07	Postconstruction Planning and Coordination
2.1.08	Environmental Health and Safety Monitoring During Remedial Action
2.1.09	Verification Monitoring During Remedial Action
3.1.10.1	Postremedial Action O&M (year 1)
4.1.10.2	Postremedial Action O&M (years 2-30)
5.1.10.3.1	Postremedial Action Verification (CERCLA year 5)
5.1.10.3.2	Postremedial Action Verification (CERCLA year 10)
5.1.10.3.3	Postremedial Action Verification (CERCLA year 15)
5.1.10.3.4	Postremedial Action Verification (CERCLA year 20)
5.1.10.3.5	Postremedial Action Verification (CERCLA year 25)
5.1.10.3.6	Postremedial Action Verification (CERCLA year 30)

1.8.3 Project Schedule

The project schedule is based on the manhours and assumed crew size. Consideration was also given to each line item for the amount of time required to accomplish a task. The schedule and appropriate application of escalation form the basis for obtaining escalated cost and the fiscal year summary cost information.

1.8.4 Reports

The following Automated Estimating System and Building Life-Cycle Cost reports are attached.

- Summary Report per WBS, Participant
- Life-Cycle Cost Analysis (Present Worth)

1.8.5 Escalated Cost Summary

The escalated cost summary based on these assumptions is:

- present worth, $45,650,000,
- capital, $51,360,000, and
- O&M, $5,804,000.

1.9 ALTERNATIVE 4—CONSOLIDATION CELL WITH EX SITU TREATMENT

1.9.1 Basis of Estimate and Assumptions

- General and subcontractor trailers, personnel and equipment decontamination facilities, an on-site laboratory, perimeter radiation rope with signs, and perimeter monitoring will be set up in support of this project. These items will require decontamination and/or removal after the remedial action is accomplished.

- Site preparation will include erosion control, contractor's laydown area, relocation of existing power and steam lines, and surface water controls. Excavated soil shall be stockpiled.

- The sludge and subimpoundment soil are relocated from Impoundment 3524 into Impoundment 3513 by remotely operated dredge. The water must be recirculated to maintain shielding. Some solid material (rock, rebar, etc.) will be encountered and removed with conventional equipment, sprayed off, and stockpiled. Solids are 5 percent of total. Remaining sludge is sprayed down to one point and pumped to Impoundment 3513. The riprap from Impoundments 3539 and 3540 is removed and stockpiled. The sludge and soil are removed as described above. Impoundments 3539 and 3540 are backfilled and compacted. A consolidation cell liner is installed inside the now empty Impoundment 3524. A stabilization/solidification facility is built at the site of the backfill impoundments. The sludge and soil from all of the impoundments (all located inside Impoundment 3513) are relocated as described above to the treatment facility. All the material is treated and pumped into concrete boxes that have been placed inside the consolidation cell. The stockpiled soils and solids are placed in the cell over the treated waste. Existing piping and valve boxes between the impoundments will be abandoned and new piping routed. Soil excavated for piping is placed inside the consolidation cell. 0.3 m (1 ft) of surface soil from around the impoundments is excavated and placed inside the cell along with stockpiled soil. A daily cover will be maintained and a closure cap and a perimeter chain link fence will

be installed. Impoundment 3513 will be backfilled with clean borrow. Demolition and decontamination of the treatment facility is assumed to be shared with two other projects.

- Groundwater monitoring wells will be installed to provide monitoring during and after the remedial action. Wet batch and solidified batch sampling of treated material will be conducted during the remedial action.

- Mobilization and demobilization is included as described in the common assumptions.

- Training and medical costs are calculated using the Energy Systems cost estimating guidance report.

- Postremedial action monitoring of groundwater is included for 30 years and is based on the RI/FS for the Bear Creek Operable Unit 2 project.

- Long-term maintenance costs include monthly visual surveillance, mowing, an annual soil patch, and fence maintenance at 5 percent of new fence costs per year. All are for 30 years and Energy Systems field maintenance will perform these tasks.

- A project contingency of 40 percent has been applied to this estimate due to the level of design at the FS stage.

- Postremedial action verification (5-year CERCLA) has been included every 5 years for 30 years. Energy Systems Environmental Restoration Program Division is calculated at 1,000 hours.

- Deed restrictions include 40 hours for an attorney.

1.9.2 Work Breakdown Structure

WBS	Title
1.1.01.01	Support Facilities
1.1.01.02	Decontamination and Removal of Support Facilities
1.1.02.01	Site Preparation
1.02.02	Consolidation Cell
1.1.02.03	Dewatering
1.1.02.04	Closure Cap (after 2 years)
1.1.02.05	Groundwater Monitoring Wells
1.1.02.06	Mobilization and Demobilization

WBS	Title
1.1.02.07	Training Contractor Personnel
1.1.03	Remedial Action Integration
1.1.11	Deed Restrictions
2.1.03	Remedial Action Integration (Indirect)
2.1.04	Remedial Design Work Plan
2.1.05	Remedial Design Report
2.1.06	Remedial Action Work Plan
2.1.07	Postconstruction Planning and Coordination
2.1.08	Environmental Health and Safety Monitoring During Remedial Action
2.1.09	Verification Monitoring During Remedial Action
3.1.10.1	Postremedial Action O&M (year 1)
4.1.10.2	Postremedial Action O&M (years 2-30)
5.1.10.3.1	Postremedial Action Verification (CERCLA year 5)
5.1.10.3.2	Postremedial Action Verification (CERCLA year 10)
5.1.10.3.3	Postremedial Action Verification (CERCLA year 15)
5.1.10.3.4	Postremedial Action Verification (CERCLA year 20)
5.1.10.3.5	Postremedial Action Verification (CERCLA year 25)
5.1.10.3.6	Postremedial Action Verification (CERCLA year 30)

1.9.3 Project Schedule

The project schedule is based on the manhours and assumed crew size. Consideration was also given to each line item for the amount of time required to accomplish a task. The schedule and appropriate application of escalation form the basis for obtaining escalated cost and the fiscal year summary cost information.

1.9.4 Reports

The following Automated Estimating System and Building Life-Cycle Cost reports are attached.

- Summary Report per WBS, Participant
- Life-Cycle Cost Analysis (Present Worth)

1.9.5 Escalated Cost Summary

The escalated cost summary based on these assumptions is:

- present worth, $87,243,000,
- capital, $93,634,000, and
- O&M, $6,509,000.

1.10 ALTERNATIVE 5—OFF-SIOU CONSOLIDATION CELL

1.10.1 Basis of Estimate and Assumptions

- General and subcontractor trailers, personnel and equipment decontamination facilities, an on-site laboratory, perimeter radiation rope with signs, and perimeter monitoring will be set up at the impoundments in support of this project. A subcontractor's trailer, personnel decontamination facility, perimeter radiation rope with signs, and perimeter monitoring will be set up at the consolidation cell. These items will require decontamination and/or removal after the remedial action is accomplished.

- Site preparation at the impoundments will include erosion control, contractor's laydown area, relocation of existing power and steam lines, and surface water controls. Site preparation at the consolidation cell will include clear and grub, erosion control, access road, contractor's laydown area, and surface water controls. Excavated soil shall be hauled to the consolidation cell and stockpiled.

- A consolidation cell with liner is constructed off site. Water is brought in by tanker for shielding. The sludge and subimpoundment soil are removed from the impoundments into settling tanks by remotely operated dredge. The water must be recirculated to maintain shielding. Some solid material (rock, rebar, etc.) will be encountered and removed with conventional equipment, sprayed off, and hauled to the consolidation cell. Solids are 5 percent of total. Remaining sludge is sprayed down to one point and pumped to the tanks. The sludge and soil are transferred from the tanks by tanker truck to the consolidation cell and deposited there. The riprap from Impoundments 3539 and 3540 is removed and stockpiled. A geotextile and geogrid are placed over the sludge. The stockpiled solids and shot rock will be placed inside the cell until shielding water is no longer required. Water will be taken by tanker to Process Waste Treatment Plant. Filter fabric is placed over the rock. Existing piping and valve boxes between the impoundments will be abandoned and new piping routed. Soil excavated for piping is hauled to the consolidation cell along with 0.3 m (1 ft) of surface soil from around the impoundments and placed inside the cell. A daily cover will be maintained and a temporary cap installed. The impoundments will be backfilled with clean borrow.

  The leachate collection system will dewater the consolidation cell in 2 years. The temporary cap will be maintained for this period.

After 2 years a closure cap is installed and a chain link fence placed around the consolidation cell.

- Groundwater monitoring wells will be installed to provide monitoring during and after the remedial action. Sediment will also be sampled during the remedial action.

- Mobilization and demobilization are included as described in the common assumptions.

- Training and medical costs are calculated using the Energy Systems cost estimating guidance report.

- Closure verification sampling of surface soil, subimpoundment soil, and stockpile area soil is included, assuming a 15- by 15-m (50- by 50-ft) grid.

- Postremedial action monitoring of groundwater is included for 30 years and is based on the RI/FS for the Bear Creek Operable Unit 2 project.

- Long-term maintenance costs include monthly visual surveillance, mowing, an annual soil patch, and fence maintenance at 5 percent of new fence costs per year. All are for 30 years and Energy Systems field maintenance will perform these tasks.

- A project contingency of 35 percent has been applied to this estimate due to the level of design at the FS stage.

- Postremedial action verification (5-year CERCLA) has been included every 5 years for 30 years. Energy Systems Environmental Restoration Program Division is calculated at 1,000 hours.

- Deed restrictions include 40 hours for an attorney.

1.10.2 Work Breakdown Structure

WBS	Title
1.1.01.01	Support Facilities
1.1.01.02	Decontamination and Removal of Support Facilities
1.1.02.01	Site Preparation
1.02.02	Consolidation Cell
1.1.02.03	Dewatering
1.1.02.04	Closure Cap (after 2 years)

WBS	Title
1.1.02.05	Groundwater Monitoring Wells
1.1.02.06	Mobilization and Demobilization
1.1.02.07	Training Contractor Personnel
1.1.03	Remedial Action Integration
1.1.11	Deed Restrictions
2.1.03	Remedial Action Integration (Indirect)
2.1.04	Remedial Design Work Plan
2.1.05	Remedial Design Report
2.1.06	Remedial Action Work Plan
2.1.07	Postconstruction Planning and Coordination
2.1.08	Environmental Health and Safety Monitoring During Remedial Action
2.1.09	Verification Monitoring During Remedial Action
3.1.10.1	Postremedial Action O&M (year 1)
4.1.10.2	Postremedial Action O&M (years 2-30)
5.1.10.3.1	Postremedial Action Verification (CERCLA year 5)
5.1.10.3.2	Postremedial Action Verification (CERCLA year 10)
5.1.10.3.3	Postremedial Action Verification (CERCLA year 15)
5.1.10.3.4	Postremedial Action Verification (CERCLA year 20)
5.1.10.3.5	Postremedial Action Verification (CERCLA year 25)
5.1.10.3.6	Postremedial Action Verification (CERCLA year 30)

1.10.3 Project Schedule

The project schedule is based on the manhours and assumed crew size. Consideration was also given to each line item for the amount of time required to accomplish a task. The schedule and appropriate application of escalation form the basis for obtaining escalated cost and the fiscal year summary cost information.

1.10.4 Reports

The following Automated Estimating System and Building Life-Cycle Cost reports are attached.

- Summary Report per WBS, Participant
- Life-Cycle Cost Analysis (Present Worth)

1.10.5 The escalated cost summary based on these assumptions is:

- present worth, $48,252,000,
- capital, $54,297,000, and
- O&M, $5,996,000.

1.11 ALTERNATIVE 6—REMOVAL, TREATMENT, AND OFF-SITE DISPOSAL

1.11.1 Basis of Estimate and Assumptions

- General and subcontractor trailers, personnel and equipment decontamination facilities, an on-site laboratory, perimeter radiation rope with signs, and perimeter monitoring will be set up in support of this project. These items will require decontamination and/or removal after the remedial action is accomplished.

- Site preparation will include erosion control, contractor's laydown area, relocation of existing power and steam lines, and surface water controls. Excavated soil shall be placed in concrete boxes.

- The sludge and subimpoundment soil are relocated from Impoundments 3539 and 3540 into Impoundment 3513 by remotely operated dredge. The water must be recirculated to maintain shielding. Some solid material (rock, rebar, etc.) will be encountered and removed with conventional equipment, sprayed off, and placed in concrete boxes. Solids are 5 percent of total. Remaining sludge is sprayed down to one point and pumped to Impoundment 3513. The riprap from Impoundments 3539 and 3540 is removed and placed in concrete boxes. The emptied impoundments are backfilled with clean borrow. A stabilization/solidification facility is built at the site of the backfilled impoundments. The sludge and soil from all of the impoundments are relocated as described above to the treatment facility. All the material is treated and pumped into concrete boxes. The boxes are then moved to a staging area. Existing piping and valve boxes between the impoundments will be abandoned and new piping routed. Soil excavated for piping is placed inside concrete boxes. 0.3 m (1 ft) of surface soil from around the impoundments is excavated and placed in concrete boxes. All impoundments will be backfilled with clean borrow and seeded. Demolition and decontamination of the treatment facility is assumed to be shared with two other projects.

  The on-operable unit material placed in concrete boxes is taken to a train loading station, hauled to Las Vegas by rail, unloaded onto trucks, hauled to Nevada Test Site, and stored by an off-site subcontractor.

- Groundwater monitoring wells will be installed to provide monitoring during and after the remedial action. Wet batch and solidified batch sampling of treated material will be conducted during the remedial action.

- Mobilization and demobilization are included as described in the common assumptions.

- Training and medical costs are calculated using the Energy Systems cost estimating guidance report.

- Closure verification sampling of surface soil, subimpoundment soil, and stockpile area soil is included, assuming a 15- by 15-m (50- by 50-ft) grid.

- Postremedial action monitoring of groundwater is included for 5 years and is based on the RI/FS for the Bear Creek Operable Unit 2 project.

- A project contingency of 40 percent has been applied to this estimate due to the level of design at the FS stage.

- Postremedial action verification (5-year CERCLA) has been included at year 5. Energy Systems Environmental Restoration Division is calculated at 1,000 hours.

1.11.2 Work Breakdown Structure

WBS	Title
1.1.01.01	Support Facilities
1.1.01.02	Decontamination and Removal of Support Facilities
1.1.02.01	Site Preparation
1.1.02.02	Relocate Material from Impoundments 3539 and 3540
1.1.02.03	Treatment Facility
1.1.02.04	Remove and Treat
1.1.02.05	D&D Treatment Facility
1.1.02.06	Groundwater Monitoring Wells
1.1.02.07	Mobilization and Demobilization
1.1.02.08	Training Contractor Personnel
1.1.02.09	Transport and Dispose Waste
1.1.03	Remedial Action Integration
2.1.04	Remedial Design Work Plan
2.1.05	Remedial Design Report
2.1.06	Remedial Action Work Plan
2.1.07	Postconstruction Planning and Coordination
2.1.08	Environmental Health and Safety Monitoring During Remedial Action
2.1.09	Verification Monitoring During Remedial Action
3.1.10.1	Postremedial Action O&M (year 1)
4.1.10.2	Postremedial Action O&M (years 2–5)
5.1.10.3.1	Postremedial Action Verification (CERCLA year 5)

1.11.3 Project Schedule

The project schedule is based on the manhours and assumed crew size. Consideration was also given to each line item for the amount of time required to accomplish a task. The schedule and appropriate application of escalation form the basis for obtaining escalated cost and the fiscal year summary cost information.

1.11.4 Reports

The following Automated Estimating System and Building Life-Cycle Cost reports are attached.

- Summary Report per WBS, Participant
- Life-Cycle Cost Analysis (Present Worth)

1.11.5 Escalated Cost Summary

The escalated cost summary based on these assumptions are:

- present worth, $148,637,000,
- capital, $162,693,000, and
- O&M, $1,335,000.

SUMMARY REPORT
Project Number: 33762.50
ALT. 1 - NO ACTION

Project ESO Number.....
Revision Number.....0
Last Update.....03/22/1995

Sort Order
1. WBS - Level 2

Approved by:

Project Estimator _____ Date _____

Estimating Manager _____ Date _____

ıse Fiscal Year/Quarter: 94/4
'ANDARD VALUE: C:\AES60F\ERDEC94C.val EXPIRES: 03/15/1996
:TIMATE FILE: C:\4000\4000REVA\ALT1.Est 03/22/1995
:HEDULE FILE: ALT1
:PORT FILE: C:\4000\4000REVA\SUM1.Out 03/22/1995 15:43:32 AES Version 6.0f

ALT. 1 - NO ACTION

SUMMARY REPORT
$1 = $1000

03/22/1995

Arranged By: WBS

	Unescalated			Escalated		
	Material $	Labor $	Total $	Material $	Labor $	Total $
1.01 INSTITUTIONAL CONTROLS	2734	1680	4414	3484	2141	5625
1.02 PROGRAM MANAGEMENT	0	1800	1800	0	2322	2322
SUB - TOTAL	2734	3480	6214	3484	4463	7947
OVERHEAD	1209	1538	2747	1540	1973	3513
SUB - TOTAL	3943	5018	8961	5024	6436	11460
CONTINGENCY	986	1255	2241	1256	1609	2865
GRAND TOTAL	4929	6273	11202	6280	8045	14325

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I S T  B L C C - D E T A I L E D  L C C  A N A L Y S I S (version 4.20-95)*
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PART I - INITIAL ASSUMPTIONS AND COST DATA

Project alternative: ALT1
Run date: 04-17-1995 09:35:12
Run type: Federal Analysis--Projects Subject to OMB A-94
Comment: NO ACTION ($1=$1000)
Input data file: ALT1.DAT, last modified: 03-29-1995/14:24:48
LCC output file: ALT1.LCC, created: 03-29-1995/14:24:50
Base Date of Study: JAN 1997
Service Date: JAN 1997
Study period: 30.00 years (JAN 1997 through DEC 2026)
Discount rate: 7.0% Real (exclusive of general inflation)
End-of-year discounting convention

INITIAL CAPITAL ASSET COSTS (NOT DISCOUNTED)

	Total Cost
TOTAL INITIAL CAPITAL ASSET COSTS	$0

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PART II - LIFE-CYCLE COST ANALYSIS
Discount Rate = 7.0% Real (exclusive of general inflation)

ROJECT ALTERNATIVE: ALT1 RUN DATE: 04-17-1995/09:35:12

	PRESENT VALUE (1997 DOLLARS)	ANNUAL VALUE (1997 DOLLARS)
ASH REQUIREMENTS AS OF SERVICE DATE	$0	$0
PERATING, MAINTENANCE & REPAIR COSTS:		
NON-ANNUALLY RECURRING COSTS	$5,569	$449
SUBTOTAL	$5,569	$449
ESALE VALUE OF ORIG CAPITAL COMPONENTS	$0	$0
ESALE VALUE OF CAPITAL REPLACEMENTS	$0	$0
OTAL LIFE-CYCLE PROJECT COST	$5,569	$449

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SUMMARY REPORT
Project Number: 33762.50
ALTERNATE 2 - MULTILAYERED CAP

Project ESO Number.....
Revision Number.....0
Last Update.....03/16/1995

Sort Order
1. WBS - Level 1
2. WBS - Level 2
3. Trace Number

Approved by:

Project Estimator _____ Date _____

Estimating Manager _____ Date _____

Base Fiscal Year/Quarter: 94/4
STANDARD VALUE: C:\AES60F\ERDEC94C.val EXPIRES: 03/15/1996
ESTIMATE FILE: C:\4000\4000REVA\ALT2.Est 03/16/1995
SCHEDULE FILE: ALT2
REPORT FILE: C:\4000\4000REVA\SUM2.Out 03/22/1995 14:06:29 AES Version 6.0f

ALTERNATE 2 - MULTILAYERED CAP

SUMMARY REPORT
$1 = $1000

03/22/1995

ıged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
RECT COSTS						
)1 REMEDIAL ACTION (FPC)						
:.1.1 SUPPORT FACILITIES	819	182	1001	887	197	1084
:.1.2 DECON & REMOVE SUPPORT FACILS	72	93	165	83	107	190
:.1.3 SITE PREPARATION	206	169	375	225	184	409
:.1.4 MULTILAYERED CAP	1535	1098	2633	1725	1234	2959
:.1.5 MOB & DEMOB	0	266	266	0	288	288
:.1.6 TRAINING & MEDICAL	182	90	272	203	101	304
ıL REMEDIAL ACTION (FPC)	2814	1898	4712	3123	2111	5234
)2 DEED RESTRICTIONS						
:.1.7 DEED RESRICTIONS	0	4	4	0	5	5
ıL DEED RESTRICTIONS	0	4	4	0	5	5
)3 REMEDIAL ACTION INTEGRATION						
:.1.8 MK-F INDIRECTS ON FP	0	658	658	0	736	736
:.1.9 MK-F DIRECTS ON FP	0	663	663	0	742	742
ıL REMEDIAL ACTION INTEGRATION	0	1321	1321	0	1478	1478
. DIRECT COSTS	2814	3223	6037	3123	3594	6717
IDIRECT COSTS						
)1 PROJECT INTEGRATION						
/.2.1 MMES PROJECT MANAGEMENT	0	390	390	0	429	429
/.2.2 MMES PROJECT ANALYST	0	390	390	0	429	429
/.2.3 MMES CONST. ENGINEER	0	180	180	0	202	202
/.2.4 A-E TITLE III ENGINEERING	0	156	156	0	175	175
/.2.5 MMES TITLE III ENGINEERING	0	120	120	0	135	135
/.2.6 MMES HEALTH & SAFETY	0	115	115	0	129	129
/.2.7 MMES QUALITY ASSURANCE	0	48	48	0	53	53
/.2.8 CLOSURE VERIF. SAMPLING	112	45	157	126	50	176
/.2.9 INDEPENDENT CERTIFICATION	10	104	114	11	117	128
/.2.10 MMES WASTE MANAGEMENT	0	58	58	0	65	65
/.2.11 MMES ENVIRONMENTAL COMPLIANCE	0	25	25	0	28	28
ıL PROJECT INTEGRATION	122	1631	1753	137	1812	1949

ALTERNATE 2 - MULTILAYERED CAP

SUMMARY REPORT
$1 = $1000

03/22/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated			Escalated		
	Material $	Labor $	Total $	Material $	Labor $	Total $
2 INDIRECT COSTS						
2.02 DESIGN						
X.3.1 A-E TITLE I & II ENGINEERING	0	936	936	0	988	988
X.3.2 MMES A/E SUPPORT	0	90	90	0	95	95
X.3.3 MMES WASTE MANAGEMENT	0	58	58	0	61	61
X.3.4 MMES TECH ADVISORY GROUP	0	30	30	0	32	32
X.3.5 MMES ENVIRONMENTAL COMPLIANCE	0	17	17	0	18	18
X.3.6 MK-F PREPLANNING	0	19	19	0	20	20
X.3.7 MMES HEALTH & SAFETY	0	2	2	0	2	2
X.3.8 MMES QUALITY ASSURANCE	0	2	2	0	2	2
X.3.9 TECHNICAL SUPPORT CONTRACTOR	0	32	32	0	33	33
X.3.10 ENGR. SUPPORT STUDIES	543	0	543	573	0	573
X.3.11 MMES ON-SITE SUBCONTRACT	50	0	50	53	0	53
TOTAL DESIGN	593	1186	1779	626	1251	1877
2.03 WASTE MANAGEMENT						
W.2.12 MMES WASTE MANAGEMENT	0	116	116	0	130	130
W.2.13 WASTE CHARACTERIZATION	212	0	212	237	0	237
W.2.14 WASTE STORAGE	618	0	618	693	0	693
W.2.15 WASTE CONTAINERS	106	122	228	119	137	256
TOTAL WASTE MANAGEMENT	936	238	1174	1049	267	1316
2.04 RA MONITORING						
Y.4.1 EH & S MONITORING DURING RA	1	30	31	1	33	3
Y.4.2 EH & S MONITORING DURING RA	26	0	26	29	0	2
Y.4.3 VERIF. MONITORING DURING RA	0	15	15	0	17	1
Y.4.4 VERIF. MONITORING DURING RA	3	0	3	4	0	
TOTAL RA MONITORING	30	45	75	34	50	8
TOTAL INDIRECT COSTS	1681	3100	4781	1846	3380	522
3 YR 1 O & M COSTS						
3.01 NEW GROUND WATER MONITORING WE						
C.1.10 GROUNDWATER MONITORING WELLS	99	24	123	116	28	14
TOTAL NEW GROUND WATER MONITORING WE	99	24	123	116	28	14

2

ALTERNATE 2 - MULTILAYERED CAP

SUMMARY REPORT
$1 = $1000

03/22/1995

ıged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
≀ 1 O & M COSTS						
)2 POST-RA MONITORING (YR 1)						
).5.1 POST-RA MONITORING (YR 1)	6	8	14	7	9	16
).5.2 POST-RA MONITORING (YR 1)	9	0	9	11	0	11
ıL POST-RA MONITORING (YR 1)	15	8	23	18	9	27
)3 POST-RA S & M (YR 1)						
).5.3 POST-RA S & M (YR 1)	4	8	12	5	10	15
ıL POST-RA S & M (YR 1)	4	8	12	5	10	15
)4 POST-RA PROJECT MGMT. (YR 1)						
).5.4 POST-RA PROJECT MGMT. (YR 1)	0	30	30	0	36	36
ıL POST-RA PROJECT MGMT. (YR 1)	0	30	30	0	36	36
)5 POST-RA PROGRAM MGMT. (YR 1)						
).5.5 POST-RA PROGRAM MGMT. (YR 1)	0	30	30	0	36	36
ıL POST-RA PROGRAM MGMT. (YR 1)	0	30	30	0	36	36
. YR 1 O & M COSTS	118	100	218	139	119	258
≀ 2-LAST O&M (30 YR STUDY)						
)1 POST-RA MONITORING (YR 2-28)						
).6.1 POST-RA MONITORING (YR 2-28)	138	208	346	178	269	447
).6.2 POST-RA MONITORING (YR 2-28)	253	0	253	326	0	326
ıL POST-RA MONITORING (YR 2-28)	391	208	599	504	269	773
)2 POST-RA S & M (YR 2-28)						
).6.3 POST-RA S & M (YR 2-28)	117	221	338	150	285	435
ıL POST-RA S & M (YR 2-28)	117	221	338	150	285	435
)3 POST-RA PROJECT MGMT. (YR 2-28						
).6.4 POST-RA PROJ. MGMT. (YR 2-28)	0	810	810	0	1044	1044
AL POST-RA PROJECT MGMT. (YR 2-28	0	810	810	0	1044	1044

ALTERNATE 2 - MULTILAYERED CAP

SUMMARY REPORT
$1 = $1000

03/22/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
4 YR 2-LAST O&M (30 YR STUDY)						
4.04 POST-RA PROGRAM MGMT. (YR 2-28						
0.6.5 POST-RA PROG. MGMT. (YR 2-28)	0	810	810	0	1044	1044
TOTAL POST-RA PROGRAM MGMT. (YR 2-28	0	810	810	0	1044	1044
TOTAL YR 2-LAST O&M (30 YR STUDY)	508	2049	2557	654	2642	3296
5 5 YR CERCLA REVIEW						
5.01 CERCLA VERIFICATION (YR 5)						
0.7.1 ER DIVISION (CERCLA YR 5)	0	11	11	0	14	14
TOTAL CERCLA VERIFICATION (YR 5)	0	11	11	0	14	14
5.02 CERCLA VERIFICATION (YR 10)						
0.7.2 ER DIVISION (CERCLA YR 10)	0	11	11	0	14	14
TOTAL CERCLA VERIFICATION (YR 10)	0	11	11	0	14	14
5.03 CERCLA VERIFICATION (YR 15)						
0.7.3 ER DIVISION (CERCLA YR 15)	0	11	11	0	14	14
TOTAL CERCLA VERIFICATION (YR 15)	0	11	11	0	14	14
5.04 CERCLA VERIFICATION (YR 20)						
0.7.4 ER DIVISION (CERCLA YR 20)	0	11	11	0	14	14
TOTAL CERCLA VERIFICATION (YR 20)	0	11	11	0	14	14
5.05 CERCLA VERIFICATION (YR 25)						
0.7.5 ER DIVISION (CERCLA YR 25)	0	11	11	0	14	14
TOTAL CERCLA VERIFICATION (YR 25)	0	11	11	0	14	14
5.06 CERCLA VERIFICATION (YR 30)						
0.7.6 ER DIVISION (CERCLA YR 30)	0	11	11	0	14	14
TOTAL CERCLA VERIFICATION (YR 30)	0	11	11	0	14	14
TOTAL 5 YR CERCLA REVIEW	0	66	66	0	84	84

ALTERNATE 2 - MULTILAYERED CAP

SUMMARY REPORT
$1 = $1000

03/22/1995

ıged By: WBS / WBS / Trace Number

	Unescalated			Escalated		
	Material $	Labor $	Total $	Material $	Labor $	Total $
- TOTAL	5121	8538	13659	5762	9819	15581
ERHEAD	1104	2057	3161	1256	2451	3707
- TOTAL	6225	10595	16820	7018	12270	19288
NTINGENCY	2178	3708	5886	2456	4295	6751
) TOTAL	8403	14303	22706	9474	16565	26039

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*N I S T  B L C C - D E T A I L E D  L C C  A N A L Y S I S (version 4.20-95)*
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PART I - INITIAL ASSUMPTIONS AND COST DATA

Project alternative: ALT2
Run date: 04-17-1995 09:35:54
Run type: Federal Analysis--Projects Subject to OMB A-94
Comment: MULTILAYER CAP ($1=$1000)
Input data file: ALT2.DAT, last modified: 03-29-1995/14:26:05
LCC output file: ALT2.LCC, created: 03-29-1995/14:26:09
Base Date of Study: JAN 1997
Service Date: JAN 1999
Study period: 30.00 years (JAN 1997 through DEC 2026)
Plan/constr. period: 2.00 years (JAN 1997 through DEC 1998)
Service Period: 28.00 years (JAN 1999 through DEC 2026)
Discount rate: 7.0% Real (exclusive of general inflation)
End-of-year discounting convention

INITIAL CAPITAL ASSET COSTS (NOT DISCOUNTED)
(ADJUSTED FOR PRICE CHANGES DURING PLAN/CONST. PERIOD, IF ANY)

	YEAR (Beginning)	Cost Phasing	Yearly Cost	Total Cost
	JAN 1997	57.8%	$10,999	
	JAN 1998	42.2%	$8,030	
AT SERVICE DATE:	JAN 1999	0.0%	$0	
TOTAL INITIAL CAPITAL ASSET COSTS				$19,029

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PART II - LIFE-CYCLE COST ANALYSIS
Discount Rate = 7.0% Real (exclusive of general inflation)

PROJECT ALTERNATIVE: ALT2 RUN DATE: 04-17-1995/09:35:54

	PRESENT VALUE (1997 DOLLARS)	ANNUAL VALUE (1997 DOLLARS)
CASH REQUIREMENTS AS OF SERVICE DATE:		
DURING CONSTRUCTION	$18,504	$1,491
AT SERVICE DATE	$0	$0
SUBTOTAL	$18,504	$1,491
OPERATING, MAINTENANCE & REPAIR COSTS:		
NON-ANNUALLY RECURRING COSTS	$2,726	$220
SUBTOTAL	$2,726	$220
RESALE VALUE OF ORIG CAPITAL COMPONENTS	$0	$0
RESALE VALUE OF CAPITAL REPLACEMENTS	$0	$0
TOTAL LIFE-CYCLE PROJECT COST	$21,230	$1,711

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SUMMARY REPORT
Project Number: 33762.50
ALT. 3 - CONSOL. CELL W/ DEWAT

Project ESO Number.....
Revision Number.....0
Last Update.....03/20/1995

Sort Order
1. WBS - Level 1
2. WBS - Level 2
3. Trace Number

Approved by:

Project Estimator _____ Date _____

Estimating Manager _____ Date _____

se Fiscal Year/Quarter: 94/4
NDARD VALUE: C:\AES60F\ERDEC94C.val EXPIRES: 03/15/1996
TIMATE FILE: C:\4000\4000REVA\ALT3.Est 03/20/1995
HEDULE FILE: ALT3
PORT FILE: C:\4000\4000REVA\SUM3.Out 03/22/1995 14:06:57 AES Version 6.0f

ALT. 3 - CONSOL. CELL W/ DEWAT

SUMMARY REPORT
$1 = $1000

03/22/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
1 DIRECT COSTS						
1.01 REMEDIAL ACTION (FPC)						
C.1.1 SUPPORT FACILITIES	878	200	1078	950	217	1167
C.1.2 DECON & REMOVE SUPPORT FACILS.	78	97	175	101	125	226
C.1.3 SITE PREPARATION	143	120	263	156	131	287
C.1.4 CONSOL. CELL	4575	4538	9113	5504	5459	10963
C.1.5 DEWATERING	83	148	231	108	191	299
C.1.6 CLOSURE CAP	311	203	514	401	262	663
C.1.7 MOB & DEMOB	0	715	715	0	774	774
C.1.8 TRAINING & MEDICAL	372	202	574	462	251	713
TOTAL REMEDIAL ACTION (FPC)	6440	6223	12663	7682	7410	15092
1.02 DEED RESTRICTIONS						
C.1.9 DEED RESRICTIONS	0	4	4	0	5	5
TOTAL DEED RESTRICTIONS	0	4	4	0	5	5
1.03 REMEDIAL ACTION INTEGRATION						
C.1.10 MK-F INDIRECTS ON FP	0	1769	1769	0	2197	2197
C.1.11 MK-F DIRECTS ON FP	0	1221	1221	0	1516	1516
TOTAL REMEDIAL ACTION INTEGRATION	0	2990	2990	0	3713	3713
TOTAL DIRECT COSTS	6440	9217	15657	7682	11128	18810
2 INDIRECT COSTS						
2.01 PROJECT INTEGRATION						
W.2.1 MMES PROJECT MANAGEMENT	0	1026	1026	0	1252	1252
W.2.2 MMES PROJECT ANALYST	0	1026	1026	0	1252	1252
W.2.3 MMES CONST. ENGINEER	0	660	660	0	820	820
W.2.4 A-E TITLE III ENGINEERING	0	569	569	0	707	707
W.2.5 MMES TITLE III ENGINEERING	0	438	438	0	544	544
W.2.6 MMES HEALTH & SAFETY	0	419	419	0	520	520
W.2.7 MMES QUALITY ASSURANCE	0	174	174	0	216	216
W.2.8 CLOSURE VERIF. SAMPLING	224	90	314	289	116	405
W.2.9 INDEPENDENT CERTIFICATION	10	380	390	12	471	483

ALT. 3 - CONSOL. CELL W/ DEWAT

SUMMARY REPORT
$1 = $1000

03/22/1995

ıged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
IDIRECT COSTS						
)1 PROJECT INTEGRATION						
./.2.10 MMES WASTE MANAGEMENT	0	213	213	0	264	264
./.2.11 MMES ENVIRONMENTAL COMPLIANCE	0	91	91	0	113	113
ıL PROJECT INTEGRATION	234	5086	5320	301	6275	6576
)2 DESIGN						
(.3.1 A-E TITLE I & II ENGINEERING	0	2535	2535	0	2677	2677
(.3.2 MMES A/E SUPPORT	0	90	90	0	95	95
(.3.3 MMES WASTE MANAGEMENT	0	58	58	0	61	61
(.3.4 MMES TECH ADVISORY GROUP	0	30	30	0	32	32
(.3.5 MMES ENVIRONMENTAL COMPLIANCE	0	17	17	0	18	18
(.3.6 MK-F PREPLANNING	0	19	19	0	20	20
(.3.7 MMES HEALTH & SAFETY	0	2	2	0	2	2
(.3.8 MMES QUALITY ASSURANCE	0	2	2	0	2	2
(.3.9 TECHNICAL SUPPORT CONTRACTOR	0	32	32	0	33	33
(.3.10 ENGR. SUPPORT STUDIES	543	0	543	573	0	573
(.3.11 MMES ON-SITE CONTRACTOR	50	0	50	53	0	53
ıL DESIGN	593	2785	3378	626	2940	3566
)3 WASTE MANAGEMENT						
./.2.12 MMES WASTE MANAGEMENT	0	116	116	0	130	130
./.2.13 WASTE CHARACTERIZATION	302	0	302	338	0	338
./.2.14 WASTE STORAGE	776	0	776	871	0	871
./.2.15 WASTE CONTAINERS	193	402	595	216	451	667
ıL WASTE MANAGEMENT	1271	518	1789	1425	581	2006
)4 RA MONITORING						
(.4.1 EH & S MONITORING DURING RA	21	416	437	27	517	544
(.4.2 EH & S MONITORING DURING RA	454	0	454	564	0	564
(.4.3 VERIF. MONITORING DURING RA	11	208	219	13	259	272
(.4.4 VERIF. MONITORING DURING RA	46	0	46	57	0	57
ıL RA MONITORING	532	624	1156	661	776	1437
- INDIRECT COSTS	2630	9013	11643	3013	10572	13585

ALT. 3 - CONSOL. CELL W/ DEWAT

SUMMARY REPORT
$1 = $1000

03/22/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
3 YR 1 O & M COSTS						
3.01 NEW GROUND WATER MONITORING WE						
C.1.12 GROUNDWATER MONITORING WELLS	99	24	123	128	31	159
TOTAL NEW GROUND WATER MONITORING WE	99	24	123	128	31	159
3.02 POST-RA MONITORING (YR 1)						
0.5.1 POST-RA MONITORING (YR 1)	6	8	14	7	10	17
0.5.2 POST-RA MONITORING (YR 1)	9	0	9	12	0	12
TOTAL POST-RA MONITORING (YR 1)	15	8	23	19	10	29
3.03 POST-RA S & M (YR 1)						
0.5.3 POST-RA S & M (YR 1)	4	8	12	5	10	15
TOTAL POST-RA S & M (YR 1)	4	8	12	5	10	15
3.04 POST-RA PROJECT MGMT. (YR 1)						
0.5.4 POST-RA PROJECT MGMT. (YR 1)	0	30	30	0	39	39
TOTAL POST-RA PROJECT MGMT. (YR 1)	0	30	30	0	39	39
3.05 POST-RA PROGRAM MGMT. (YR 1)						
0.5.5 POST-RA PROGRAM MGMT. (YR 1)	0	30	30	0	39	39
TOTAL POST-RA PROGRAM MGMT. (YR 1)	0	30	30	0	39	39
TOTAL YR 1 O & M COSTS	118	100	218	152	129	281
4 YR 2-LAST O&M (30 YR STUDY)						
4.01 POST-RA MONITORING (YR 2-23)						
0.6.1 POST-RA MONITORING (YR 2-23)	113	170	283	146	219	365
0.6.2 POST-RA MONITORING (YR 2-23)	206	0	206	266	0	266
TOTAL POST-RA MONITORING (YR 2-23)	319	170	489	412	219	631
4.02 POST-RA S & M (YR 2-23)						
0.6.3 POST-RA S & M (YR 2-23)	78	171	249	100	221	321
TOTAL POST-RA S & M (YR 2-23)	78	171	249	100	221	321

ALT. 3 - CONSOL. CELL W/ DEWAT

SUMMARY REPORT
$1 = $1000

03/22/1995

nged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
R 2-LAST O&M (30 YR STUDY)						
03 POST-RA PROJECT MGMT. (YR 2-23						
3.6.4 POST-RA PROJ. MGMT. (YR 2-23)	0	660	660	0	853	853
AL POST-RA PROJECT MGMT. (YR 2-23	0	660	660	0	853	853
04 POST-RA PROGRAM MGMT. (YR 2-23						
3.6.5 POST-RA PROG. MGMT. (YR 2-23)	0	660	660	0	853	853
AL POST-RA PROGRAM MGMT. (YR 2-23	0	660	660	0	853	853
. YR 2-LAST O&M (30 YR STUDY)	397	1661	2058	512	2146	2658
YR CERCLA REVIEW						
01 CERCLA VERIFICATION (YR 5)						
3.7.1 ER DIVISION (CERCLA YR 5)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 5)	0	11	11	0	14	14
02 CERCLA VERIFICATION (YR 10)						
3.7.2 ER DIVISION (CERCLA YR 10)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 10)	0	11	11	0	14	14
03 CERCLA VERIFICATION (YR 15)						
3.7.3 ER DIVISION (CERCLA YR 15)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 15)	0	11	11	0	14	14
04 CERCLA VERIFICATION (YR 20)						
3.7.4 ER DIVISION (CERCLA YR 20)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 20)	0	11	11	0	14	14
05 CERCLA VERIFICATION (YR 25)						
3.7.5 ER DIVISION (CERCLA YR 25)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 25)	0	11	11	0	14	14

ALT. 3 - CONSOL. CELL W/ DEWAT

SUMMARY REPORT
$1 = $1000

03/22/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated			Escalated		
	Material $	Labor $	Total $	Material $	Labor $	Total $
5 5 YR CERCLA REVIEW						
5.06 CERCLA VERIFICATION (YR 30)						
0.7.6 ER DIVISION (CERCLA YR 30)	0	11	11	0	14	14
TOTAL CERCLA VERIFICATION (YR 30)	0	11	11	0	14	14
TOTAL 5 YR CERCLA REVIEW	0	66	66	0	84	84
SUB - TOTAL	9585	20057	29642	11359	24059	35418
OVERHEAD	1710	4004	5714	2004	4922	6926
SUB - TOTAL	11295	24061	35356	13363	28981	42344
CONTINGENCY	3952	8420	12372	4677	10143	14820
GRAND TOTAL	15247	32481	47728	18040	39124	57164

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: S T  B L C C - D E T A I L E D  L C C  A N A L Y S I S (version 4.20-95)*
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PART I - INITIAL ASSUMPTIONS AND COST DATA

Project alternative: ALT3
Run date: 04-17-1995 09:35:59
Run type: Federal Analysis--Projects Subject to OMB A-94
Comment: CONSOL CELL W/ DEWATER ($1=$1000)
Input data file: ALT3.DAT, last modified: 03-29-1995/14:27:34
LCC output file: ALT3.LCC, created: 03-29-1995/14:27:36
Base Date of Study: JAN 1997
Service Date: JAN 2004
Study period: 30.00 years (JAN 1997 through DEC 2026)
Plan/constr. period: 7.00 years (JAN 1997 through DEC 2003)
Service Period: 23.00 years (JAN 2004 through DEC 2026)
Discount rate: 7.0% Real (exclusive of general inflation)
End-of-year discounting convention

INITIAL CAPITAL ASSET COSTS (NOT DISCOUNTED)
(ADJUSTED FOR PRICE CHANGES DURING PLAN/CONST. PERIOD, IF ANY)

	YEAR (Beginning)	Cost Phasing	Yearly Cost	Total Cost
	JAN 1997	21.4%	$10,994	
	JAN 1998	12.1%	$6,216	
	JAN 1999	16.7%	$8,580	
	JAN 2000	21.1%	$10,840	
	JAN 2001	13.7%	$7,038	
	JAN 2002	8.0%	$4,110	
	JAN 2003	7.0%	$3,596	
AT SERVICE DATE:	JAN 2004	0.0%	$0	
TOTAL INITIAL CAPITAL ASSET COSTS				$51,375

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PART II - LIFE-CYCLE COST ANALYSIS
Discount Rate = 7.0% Real (exclusive of general inflation)

JECT ALTERNATIVE: ALT3 RUN DATE: 04-17-1995/09:35:59

	PRESENT VALUE (1997 DOLLARS)	ANNUAL VALUE (1997 DOLLARS)
H REQUIREMENTS AS OF SERVICE DATE:		
DURING CONSTRUCTION	$43,843	$3,533
AT SERVICE DATE	$0	$0
SUBTOTAL	$43,843	$3,533
RATING, MAINTENANCE & REPAIR COSTS:		
NON-ANNUALLY RECURRING COSTS	$1,807	$146
SUBTOTAL	$1,807	$146
ALE VALUE OF ORIG CAPITAL COMPONENTS	$0	$0

RESALE VALUE OF CAPITAL REPLACEMENTS	$0	$0
TOTAL LIFE-CYCLE PROJECT COST	$45,650	$3,679

* *

SUMMARY REPORT
Project Number: 33762.50
ALT. 4 - CONSOL. CELL W/TRTMT

Project ESO Number.....
Revision Number.....0
Last Update.....03/23/1995

Sort Order
1. WBS - Level 1
2. WBS - Level 2
3. Trace Number

Approved by:

Project Estimator _____ Date _____

Estimating Manager _____ Date _____

:e Fiscal Year/Quarter: 94/4
\NDARD VALUE: C:\AES60F\ERDEC94C.val EXPIRES: 03/15/1996
'IMATE FILE: C:\4000\4000REVA\ALT4.Est 03/23/1995
IEDULE FILE: ALT4
'ORT FILE: C:\4000\4000REVA\SUM4.Out 03/23/1995 10:07:47 AES Version 6.0f

ALT. 4 - CONSOL. CELL W/TRTMT

SUMMARY REPORT
$1 = $1000

03/23/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
1 DIRECT COSTS						
1.01 REMEDIAL ACTION (FPC)						
C.1.1 SUPPORT FACILITIES	878	200	1078	950	217	1167
C.1.2 DECON & REMOVE SUPPORT FACILS.	78	97	175	101	125	226
C.1.3 SITE PREPARATION	143	120	263	156	131	287
C.1.4 CONSOL. CELL	2111	1411	3522	2368	1583	3951
C.1.5 TREATMENT FACILITY	5208	0	5208	6024	0	6024
C.1.6 TREAT, DISPOSE & CAP	2688	3285	5973	3308	4043	7351
C.1.7 D & D TRTMT FACIL	1215	75	1290	1549	95	1644
C.1.8 MOB & DEMOB	0	1084	1084	0	1173	1173
C.1.9 TRAINING & MEDICAL	391	195	586	467	233	700
TOTAL REMEDIAL ACTION (FPC)	12712	6467	19179	14923	7600	22523
1.02 DEED RESTRICTIONS						
C.1.10 DEED RESTRICTIONS	0	4	4	0	5	5
TOTAL DEED RESTRICTIONS	0	4	4	0	5	5
1.03 REMEDIAL ACTION INTEGRATION						
C.1.11 MK-F INDIRECTS ON FP	0	2681	2681	0	3204	3204
C.1.12 MK-F DIRECTS ON FP	0	1850	1850	0	2212	2212
TOTAL REMEDIAL ACTION INTEGRATION	0	4531	4531	0	5416	5416
TOTAL DIRECT COSTS	12712	11002	23714	14923	13021	27944
2 INDIRECT COSTS						
2.01 PROJECT INTEGRATION						
W.2.1 MMES PROJECT MANAGEMENT	0	750	750	0	878	878
W.2.2 MMES PROJECT ANALYST	0	750	750	0	878	878
W.2.3 MMES CONST. ENGINEER	0	450	450	0	538	538
W.2.4 A-E TITLE III ENGINEERING	0	390	390	0	466	466
W.2.5 MMES TITLE III ENGINEERING	0	300	300	0	359	359
W.2.6 MMES HEALTH & SAFETY	0	287	287	0	343	343
W.2.7 MMES QUALITY ASSURANCE	0	119	119	0	142	142
W.2.8 CLOSURE VERIF. SAMPLING	224	90	314	289	116	405

ALT. 4 - CONSOL. CELL W/TRTMT

SUMMARY REPORT
$1 = $1000

03/23/1995

ıged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
DIRECT COSTS						
:1 PROJECT INTEGRATION						
:.2.9 INDEPENDENT CERTIFICATION	10	260	270	12	311	323
'.2.10 MMES WASTE MANAGEMENT	0	145	145	0	174	174
/.2.11 MMES ENVIRONMENTAL COMPLIANCE	0	62	62	0	75	75
ıL PROJECT INTEGRATION	234	3603	3837	301	4280	4581
)2 DESIGN						
..3.1 A-E TITLE I & II ENGINEERING	0	3822	3822	0	4035	4035
..3.2 MMES A/E SUPPORT	0	150	150	0	158	158
..3.3 MMES WASTE MANAGEMENT	0	58	58	0	61	61
..3.4 MMES TECH ADVISORY GROUP	0	30	30	0	32	32
:.3.5 MMES ENVIRONMENTAL COMPLIANCE	0	17	17	0	18	18
:.3.6 MK-F PREPLANNING	0	19	19	0	20	20
:.3.7 MMES HEALTH & SAFETY	0	2	2	0	2	2
:.3.8 MMES QUALITY ASSURANCE	0	2	2	0	2	2
:.3.9 TECHNICAL SUPPORT CONTRACTOR	0	32	32	0	33	33
:.3.10 ENGR. SUPPORT STUDIES	1628	0	1628	1718	0	1718
:.3.11 MMES ON-SITE SUBCONTRACT	50	0	50	53	0	53
.L DESIGN	1678	4132	5810	1771	4361	6132
)3 WASTE MANAGEMENT						
/.2.12 MMES WASTE MANAGEMENT	0	116	116	0	130	130
/.2.13 WASTE CHARACTERIZATION	527	0	527	591	0	591
/.2.14 WASTE STORAGE	980	0	980	1099	0	1099
/.2.15 WASTE CONTAINERS	7486	286	7772	8400	321	8721
.L WASTE MANAGEMENT	8993	402	9395	10090	451	10541
·4 RA MONITORING						
.4.1 EH & S MONITORING DURING RA	54	901	955	64	1077	1141
.4.2 EH & S MONITORING DURING RA	3128	0	3128	3738	0	3738
.4.3 VERIF. MONITORING DURING RA	27	451	478	32	539	571
.4.4 VERIF. MONITORING DURING RA	314	0	314	375	0	375
ıL RA MONITORING	3523	1352	4875	4209	1616	5825
. INDIRECT COSTS	14428	9489	23917	16371	10708	27079

ALT. 4 - CONSOL. CELL W/TRTMT

SUMMARY REPORT
$1 = $1000

03/23/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
3 YR 1 O & M COSTS						
3.01 NEW GROUND WATER MONITORING WE						
C.1.13 GROUNDWATER MONITORING WELLS	99	23	122	128	30	158
TOTAL NEW GROUND WATER MONITORING WE	99	23	122	128	30	158
3.02 POST-RA MONITORING (YR 1)						
0.5.1 POST-RA MONITORING (YR 1)	6	8	14	7	10	17
0.5.2 POST-RA MONITORING (YR 1)	9	0	9	12	0	12
TOTAL POST-RA MONITORING (YR 1)	15	8	23	19	10	29
3.03 POST-RA S & M (YR 1)						
0.5.3 POST-RA S & M (YR 1)	4	8	12	5	10	15
TOTAL POST-RA S & M (YR 1)	4	8	12	5	10	15
3.04 POST-RA PROJECT MGMT. (YR 1)						
0.5.4 POST-RA PROJECT MGMT. (YR 1)	0	30	30	0	39	39
TOTAL POST-RA PROJECT MGMT. (YR 1)	0	30	30	0	39	39
3.05 POST-RA PROGRAM MGMT. (YR 1)						
0.5.5 POST-RA PROGRAM MGMT. (YR 1)	0	30	30	0	39	39
TOTAL POST-RA PROGRAM MGMT. (YR 1)	0	30	30	0	39	39
TOTAL YR 1 O & M COSTS	118	99	217	152	128	280
4 YR 2-LAST O&M (30 YR STUDY)						
4.01 POST-RA MONITORING (YR 2-25)						
0.6.1 POST-RA MONITORING (YR 2-25)	123	185	308	159	239	398
0.6.2 POST-RA MONITORING (YR 2-25)	225	0	225	290	0	290
TOTAL POST-RA MONITORING (YR 2-25)	348	185	533	449	239	688
4.02 POST-RA S & M (YR 2-25)						
0.6.3 POST-RA S & M (YR 2-25)	86	187	273	111	242	353
TOTAL POST-RA S & M (YR 2-25)	86	187	273	111	242	353

ALT. 4 - CONSOL. CELL W/TRTMT

SUMMARY REPORT
$1 = $1000

03/23/1995

nged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
R 2-LAST O&M (30 YR STUDY)						
03 POST-RA PROJECT MGMT. (YR 2-25						
0.6.4 POST-RA PROJ. MGMT. (YR 2-25)	0	720	720	0	930	930
AL POST-RA PROJECT MGMT. (YR 2-25	0	720	720	0	930	930
04 POST-RA PROGRAM MGMT. (YR 2-25						
0.6.5 POST-RA PROG. MGMT. (YR 2-25)	0	720	720	0	930	930
AL POST-RA PROGRAM MGMT. (YR 2-25	0	720	720	0	930	930
L YR 2-LAST O&M (30 YR STUDY)	434	1812	2246	560	2341	2901
YR CERCLA REVIEW						
01 CERCLA VERIFICATION (YR 5)						
0.7.1 ER DIVISION (CERCLA YR 5)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 5)	0	11	11	0	14	14
02 CERCLA VERIFICATION (YR 10)						
0.7.2 ER DIVISION (CERCLA YR 10)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 10)	0	11	11	0	14	14
03 CERCLA VERIFICATION (YR 15)						
0.7.3 ER DIVISION (CERCLA YR 15)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 15)	0	11	11	0	14	14
04 CERCLA VERIFICATION (YR 20)						
0.7.4 ER DIVISION (CERCLA YR 20)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 20)	0	11	11	0	14	14
05 CERCLA VERIFICATION (YR 25)						
0.7.5 ER DIVISION (CERCLA YR 25))	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 25)	0	11	11	0	14	14

ALT. 4 - CONSOL. CELL W/TRTMT

SUMMARY REPORT
$1 = $1000

03/23/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
5 5 YR CERCLA REVIEW						
5.06 CERCLA VERIFICATION (YR 30)						
0.7.6 ER DIVISION (CERCLA YR 30)	0	11	11	0	14	14
TOTAL CERCLA VERIFICATION (YR 30)	0	11	11	0	14	14
TOTAL 5 YR CERCLA REVIEW	0	66	66	0	84	84
SUB - TOTAL	27692	22468	50160	32006	26282	58288
OVERHEAD	7393	3987	11380	8455	4794	13249
SUB - TOTAL	35085	26455	61540	40461	31076	71537
CONTINGENCY	14032	10581	24613	16185	12431	28616
GRAND TOTAL	49117	37036	86153	56646	43507	100153

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* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
S T  B L C C - D E T A I L E D  L C C  A N A L Y S I S (version 4.20-95)*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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PART I - INITIAL ASSUMPTIONS AND COST DATA

Project alternative: ALT4
Run date: 04-17-1995 09:36:04
Run type: Federal Analysis--Projects Subject to OMB A-94
Comment: CONSOL CELL W/ TREATMENT ($1=$1000)
Input data file: ALT4.DAT, last modified: 03-29-1995/14:28:34
LCC output file: ALT4.LCC, created: 03-29-1995/14:28:35
Base Date of Study: JAN 1997
Service Date: JAN 2002
Study period: 30.00 years (JAN 1997 through DEC 2026)
Plan/constr. period: 5.00 years (JAN 1997 through DEC 2001)
Service Period: 25.00 years (JAN 2002 through DEC 2026)
Discount rate: 7.0% Real (exclusive of general inflation)
End-of-year discounting convention

INITIAL CAPITAL ASSET COSTS (NOT DISCOUNTED)
(ADJUSTED FOR PRICE CHANGES DURING PLAN/CONST. PERIOD, IF ANY)

	YEAR (Beginning)	Cost Phasing	Yearly Cost	Total Cost
	JAN 1997	27.3%	$25,565	
	JAN 1998	32.4%	$30,341	
	JAN 1999	13.5%	$12,642	
	JAN 2000	17.7%	$16,575	
	JAN 2001	9.1%	$8,522	
AT SERVICE DATE:	JAN 2002	0.0%	$0	
TOTAL INITIAL CAPITAL ASSET COSTS				$93,645

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PART II - LIFE-CYCLE COST ANALYSIS
Discount Rate = 7.0% Real (exclusive of general inflation)

JECT ALTERNATIVE: ALT4 RUN DATE: 04-17-1995/09:36:04

	PRESENT VALUE (1997 DOLLARS)	ANNUAL VALUE (1997 DOLLARS)
H REQUIREMENTS AS OF SERVICE DATE:		
DURING CONSTRUCTION	$84,995	$6,849
AT SERVICE DATE	$0	$0
SUBTOTAL	$84,995	$6,849
RATING, MAINTENANCE & REPAIR COSTS:		
NON-ANNUALLY RECURRING COSTS	$2,248	$181
SUBTOTAL	$2,248	$181
ALE VALUE OF ORIG CAPITAL COMPONENTS	$0	$0
ALE VALUE OF CAPITAL REPLACEMENTS	$0	$0

TOTAL LIFE-CYCLE PROJECT COST	$87,243	$7,031

* *

SUMMARY REPORT
Project Number: 33762.50
ALT. 5 - CONSOL. CELL OFF OU

Project ESO Number.....
Revision Number.....0
Last Update.....03/21/1995

Sort Order
1. WBS - Level 1
2. WBS - Level 2
3. Trace Number

Approved by:

Project Estimator _____ Date _____

Estimating Manager _____ Date _____

se Fiscal Year/Quarter: 94/4
ANDARD VALUE: C:\AES60F\ERDEC94C.val EXPIRES: 03/15/1996
TIMATE FILE: C:\4000\4000REVA\ALT5.Est 03/21/1995
HEDULE FILE: ALT5
PORT FILE: C:\4000\4000REVA\SUM5.Out 03/22/1995 14:07:49 AES Version 6.0f

ALT. 5 - CONSOL. CELL OFF OU

SUMMARY REPORT
$1 = $1000

03/22/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
1 DIRECT COSTS						
1.01 REMEDIAL ACTION (FPC)						
C.1.1 SUPPORT FACILITIES @ IMPDS.	878	200	1078	951	217	1168
C.1.2 SUPPORT FACILS @ CONSOL CELL	197	24	221	214	26	240
C.1.3 DECON & REMOVE SUPPORT FACILS	97	130	227	126	168	294
C.1.4 SITE PREPARATION @ IMPDS	141	118	259	154	129	283
C.1.5 SITE PREPARATION @ CONSOL CELL	28	11	39	30	12	42
C.1.6 CONSOL. CELL CONST.	490	345	835	544	383	927
C.1.7 RELOC. & CAP CONTAM. MATL.	5097	3800	8897	6222	4638	10860
C.1.8 DEWATERING	83	134	217	108	173	281
C.1.9 CLOSURE CAP (AFTER 2 YRS)	311	176	487	401	228	629
C.1.10 MOB & DEMOB	0	762	762	0	824	824
C.1.11 TRAINING & MEDICAL	304	158	462	378	197	575
TOTAL REMEDIAL ACTION (FPC)	7626	5858	13484	9128	6995	16123
1.02 DEED RESTRICTIONS						
C.1.12 DEED RESRICTIONS	0	4	4	0	5	5
TOTAL DEED RESTRICTIONS	0	4	4	0	5	5
1.03 REMEDIAL ACTION INTEGRATION						
C.1.13 MK-F INDIRECTS ON FP	0	1884	1884	0	2343	2343
C.1.14 MK-F DIRECTS ON FP	0	1301	1301	0	1617	1617
TOTAL REMEDIAL ACTION INTEGRATION	0	3185	3185	0	3960	3960
TOTAL DIRECT COSTS	7626	9047	16673	9128	10960	20088
2 INDIRECT COSTS						
2.01 PROJECT INTEGRATION						
W.2.1 MMES PROJECT MANAGEMENT	0	1038	1038	0	1268	1268
W.2.2 MMES PROJECT ANALYST	0	1038	1038	0	1268	1268
W.2.3 MMES CONST. ENGINEER	0	666	666	0	828	828
W.2.4 A-E TITLE III ENGINEERING	0	577	577	0	718	718
W.2.5 MMES TITLE III ENGINEERING	0	444	444	0	552	552
W.2.6 MMES HEALTH & SAFETY	0	425	425	0	528	528

ALT. 5 - CONSOL. CELL OFF OU

SUMMARY REPORT
$1 = $1000

03/22/1995

ıged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
IDIRECT COSTS						
)1 PROJECT INTEGRATION						
).2.7 MMES QUALITY ASSURANCE	0	176	176	0	219	219
).2.8 CLOSURE VERIF. SAMPLING	224	90	314	289	116	405
).2.9 INDEPENDENT CERTIFICATION	10	385	395	12	478	490
).2.10 MMES WASTE MANAGEMENT	0	215	215	0	267	267
).2.11 MMES ENVIRONMENTAL COMPLIANCE	0	95	95	0	118	118
ıL PROJECT INTEGRATION	234	5149	5383	301	6360	6661
)2 DESIGN						
(.3.1 A-E TITLE I & II ENGINEERING	0	2691	2691	0	2841	2841
(.3.2 MMES A/E SUPPORT	0	114	114	0	120	120
(.3.3 MMES WASTE MANAGEMENT	0	58	58	0	61	61
(.3.4 MMES TECH ADVISORY GROUP	0	30	30	0	32	32
(.3.5 MMES ENVIRONMENTAL COMPLIANCE	0	17	17	0	18	18
(.3.6 MK-F PREPLANNING	0	19	19	0	20	20
(.3.7 MMES HEALTH & SAFETY	0	2	2	0	2	2
(.3.8 MMES QUALITY ASSURANCE	0	2	2	0	2	2
(.3.9 TECHNICAL SUPPORT CONTRACTOR	0	32	32	0	33	33
(.3.10 ENGR. SUPPORT STUDIES	543	0	543	573	0	573
(.3.11 MMES ONSITE SUBCONTRACT	50	0	50	53	0	53
ıL DESIGN	593	2965	3558	626	3129	3755
)3 WASTE MANAGEMENT						
).2.12 MMES WASTE MANAGEMENT	0	116	116	0	130	130
).2.13 WASTE CHARACTERIZATION	482	0	482	540	0	540
).2.14 WASTE STORAGE	1042	0	1042	1169	0	1169
).2.15 WASTE CONTAINERS	238	411	649	267	461	728
ıL WASTE MANAGEMENT	1762	527	2289	1976	591	2567
)4 RA MONITORING						
'.4.1 EH & S MONITORING DURING RA	18	366	384	23	455	478
'.4.2 EH & S MONITORING DURING RA	394	0	394	490	0	490
'.4.3 VERIF. MONITORING DURING RA	9	183	192	11	227	238
'.4.4 VERIF. MONITORING DURING RA	40	0	40	49	0	49
ıL RA MONITORING	461	549	1010	573	682	1255
. INDIRECT COSTS	3050	9190	12240	3476	10762	14238

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ALT. 5 - CONSOL. CELL OFF OU

SUMMARY REPORT
$1 = $1000

03/22/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
3 YR 1 O & M COSTS						
3.01 NEW GROUND WATER MONITORING WE						
C.1.15 GROUNDWATER MONITORING WELLS	191	35	226	247	45	292
TOTAL NEW GROUND WATER MONITORING WE	191	35	226	247	45	292
3.02 POST-RA MONITORING (YR 1)						
0.5.1 POST-RA MONITORING (YR 1)	6	8	14	7	10	17
0.5.2 POST-RA MONITORING (YR 1)	9	0	9	12	0	12
TOTAL POST-RA MONITORING (YR 1)	15	8	23	19	10	29
3.03 POST-RA S & M (YR 1)						
0.5.3 POST-RA S & M (YR 1)	4	8	12	5	10	15
TOTAL POST-RA S & M (YR 1)	4	8	12	5	10	15
3.04 POST-RA PROJECT MGMT. (YR 1)						
0.5.4 POST-RA PROJECT MGMT. (YR 1)	0	30	30	0	39	39
TOTAL POST-RA PROJECT MGMT. (YR 1)	0	30	30	0	39	39
3.05 POST-RA PROGRAM MGMT. (YR 1)						
0.5.5 POST-RA PROGRAM MGMT. (YR 1)	0	30	30	0	39	39
TOTAL POST-RA PROGRAM MGMT. (YR 1)	0	30	30	0	39	39
TOTAL YR 1 O & M COSTS	210	111	321	271	143	414
4 YR 2-LAST O&M (30 YR STUDY)						
4.01 POST-RA MONITORING (YR 2-23)						
0.6.1 POST-RA MONITORING (YR 2-23)	113	170	283	146	219	365
0.6.2 POST-RA MONITORING (YR 2-23)	206	0	206	266	0	266
TOTAL POST-RA MONITORING (YR 2-23)	319	170	489	412	219	63[illegible]
4.02 POST-RA S & M (YR 2-23)						
0.6.3 POST-RA S & M (YR 2-23)	77	169	246	100	219	31[illegible]
TOTAL POST-RA S & M (YR 2-23)	77	169	246	100	219	31[illegible]

ALT. 5 - CONSOL. CELL OFF OU

SUMMARY REPORT
$1 = $1000

03/22/1995

ıged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
٤ 2-LAST O&M (30 YR STUDY)						
)3 POST-RA PROJECT MGMT. (YR 2-23						
).6.4 POST-RA PROJ. MGMT. (YR 2-23)	0	660	660	0	853	853
٨L POST-RA PROJECT MGMT. (YR 2-23	0	660	660	0	853	853
)4 POST-RA PROGRAM MGMT. (YR 2-23						
)ः6.5 POST-RA PROG. MGMT. (YR 2-23)	0	660	660	0	853	853
AL POST-RA PROGRAM MGMT. (YR 2-23	0	660	660	0	853	853
L YR 2-LAST O&M (30 YR STUDY)	396	1659	2055	512	2144	2656
YR CERCLA REVIEW						
01 CERCLA VERIFICATION (YR 5)						
0.7.1 ER DIVISION (CERCLA YR 5)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 5)	0	11	11	0	14	14
02 CERCLA VERIFICATION (YR 10)						
0.7.2 ER DIVISION (CERCLA YR 10)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 10)	0	11	11	0	14	14
03 CERCLA VERIFICATION (YR 15)						
0.7.3 ER DIVISION (CERCLA YR 15)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 15)	0	11	11	0	14	14
04 CERCLA VERIFICATION (YR 20)						
0.7.4 ER DIVISION (CERCLA YR 20)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 20)	0	11	11	0	14	14
05 CERCLA VERIFICATION (YR 25)						
0.7.5 ER DIVISION (CERCLA YR 25)	0	11	11	0	14	14
AL CERCLA VERIFICATION (YR 25)	0	11	11	0	14	14

ALT. 5 - CONSOL. CELL OFF OU

SUMMARY REPORT
$1 = $1000

03/22/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated			Escalated		
	Material $	Labor $	Total $	Material $	Labor $	Total $
5 5 YR CERCLA REVIEW						
5.06 CERCLA VERIFICATION (YR 30)						
0.7.6 ER DIVISION (CERCLA YR 30)	0	11	11	0	14	14
TOTAL CERCLA VERIFICATION (YR 30)	0	11	11	0	14	14
TOTAL 5 YR CERCLA REVIEW	0	66	66	0	84	84
SUB - TOTAL	11282	20073	31355	13387	24093	37480
OVERHEAD	1940	3994	5934	2270	4914	7184
SUB - TOTAL	13222	24067	37289	15657	29007	44664
CONTINGENCY	4627	8422	13049	5480	10153	15633
GRAND TOTAL	17849	32489	50338	21137	39160	60297

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I S T  B L C C - D E T A I L E D  L C C  A N A L Y S I S (version 4.20-95)*
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PART I - INITIAL ASSUMPTIONS AND COST DATA

Project alternative: ALT5
Run date: 04-17-1995 09:36:10
Run type: Federal Analysis--Projects Subject to OMB A-94
Comment: CONSOL CELL - OFF-OU ($1=$1000)
Input data file: ALT5.DAT, last modified: 03-29-1995/14:30:03
LCC output file: ALT5.LCC, created: 03-29-1995/14:30:05
Base Date of Study: JAN 1997
Service Date: JAN 2004
Study period: 30.00 years (JAN 1997 through DEC 2026)
Plan/constr. period: 7.00 years (JAN 1997 through DEC 2003)
Service Period: 23.00 years (JAN 2004 through DEC 2026)
Discount rate: 7.0% Real (exclusive of general inflation)
End-of-year discounting convention

INITIAL CAPITAL ASSET COSTS (NOT DISCOUNTED)
(ADJUSTED FOR PRICE CHANGES DURING PLAN/CONST. PERIOD, IF ANY)

	YEAR (Beginning)	Cost Phasing	Yearly Cost	Total Cost
	JAN 1997	23.9%	$12,981	
	JAN 1998	10.2%	$5,540	
	JAN 1999	13.5%	$7,332	
	JAN 2000	22.1%	$12,003	
	JAN 2001	15.5%	$8,419	
	JAN 2002	7.7%	$4,182	
	JAN 2003	7.1%	$3,856	
AT SERVICE DATE:	JAN 2004	0.0%	$0	
TOTAL INITIAL CAPITAL ASSET COSTS				$54,314

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PART II - LIFE-CYCLE COST ANALYSIS
Discount Rate = 7.0% Real (exclusive of general inflation)

ROJECT ALTERNATIVE: ALT5 RUN DATE: 04-17-1995/09:36:10

	PRESENT VALUE (1997 DOLLARS)	ANNUAL VALUE (1997 DOLLARS)
ASH REQUIREMENTS AS OF SERVICE DATE:		
DURING CONSTRUCTION	$46,335	$3,734
AT SERVICE DATE	$0	$0
SUBTOTAL	$46,335	$3,734
PERATING, MAINTENANCE & REPAIR COSTS:		
NON-ANNUALLY RECURRING COSTS	$1,917	$154
SUBTOTAL	$1,917	$154
ESALE VALUE OF ORIG CAPITAL COMPONENTS	$0	$0

RESALE VALUE OF CAPITAL REPLACEMENTS	$0	$0
TOTAL LIFE-CYCLE PROJECT COST	$48,252	$3,888

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SUMMARY REPORT
Project Number: 33762.50
ALT. 6 - RMV, TRT, DSPS(OF-ST)

Project ESO Number.....
Revision Number.....0
Last Update.....03/23/1995

Sort Order
1. WBS - Level 1
2. WBS - Level 2
3. Trace Number

Approved by:

Project Estimator Date

Estimating Manager Date

e Fiscal Year/Quarter: 94/4
NDARD VALUE: C:\AES60F\ERDEC94C.val EXPIRES: 03/15/1996
IMATE FILE: C:\4000\4000REVA\ALT6.Est 03/23/1995
EDULE FILE: ALT6
ORT FILE: C:\4000\4000REVA\SUM6.Out 03/23/1995 10:08:17 AES Version 6.0f

ALT. 6 - RMV, TRT, DSPS(OF-ST)

SUMMARY REPORT
$1 = $1000

03/23/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
1 DIRECT COSTS						
1.01 REMEDIAL ACTION (FPC)						
C.1.1 SUPPORT FACILITIES	927	219	1146	1004	237	1241
C.1.2 DECON & REMOVE SUPPORT FACILS.	78	97	175	98	122	220
C.1.3 SITE PREPARATION	181	185	366	197	202	399
C.1.4 RELOC MATL FROM 3539 & 3540	985	276	1261	1089	305	1394
C.1.5 TREATMENT FACILITY	7812	0	7812	8828	0	8828
C.1.6 REMOVE & TREAT	3225	4397	7622	3883	5294	9177
C.1.7 D & D TRTMT FACIL	1215	75	1290	1528	94	1622
C.1.8 MOB & DEMOB	0	1228	1228	0	1329	1329
C.1.9 TRAINING & MEDICAL	534	271	805	629	319	948
C.1.10 TRANSPORT & DISPOSE WASTE	19009	0	19009	22975	0	22975
TOTAL REMEDIAL ACTION (FPC)	33966	6748	40714	40231	7902	48133
1.02 REMEDIAL ACTION INTEGRATION						
C.1.11 MK-F INDIRECTS ON FP	0	3037	3037	0	3575	3575
C.1.12 MK-F DIRECTS ON FP	0	2096	2096	0	2468	2468
TOTAL REMEDIAL ACTION INTEGRATION	0	5133	5133	0	6043	6043
TOTAL DIRECT COSTS	33966	11881	45847	40231	13945	54176
2 INDIRECT COSTS						
2.01 PROJECT INTEGRATION						
W.2.1 MMES PROJECT MANAGEMENT	0	666	666	0	768	768
W.2.2 MMES PROJECT ANALYST	0	666	666	0	768	768
W.2.3 MMES CONST. ENGINEER	0	388	388	0	456	456
W.2.4 A-E TITLE III ENGINEERING	0	335	335	0	395	395
W.2.5 MMES TITLE III ENGINEERING	0	258	258	0	304	304
W.2.6 MMES HEALTH & SAFETY	0	247	247	0	290	290
W.2.7 MMES QUALITY ASSURANCE	0	103	103	0	121	121
W.2.8 CLOSURE VERIF. SAMPLING	224	90	314	279	111	390
W.2.9 INDEPENDENT CERTIFICATION	10	224	234	12	263	275
W.2.10 MMES WASTE MANAGEMENT	0	250	250	0	294	294
W.2.11 MMES ENVIRONMENTAL COMPLIANCE	0	54	54	0	63	63
TOTAL PROJECT INTEGRATION	234	3281	3515	291	3833	4124

ALT. 6 - RMV, TRT, DSPS(OF-ST)

SUMMARY REPORT
$1 = $1000

03/23/1995

ıged By: WBS / WBS / Trace Number

	Unescalated			Escalated		
	Material $	Labor $	Total $	Material $	Labor $	Total $
IDIRECT COSTS						
)2 DESIGN						
..3.1 A-E TITLE I & II ENGINEERING	0	4339	4339	0	4581	4581
:.3.2 MMES A/E SUPPORT	0	150	150	0	158	158
:.3.3 MMES WASTE MANAGEMENT	0	58	58	0	61	61
:.3.4 MMES TECH ADVISORY GROUP	0	30	30	0	32	32
:.3.5 MMES ENVIRONMENTAL COMPLIANCE	0	17	17	0	18	18
:.3.6 MK-F PREPLANNING	0	19	19	0	20	20
:.3.7 MMES HEALTH & SAFETY	0	2	2	0	2	2
:.3.8 MMES QUALITY ASSURANCE	0	2	2	0	2	2
:.3.9 TECHNICAL SUPPORT CONTRACTOR	0	32	32	0	33	33
:.3.10 ENGR. SUPPORT STUDIES	1628	0	1628	1718	0	1718
:.3.11 MMES ONSITE SUBCONTRACT	50	0	50	53	0	53
ıL DESIGN	1678	4649	6327	1771	4907	6678
)3 WASTE MANAGEMENT						
/.2.12 MMES WASTE MANAGEMENT	0	116	116	0	130	130
/.2.13 WASTE CHARACTERIZATION	5443	218	5661	6108	245	6353
/.2.14 WASTE STORAGE	2432	0	2432	2729	0	2729
/.2.15 WASTE CONTAINERS	11178	1791	12969	12543	2010	14553
ıL WASTE MANAGEMENT	19053	2125	21178	21380	2385	23765
)4 RA MONITORING						
.4.1 EH & S MONITORING DURING RA	81	1321	1402	95	1555	1650
.4.2 EH & S MONITORING DURING RA	4681	0	4681	5510	0	5510
.4.3 VERIF. MONITORING DURING RA	40	661	701	47	778	825
.4.4 VERIF. MONITORING DURING RA	469	0	469	552	0	552
L RA MONITORING	5271	1982	7253	6204	2333	8537
INDIRECT COSTS	26236	12037	38273	29646	13458	43104
1 O & M COSTS						
)1 NEW GROUND WATER MONITORING WE						
:.1.13 GROUNDWATER MONITORING WELLS	99	23	122	126	29	155
ıL NEW GROUND WATER MONITORING WE	99	23	122	126	29	155

ALT. 6 - RMV, TRT, DSPS(OF-ST)

SUMMARY REPORT
$1 = $1000

03/23/1995

Arranged By: WBS / WBS / Trace Number

	Unescalated Material $	Unescalated Labor $	Unescalated Total $	Escalated Material $	Escalated Labor $	Escalated Total $
3 YR 1 O & M COSTS						
3.02 POST-RA MONITORING (YR 1)						
0.5.1 POST-RA MONITORING (YR 1)	6	8	14	7	10	17
0.5.2 POST-RA MONITORING (YR 1)	9	0	9	12	0	12
TOTAL POST-RA MONITORING (YR 1)	15	8	23	19	10	29
3.03 POST-RA PROJECT MGMT. (YR 1)						
0.5.3 POST-RA PROJECT MGMT. (YR 1)	0	30	30	0	39	39
TOTAL POST-RA PROJECT MGMT. (YR 1)	0	30	30	0	39	39
3.04 POST-RA PROGRAM MGMT. (YR 1)						
0.5.4 POST-RA PROGRAM MGMT. (YR 1)	0	30	30	0	39	39
TOTAL POST-RA PROGRAM MGMT. (YR 1)	0	30	30	0	39	39
TOTAL YR 1 O & M COSTS	114	91	205	145	117	262
4 YR 2-5 O & M COSTS						
4.01 POST-RA MONITORING (YR 2-5)						
0.6.1 POST-RA MONITORING (YR 2-5)	21	31	52	27	40	67
0.6.2 POST-RA MONITORING (YR 2-5)	37	0	37	48	0	48
TOTAL POST-RA MONITORING (YR 2-5)	58	31	89	75	40	115
4.02 POST-RA PROJECT MGMT. (YR 2-5)						
0.6.3 POST-RA PROJ. MGMT. (YR 2-5)	0	120	120	0	155	155
TOTAL POST-RA PROJECT MGMT. (YR 2-5)	0	120	120	0	155	155
4.03 POST-RA PROGRAM MGMT. (YR 2-5)						
0.6.4 POST-RA PROG. MGMT. (YR 2-5)	0	120	120	0	155	155
TOTAL POST-RA PROGRAM MGMT. (YR 2-5)	0	120	120	0	155	155
TOTAL YR 2-5 O & M COSTS	58	271	329	75	350	425

ALT. 6 - RMV, TRT, DSPS(OF-ST)

SUMMARY REPORT
$1 = $1000

03/23/1995

ged By: WBS / WBS / Trace Number

	Unescalated			Escalated		
	Material $	Labor $	Total $	Material $	Labor $	Total $
YR CERCLA REVIEW						
1 CERCLA VERIFICATION (YR 5)						
.7.1 ER DIVISION (CERCLA YR 5)	0	11	11	0	14	14
CERCLA VERIFICATION (YR 5)	0	11	11	0	14	14
5 YR CERCLA REVIEW	0	11	11	0	14	14
TOTAL	60374	24291	84665	70097	27884	97981
RHEAD	12497	4209	16706	14291	4893	19184
TOTAL	72871	28500	101371	84388	32777	117165
TINGENCY	29149	11400	40549	33755	13111	46866
TOTAL	102020	39900	141920	118143	45888	164031

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* N I S T  B L C C - D E T A I L E D  L C C  A N A L Y S I S (version 4.20-95)*
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PART I - INITIAL ASSUMPTIONS AND COST DATA

Project alternative: ALT6
Run date: 04-17-1995 09:36:15
Run type: Federal Analysis--Projects Subject to OMB A-94
Comment: REMOVE, TREAT, DISPOSE OFF-SITE ($1=$1000)
Input data file: ALT6.DAT, last modified: 03-29-1995/14:30:56
LCC output file: ALT6.LCC, created: 03-29-1995/14:30:58
Base Date of Study: JAN 1997
Service Date: JAN 2001
Study period: 9.00 years (JAN 1997 through DEC 2005)
Plan/constr. period: 4.00 years (JAN 1997 through DEC 2000)
Service Period: 5.00 years (JAN 2001 through DEC 2005)
Discount rate: 7.0% Real (exclusive of general inflation)
End-of-year discounting convention

INITIAL CAPITAL ASSET COSTS (NOT DISCOUNTED)
(ADJUSTED FOR PRICE CHANGES DURING PLAN/CONST. PERIOD, IF ANY)

	YEAR (Beginning)	Cost Phasing	Yearly Cost	Total Cost
	JAN 1997	23.1%	$37,580	
	JAN 1998	31.2%	$50,757	
	JAN 1999	22.4%	$36,441	
	JAN 2000	23.3%	$37,905	
AT SERVICE DATE:	JAN 2001	0.0%	$0	
TOTAL INITIAL CAPITAL ASSET COSTS				$162,684

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PART II - LIFE-CYCLE COST ANALYSIS
Discount Rate = 7.0% Real (exclusive of general inflation)

PROJECT ALTERNATIVE: ALT6 RUN DATE: 04-17-1995/09:36:15

	PRESENT VALUE (1997 DOLLARS)	ANNUAL VALUE (1997 DOLLARS)
CASH REQUIREMENTS AS OF SERVICE DATE:		
DURING CONSTRUCTION	$147,788	$22,683
AT SERVICE DATE	$0	$0
SUBTOTAL	$147,788	$22,683
OPERATING, MAINTENANCE & REPAIR COSTS:		
NON-ANNUALLY RECURRING COSTS	$849	$130
SUBTOTAL	$849	$130
RESALE VALUE OF ORIG CAPITAL COMPONENTS	$0	$0
RESALE VALUE OF CAPITAL REPLACEMENTS	$0	$0
TOTAL LIFE-CYCLE PROJECT COST	$148,637	$22,814