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FINAL
INTERIM WASTE CONTAINMENT STRUCTURE REMEDIAL ALTERNATIVES TECHNOLOGIES DEVELOPMENT AND SCREENING TECHNICAL MEMORANDUM

FOR THE
NIAGARA FALLS STORAGE SITE
LEWISTON, NEW YORK

April 2013

FINAL

INTERIM WASTE CONTAINMENT STRUCTURE REMEDIAL ALTERNATIVES TECHNOLOGIES DEVELOPMENT AND SCREENING TECHNICAL MEMORANDUM FOR THE NIAGARA FALLS STORAGE SITE LEWISTON, NEW YORK

Prepared by:

U. S. Army Corps of Engineers
Buffalo District

Supported by:

Science Applications International Corporation
4449 Easton Way, Suite 130
Columbus, Ohio 43219

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ACRONYMS AND ABBREVIATIONS

AEC	Atomic Energy Commission
ARAR	Applicable or Relevant and Appropriate Requirement
BOP	Balance of Plant
°C	Degrees Celsius
CCIM	Cold Crucible Induction Melter
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
Ci	Curie
cm	Centimeter
cm/s	Centimeters per Second
cm^2	Square Centimeters
COPC	Contaminant of Potential Concern
COC	Contaminant of Concern
DOE	U. S. Department of Energy
DOT	U. S. Department of Transportation
$	Dollars
EPA	U. S. Environmental Protection Agency
°F	Degrees Fahrenheit
FS	Feasibility Study
ft	Feet
ft^2	Square Feet
FUSRAP	Formerly Utilized Sites Remedial Action Program
gal	Gallon
GRA	General Response Action
ha	Hectare
hr	Hour
in.	Inch
IWCS	Interim Waste Containment Structure
JHCM	Joule-Heated Ceramic Melter
kg	Kilogram
km	Kilometer
km^2	Square Kilometers
L	Liter
LLMW	Low-Level Mixed Waste
LLRW	Low-Level Radioactive Waste
LOOW	Lake Ontario Ordnance Works
LTM	Long-Term Monitoring
LUC	Land-Use Control
LWBZ	Lower Water-Bearing Zone
m	Meter
µg/kg	Micrograms per Kilogram
µm	Micron
m^2	Square Meter
m^3	Cubic Meters
m/s	Meters per Second
MED	Manhattan Engineer District
MeV	Million Electron Volts
mg/kg	Milligrams per Kilogram
min	Minute
mm	Millimeter
mrem	Millirem

ACRONYMS AND ABBREVIATIONS (continued)

NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NFSS	Niagara Falls Storage Site
NRC	U. S. Nuclear Regulatory Commission
OU	Operable Unit
%	Percent
PCB	Polychlorinated Biphenyl
pCi/g	Picocuries per Gram
pCi/L	Picocuries per Liter
pCi/m^2/s	Picocuries per Square Meter per Second
PRB	Permeable Reactive Barrier
psi	Pounds per Square Inch
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RCS	Radon Control System
RI	Remedial Investigation
ROD	Record of Decision
S/S	Solidification/Stabilization
TM	Technical Memorandum
TNT	Trinitrotoluene
USACE	U. S. Army Corps of Engineers
UWBZ	Upper Water-Bearing Zone
WAC	Waste Acceptance Criteria
yd^3	Cubic Yards

METRIC CONVERSION CHART

To Convert to Metric			To Convert from Metric		
If You Know	**Multiply By**	**To Get**	**If You Know**	**Multiply By**	**To Get**
Length					
inches	2.54	centimeters	centimeters	0.3937	inches
feet	30.48	centimeters	centimeters	0.0328	feet
feet	0.3048	meters	meters	3.281	feet
yards	0.9144	meters	meters	1.0936	yards
miles	1.60934	kilometers	kilometers	0.6214	miles
Area					
square inches	6.4516	square centimeters	square centimeters	0.155	square inches
square feet	0.092903	square meters	square meters	10.7639	square feet
square yards	0.8361	square meters	square meters	1.196	square yards
acres	0.40469	hectares	hectares	2.471	acres
square miles	2.58999	square kilometers	square kilometers	0.3861	square miles
Volume					
fluid ounces	29.574	milliliters	milliliters	0.0338	fluid ounces
gallons	3.7854	liters	liters	0.26417	gallons
gallons	0.00378	cubic meters	cubic meters	264.55	gallons
cubic feet	0.028317	cubic meters	cubic meters	35.315	cubic feet
cubic yards	0.76455	cubic meters	cubic meters	1.308	cubic yards
Weight					
ounces	28.3495	grams	grams	0.03527	ounces
pounds	0.4536	kilograms	kilograms	2.2046	pounds
Temperature					
Fahrenheit	Subtract 32 then multiply by 5/9ths	Celsius	Celsius	Multiply by 9/5ths then add 32	Fahrenheit
Radiation					
picocurie	0.037	Becquerel	Becquerel	27.027027	Picocuries
curie	3.70E+10	Becquerel	Becquerel	2.703E-11	Curies
rem	0.01	sievert	sievert	100	rem
RAD	0.01	Gray	Gray	100	RADs

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EXECUTIVE SUMMARY

The Niagara Falls Storage Site (NFSS) is a 77.3-hectare (ha) (191-acre) property that is owned by the United States Government in the form of the U.S. Department of Energy (DOE) and is located at 1397 Pletcher Road in the township of Lewiston, Niagara County, New York. The NFSS is part of the former Lake Ontario Ordnance Works (LOOW) that was used by the War Department beginning in 1942 for the production of trinitrotoluene (TNT). During the 1940s and 1950s, the Manhattan Engineer District (MED) and the Atomic Energy Commission (AEC) brought various radioactive wastes and uranium processing byproducts (residues) resulting from our nation's atomic energy program to the LOOW for storage. In 1982, the DOE began cleanup and consolidation of the radioactive residues, wastes, and debris into a 4.0-ha (10-acre) Interim Waste Containment Structure (IWCS) that was constructed on the NFSS property and completed in 1986 (Figure 1-2). The IWCS contains radioactive residues, contaminated rubble and debris from demolition of buildings, and contaminated soil from the site and adjacent properties.

The U. S. Army Corps of Engineers (USACE)-Buffalo District is the lead Federal agency for Formerly Utilized Sites Remedial Action Program (FUSRAP) remediation of the NFSS. As the lead agency, USACE is conducting a remedial investigation/feasibility study (RI/FS) pursuant to the protocols set forth in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). CERCLA activities at the NFSS have transitioned from the site RI activities to the FS evaluation of potential remediation alternatives.

USACE recognizes the need to implement a focused CERCLA FS process and, therefore, has established three separate operable units (OUs) for NFSS: the IWCS OU, the Balance of Plant (BOP) OU, and the Groundwater OU. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (Title 40 *Code of Federal Regulations [CFR]* Section 300.430[a][ii][A]) states that sites should generally be remediated in OUs when phased analysis is necessary given the size or complexity of a site. The OU approach to the FS process allows USACE to address the IWCS first given that selection of a remedy in which some or all of the waste materials remain in the IWCS would influence land uses for the BOP area (i.e., area outside of the IWCS but within the NFSS boundary) and the resultant exposure scenarios used to develop cleanup criteria. The BOP OU FS would then be prepared, followed by the Groundwater OU FS.

USACE is committed to keeping the public well informed on the components of the IWCS FS and to providing a vehicle for public participation. The publication of a series of Technical Memoranda (TM) provides opportunities for active public involvement in the process. USACE released the *Development of Interim Waste Containment Structure Remedial Alternatives Technologies Development and Screening Technical Memorandum Fact Sheet* (USACE 2010) in December 2010 to inform the public of the scope and objectives for this TM. The public comments received were evaluated during development of this TM and will be further addressed during the development of the IWCS FS document.

ES.1 Scope and Purpose

The primary purpose of this TM is to aid in the development of a final remedy for the IWCS OU. The National Oil and Hazardous Substances Pollution Contingency Plan (Title 40 *Code of Federal Regulations* §300.430[a][1][i]) states that the goal of the remedy selection process is to select remedies that are protective of human health and the environment, that maintain protection over time, and that minimize untreated waste.

This TM presents the results of the initial evaluation of remedial technologies that can be consolidated to form remedial alternatives for the IWCS. The list of alternatives developed from this process will undergo further detailed analysis in the FS report.

ES.2 IWCS Operable Unit Description

The IWCS is approximately 300 m (990 feet) long by 140 m (450 feet) wide (10 acres). It was designed as a waste containment system with an engineered cap, dike, sidewall, and natural clay bottom to inhibit radon emissions, infiltration from precipitation, and migration of contamination to groundwater. The specified design life of the IWCS cap is 25 to 50 years; whereas the specified design life of the bottom, dike, and cut-off walls is 200 to 1,000 years (DOE 1986b).

The main hazards in the IWCS are the residues, which were generated from the processing of uranium ore elsewhere and are otherwise known as uranium ore mill tailings. These residues, identified as K-65, R-10, L-30, L-50, and F-32, contain varying concentrations of radium-226 due to the original concentration of uranium contained in the ores from which they were processed. Among the residues, the K-65 residues contain the highest concentration of radium-226, approximately 520,000 picocuries per gram (pCi/g). As radium-226 undergoes radioactive decay, it releases gamma radiation and radon-222 gas. Table ES-1 provides the calculated average source term and associated waste volumes for the residues, soil, and wastes associated with the IWCS.

The IWCS OU is defined as waste material (i.e., radioactive residues and other waste) that the DOE placed in the disposal cell within the diked area. The scope for the IWCS FS involves development of remedial alternatives for addressing the residues and other waste material only. A remedial alternative for the waste material is complete removal. If that alternative is selected, then the remaining IWCS structure (e.g., remaining cap material, the dike, cut-off walls, residual soil that had waste placed on it, etc.) would be addressed within the scope of the Balance of Plant OU (USACE 2009).

Table ES-1 Average In-Situ Radium-226 Concentrations in Materials Stored in the IWCS at the NFSS and Associated Waste Volumes

IWCS Material	Radium-226 (pCi/g)[a]	Total Waste Volume[b]	
		(m^3)	(yd^3)
K-65 Residues	520,000	3,080	4,030
Other IWCS Residues			
L-30 Residues	12,000	6,090	7,960
L-50 Residues	3,300	1,640	2,150
F-32 Residues	300	340	440
Tower Soils	10,400	3,150	4,115
Contaminated Rubble/Waste	6,181[c]	35,650	46,610
R-10 Residues and Soil	95	45,500	59,500
Contaminated Soil	16	189,680	248,100
Total Waste Volume		**285,130**	**372,905**

[a] Radium-226 concentrations as reported in Table B-2, Appendix B.

[b] Waste volumes as reported in Table B-1, Appendix B.

[c] Radium-226 concentrations for contaminated rubble/waste were estimated from the weighted average of the volume and source-term concentrations presented in Appendix B for each of the wastes in Building 411 (L-30, F-32, Tower Soils, and contaminated soil excluding the K-65 residues) as a conservative estimate (USACE 2011c).

IWCS = Interim Waste Containment Structure.
m^3 = Cubic meters.
NFSS = Niagara Falls Storage Site.
pCi/g = Picocuries per gram.
yd^3 = Cubic yards.

As indicated in Table ES-1, the majority of materials in the IWCS are contaminated soils, which were removed from onsite and offsite areas impacted by historical releases from the residues during the operational period of the NFSS, including in drainage areas (ditches) at the site. Therefore, contaminants found in these materials are expected to be similar to (but with much lower contaminant concentrations than) those in the residues.

ES.3 Identification of Remedial Action Objectives

The first step of the FS is to identify remedial action objectives (RAOs) that are used to guide the selection of a remedy. RAOs specify constituents and media of concern, potential exposure pathways, and remediation goals.

Although the wastes within the IWCS are currently safely contained, potential exposure to contaminants in the IWCS was evaluated to support the development and screening of remedial alternatives in the FS. Pathways evaluated include (1) airborne releases due to a hypothetical cap breach and (2) migration to groundwater due to infiltration of precipitation through the cap and the leaching of contaminants beyond the IWCS containment structure.

The results of these evaluations, presented in the *Groundwater Flow and Contaminant Transport Modeling* (USACE 2007b, 2011b) and the *Preliminary Evaluation of Health Effects for Hypothetical Exposures to Contaminants from the Interim Waste Containment Structure Technical Memorandum* (Health Effects TM) (USACE 2012b), confirmed that the principal contaminants of concern (COCs) for the IWCS are radium-226 and its short-lived decay products due to its high concentrations in the residues and its potential to emit substantial gamma radiation and to release radon-222 gas. Among the wastes stored in the IWCS, the K-65 residues contain the highest concentration of radium-226.

The preliminary RAOs for the IWCS OU are as follows:

- Prevent unacceptable exposure of receptors to the hazardous substances associated with uranium ore mill tailings (e.g., radium-226 and its short lived decay products) inside the IWCS.
- Minimize/prevent the transport of hazardous substances within the IWCS to other environmental media (e.g., soil, groundwater, surface water, sediment, and air) outside of the IWCS.
- During implementation of the remedial alternatives(s), minimize/prevent releases and other impacts that could adversely affect human health and the environment, including ecological receptors.

In accordance with 40 CFR Part 300.430(e)(9)(iii), alternatives shall be assessed to determine whether they attain applicable or relevant and appropriate requirements (ARARs). ARARs are substantive standards, requirements, criteria, and limitations promulgated under Federal or more stringent state environmental siting laws that address hazardous substances, pollutants or contaminants, remedial action, location, or other circumstance at a CERCLA site. The applicable or relevant and appropriate requirements for the IWCS OU will be identified in the fifth and final technical memorandum entitled *Applicable or Relevant and Appropriate Requirements for the Interim Waste Containment Structure Operable Unit*.

ES.4 Development of General Response Actions and Initial Screening of Technologies and Process Options

General Response Actions (GRAs) are defined as broad response actions that satisfy the RAOs for the IWCS residues and wastes. GRAs include several remedial categories, such as containment, removal, disposal, and treatment. Individually, GRAs may meet the RAOs; however, they also can be grouped together to form alternatives that have the potential to meet RAOs. GRAs that satisfy the RAOs for the IWCS OU are retained and appropriate remedial technology types and process options that are capable of addressing the contaminated media are organized under each GRA.

The first step in screening a remedial technology or process option is to determine if it is implementable. A technology or process option was eliminated from further consideration if available information indicated that the technology or process option is incompatible with site conditions, waste characteristics, and/or COCs; cannot be implemented effectively due to physical limitations or constraints at the site; or has not been implemented on a large scale. Based on this evaluation, the following technologies were retained for further consideration:

- Land-Use Controls
  - Institutional controls,
  - Engineering controls,
  - Environmental monitoring, and
  - Surveillance and maintenance
- Containment
  - Engineered caps
    - Multi-layer engineered cap
- Removal
  - Mechanical Removal
    - Conventional earthmoving equipment,
    - Overhead removal,
    - Dragline systems,
    - Remotely operated equipment, and
    - Auger mining
  - Hydraulic and Pneumatic Removal
    - Hydraulic mining
- Demolition
  - Concrete cutting and
  - Mechanical demolition
- Treatment
  - Physical Processes
    - Ex-situ conventional solidification/stabilization (S/S) (including ex-situ encapsulation),
    - Ex-situ vitrification,
    - Decontamination (surface decontamination),
    - Decontamination (surface removal), and
    - Surface barriers (sealants)
  - Chemical Processes
    - Chemical extraction/metals recovery
- Disposal
  - On-site engineered disposal facility
    - Engineered disposal cell
  - Off-site disposal facility
    - Licensed disposal facility

ES.5 IWCS Subunits and Evaluation of Remedial Technologies

The IWCS OU was divided into "subunits" for the purpose of identifying remedial alternatives that would comprehensively address the entire IWCS. A key driver was the acknowledgment that the residues (K-65, L-30, L-50, and F-32) could require a different remedy or different implementation of the same remedy than the rest of the IWCS.

The material within the IWCS was divided into three subunits called Subunit A, Subunit B, and Subunit C that were based primarily on waste characteristic and storage location within the IWCS. A brief description of each of the three subunits is presented as follows:

- Subunit A: Radioactive residues K-65, L-30, L-50, and F-32 and any other materials placed in Buildings 411, 413, and 414
- Subunit B: Debris and wastes in the south end of the IWCS, including the building structures and contaminated rubble/debris/soil
- Subunit C: R-10 residues and wastes in the north end of the IWCS

The subunit designation is intended to support the evaluation of technologies and the development of subunit actions in this TM, but further studies and analysis in the IWCS OU FS may require modification of the subunit designations.

Each of the technically implementable remedial technologies and process options retained from the initial screening was qualitatively evaluated based on effectiveness, implementability, and cost. This evaluation resulted in a ranking of high, moderate, or low for each criterion. Those technology and process options that have demonstrated effectiveness in treating wastes and contaminants similar to the IWCS are rated high or moderate for effectiveness, while those options that do not provide adequate protection of human health and the environment are rated as low for effectiveness. Implementability assesses factors such as the ability to construct and operate the technology; the availability and capacity of treatment, storage, and disposal services; and the ease of undertaking additional steps that may be required to implement a technology such as pre-treatment or management of residual wastes. Process options that are infeasible are rated as low for implementability. Costs for each technology are rated qualitatively on the basis of engineering judgment and relative to the other process options in the same technology type.

In general, remedial technologies or process options that are proposed to be eliminated from further consideration in the FS are those that have low ratings for effectiveness and implementability. However, in a few cases, technologies that have a rating of moderate effectiveness are also recommended for elimination because historical implementability issues appear too great to overcome for some technologies such as vitrification, which is further discussed in this TM. Table ES-2 summarizes the evaluation of technologies.

Table ES-2. Summary of Technology/Process Option Ratings

Technology/Process Option	**Rating** [a]			**Retained?**
	Effectiveness	**Implementability**	**Cost**	
Land-Use Controls[b]	Moderate	High	Moderate	Yes
Enhanced Containment	Moderate	High	Moderate	Yes
Mechanical Removal	Low to High	Moderate	Moderate to High	Yes
Hydraulic Removal	Moderate	Low	High	Yes (Subunit A)
Demolition	Moderate to High	Moderate to High	Low to Moderate	Yes (Subunit B)
Ex-Situ Conventional Solidification/Stabilization[c]	Moderate	High	Moderate	Yes (Subunit A)
Ex-Situ Vitrification	Moderate	Low	High	No
Decontamination	High	Moderate to High	Low	Yes (Subunit B)
Surface Barriers	Moderate	High	Low	Yes (Subunit B)
Chemical Extraction/Metals Recovery	Moderate	Low	High	No
On-Site Engineered Disposal Facility	Moderate	Low	Moderate	No
Off-Site Licensed Disposal Facility	High	High	High	Yes

[a] Ratings apply to all subunits (A, B, and C) unless specifically identified.
[b] When used in combination with other general response actions.
[c] Includes potential use of Ex-situ Encapsulation

ES.6 Development of Remedial Action Alternatives

The retained remedial technologies and process options were combined to develop potential actions for each subunit. In accordance with the National Oil and Hazardous Substances Pollution Contingency Plan [40 *Code of Federal Regulations* 300.430(3)(6)], the no action alternative must be evaluated as part of the FS process as a baseline for comparison to the other actions under consideration.

Subunit A: Residues and Commingled Wastes Within Buildings 411, 413, and 414

A1: No Action
A2: Enhanced Containment with Land-Use Controls
A3: Removal, Treatment, and Off-Site Disposal

Subunit B: Debris and Wastes in the South End of the IWCS

B1: No Action
B2: Enhanced Containment with Land-Use Controls
B3: Removal and Off-Site Disposal

Subunit C: R-10 Residues and Wastes in the North End of the IWCS

C1: No Action
C2: Enhanced Containment with Land-Use Controls
C3: Removal and Off-Site Disposal

The final effort in this TM is to identify likely combinations of subunit actions to develop the alternatives for detailed analysis in the FS. These combinations, presented in Table ES-3, reflect the fact that the lower-activity wastes would not be recommended to be remedied to a higher level of protection than the residues. The FS will evaluate the five alternatives listed in Table ES-3 to ensure that the overall remedy meets the RAOs for the IWCS.

Table ES-3. Combined Alternatives for the IWCS OU

Alternative Type	Alternative ID	Alternative[a]
No Action	1	No Action
Enhanced Containment	2	Enhanced Containment
Partial Removal with Off-Site Disposal	3A	Removal, Treatment, and Off-Site Disposal of Subunit A Enhanced Containment of Subunits B and C
	3B	Removal, Treatment, and Off-Site Disposal of Subunits A and B Enhanced Containment of Subunit C
Complete Removal	4	Removal, Treatment, and Off-Site Disposal of Subunits A, B, and C

[a] All removal alternatives (3A, 3B, and 4) assume treatment of Subunit A waste. Land-use controls are assumed for any alternative where IWCS waste would remain on-site.

ID = Identifier.
IWCS = Interim Waste Containment Structure.
OU = Operable unit.

ES.7 Recommendations

This TM also identifies additional information that may be necessary to complete the detailed analysis of alternatives in the FS.

- A review of historic records and documents during the FS to create an inventory and cross-section, to the extent possible, of all recorded contents and IWCS structures that will be potentially removed for disposal or otherwise handled; this inventory would be used to better define the conceptual design and cost considerations associated with the removal alternatives developed in the FS for the various subunits.

- Solidification/Stabilization is a proven technology for the K-65 residues; however, if removal and treatment are selected for the residues, treatability studies will be necessary in the design/implementation phase of the project.
- Additional contaminant fate and transport studies may be necessary if a reconfiguration of some waste within the IWCS is left in place under enhanced containment (i.e., removal of a Subunit A or B). These studies would provide information regarding design requirements for permanent containment within the IWCS.
- Additional information on potential modes of transportation (e.g., rail, truck, and bimodal) will be obtained for the analysis of off-site disposal alternatives.

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1.0 INTRODUCTION

The Niagara Falls Storage Site (NFSS) is a 77.3-hectare (ha) (191-acre) property that is owned by the United States Government in the form of the U.S. Department of Energy (DOE) and is located at 1397 Pletcher Road in the township of Lewiston, Niagara County, New York (Figure 1-1). The NFSS is part of the former Lake Ontario Ordnance Works (LOOW) that was used by the War Department beginning in 1942 for the production of trinitrotoluene (TNT). During the 1940s and 1950s, the Manhattan Engineer District (MED) and the Atomic Energy Commission (AEC) brought various radioactive wastes and uranium processing byproducts (residues) resulting from our nation's atomic energy program to the LOOW for storage. In 1982, the DOE began cleanup and consolidation of the radioactive residues, wastes, and debris into a 4.0-ha (10-acre) Interim Waste Containment Structure (IWCS) that was constructed on the NFSS property and completed in 1986 (Figure 1-2). The IWCS contains radioactive residues, contaminated rubble and debris from demolition of buildings, and contaminated soil from the site and adjacent properties.

The U. S. Army Corps of Engineers (USACE)-Buffalo District is the lead Federal agency for Formerly Utilized Sites Remedial Action Program (FUSRAP) remediation of the NFSS. As the lead agency, USACE is conducting a remedial investigation/feasibility study (RI/FS) pursuant to the protocols set forth in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). CERCLA activities at the NFSS have transitioned from the site RI activities to the FS evaluation of potential remediation alternatives. USACE recognizes the need to implement a focused CERCLA FS process and, therefore, has established three separate operable units (OUs): the IWCS OU, the Balance of Plant (BOP) OU, and the Groundwater OU. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (Title 40 *Code of Federal Regulations [CFR]* Section 300.430[a][ii][A]) states that sites should generally be remediated in OUs when phased analysis is necessary given the size or complexity of a site. The OU approach to the FS process allows USACE to address the IWCS first given that selection of a remedy in which some or all of the waste materials remain in the IWCS would influence land uses for the BOP area (i.e., area outside of the IWCS but within the NFSS boundary) and the resultant exposure scenarios used to develop cleanup criteria. The BOP OU FS would then be prepared, followed by the Groundwater OU FS.

1.1 Purpose

The primary purpose of this TM is to aid in the development of a final remedy for the IWCS OU. The National Oil and Hazardous Substances Pollution Contingency Plan (Title 40 *Code of Federal Regulations* §300.430[a][1][i]) states that the goal of the remedy selection process is to select remedies that are protective of human health and the environment, that maintain protection over time, and that minimize untreated waste.

This TM also allows USACE to:

- Engage and inform the public on key technical issues in the early stages of the IWCS OU FS process so that public concerns will be considered during the development of the FS document.
- Enable the final IWCS OU FS to contain information and conclusions that have previously received input from the public, thus promoting a more efficient public review process for the IWCS OU FS document.

USACE requested and received public comments (see Appendix A) on the scope and objectives of this TM through the release of the *Development of Interim Waste Containment Structure Remedial Alternatives Technologies and Screening Technical Memorandum Fact Sheet* (USACE 2010, also see Appendix A). The public comments were evaluated during development of this TM and will be further addressed during the development of the IWCS OU FS document.

1.2 Brief Site Description and History

During World War II, USACE built several facilities across the United States to manufacture munitions for the U.S. Army. To this end, USACE acquired 3,035 ha (7,500 acres) of agricultural land in northwestern New York State, which became the LOOW site, where a plant was constructed to produce TNT. Beginning in 1942, six TNT production lines, several storage facilities for raw materials and finished products, and several miscellaneous shops and support facilities were built on the 1,012-ha (2,500-acre) operations area located in the east-central portion of the LOOW. The LOOW produced TNT for approximately 8 months before the government determined that there was excess TNT production capacity in the United States. TNT production ceased at the LOOW at the end of July 1943 (USACE 2007a).

The 77.3-ha (191-acre) NFSS was created in 1944 when MED was granted permission to use a portion of the LOOW property for the storage of radioactive residues (i.e., K-65, L-30, L-50, and F-32) that resulted from the processing of uranium ores during the development of the atomic bomb. On January 1, 1947, AEC took over the functions of MED. MED/AEC continued to periodically ship radioactive residues and materials to the NFSS for storage until 1954.

In 1974, AEC initiated FUSRAP to identify, remediate, or otherwise control sites where residual radioactivity remained from operations conducted for AEC. In 1977, DOE assumed responsibility for the NFSS and, during the 1980s, initiated measures to consolidate and store all radioactive materials at the site and adjacent properties (National Research Council 1995). Several removal actions to address radiologically-impacted soil also were performed at the NFSS and several adjacent properties, referred to as vicinity properties. Other remedial actions were performed in the 1980s, culminating with the construction of the IWCS from 1982 to 1986 (USACE 2007a).

A majority of the residues (K-65, L-30, and F-32) were placed into the IWCS in the reinforced concrete reservoir of Building 411, which was designed to securely hold liquids as it was part of the original freshwater treatment plant for the LOOW (Figure 1-3). These residues were stored in four bays (designated as Bays A, B, C, and D) formed within the substructure of Building 411. Before placing the residues in Building 411, drains, pipes, and openings were sealed (DOE 1990). Other radioactive residues (the L-50 residues) were placed in the clarifier tanks identified as Buildings 413 and 414 (Figure 1-3). The remaining buildings within the IWCS were demolished. Contaminated soil and rubble from various buildings (including the K-65 storage silo known as Building 434), also were stored in the IWCS. In 1986, the entire containment area holding the residues and waste was covered with an interim facility cap.

Because the radionuclides in the IWCS residues and waste have relatively long half-lives and the potential hazard will not diminish appreciably for thousands of years, DOE determined that there will be a continuing need for management of these materials (DOE 1986a). In September 1986, DOE issued a Record of Decision (ROD) for remedial actions at the NFSS, which provided for the construction of a long-term cap over the IWCS. However, regulatory agencies expressed concerns over DOE’s plan for long-term management of the residues; therefore, construction of the final cap did not occur (USACE 2007a).

Additional actions took place in 1988 when isolated areas of residual radioactivity from across the NFSS were excavated and placed into temporary storage prior to being incorporated into the IWCS in 1991 (DOE 1994). With the exception of annual monitoring and maintenance, no other activities took place after 1991 at the NFSS until 1997 when Congress transferred management of FUSRAP from DOE to USACE.

Environmental investigation and operations and maintenance activities at the NFSS are managed by USACE-Buffalo District under FUSRAP. The Energy and Water Development Appropriations Act for Fiscal Year 2000, Public Law 106-60, requires that USACE comply with CERCLA, 42 U. S. Code 9601 et seq., as amended, in conducting FUSRAP cleanup work. The CERCLA RI/FS process is being used to reach a decision for the completion of remedial activities at the NFSS. The NFSS RI site characterization has been completed, and an RI Report (USACE 2007a) and RI Report Addendum (USACE 2011a) have been issued. The subsequent FS process for each of the three NFSS OUs (the IWCS OU, BOP OU, and Groundwater OU) will consider regulatory changes, stakeholder comments, and additional data that have been generated since remedial alternatives were initially proposed for the site in an Environmental Impact Statement issued by DOE in 1986 (USACE 2007a).

1.3 Scope and Objectives of the Technical Memorandum

The primary objective of this TM is to provide information necessary to support the remedy selection process that will be conducted in the FS for the IWCS OU. Remedial action alternatives are identified through the CERCLA remedy selection process based on their ability to reduce potential risks to human health and the environment. According to the NCP (40 *CFR* §300.430[a][1][i]), the goal of the FS remedy selection process is to implement remedies that eliminate, reduce, or control risks to human health and the environment; that maintain protection over time; and that minimize untreated waste.

The IWCS OU is defined as waste material (i.e., residues and other remedial action waste) that DOE placed in the disposal cell within the dike area. If the selected remedial alternative for the IWCS involves removal of the waste material in the IWCS, then the remaining IWCS structure (e.g., remaining cap material, the dike, cut-off walls, residual soil that had waste placed on it, etc.) would be addressed within the scope of the BOP OU. For all alternatives, including alternatives that involve leaving any waste material in the IWCS, the FS would have to demonstrate that the alternative is protective of human health and the environment.

This TM initiates the steps associated with the screening of remedial technologies and the development of remedial action alternatives that will undergo further analysis and evaluation in the FS report. The specific steps of the FS remedy selection process addressed in this TM are illustrated in Figure 1-4 and are the objectives of this TM. They are as follows:

1. Identify the types of waste and provide an estimate of the volume of waste to support the evaluation of technologies.
2. Determine the General Response Actions (GRAs) that can be used to attain the remedial action objectives (RAOs).
3. Screen remedial technologies and process options to determine if they are technically implementable at the NFSS.
4. Evaluate the remedial technologies and process options in the three broad areas of effectiveness, implementability, and cost.
5. Develop remedial action alternatives by assembling combinations of the GRAs and technologies retained after evaluation.
6. Identify alternatives that will be carried forward for detailed analysis in the IWCS OU FS.

The detailed analysis in the FS will provide an evaluation of the alternatives proposed against seven of the nine CERCLA criteria. The nine criteria are divided into three categories: threshold, balancing, and modifying. The first two criteria (overall protection of human health and the environment and compliance with applicable or relevant and appropriate requirements) are classified as threshold criteria. An alternative must satisfy these two criteria in the detailed analysis to be a candidate for the preferred alternative. The five balancing criteria are used to weigh major trade-offs among alternatives. The five balancing criteria are long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost. The last two criteria, classified as the modifying criteria, are state and community acceptance and are used to address the acceptability of remedial alternatives to stakeholders. They are typically evaluated as part of the Proposed Plan; however, stakeholder input received on this and other NFSS TMs will be considered in the development and detailed evaluation of remedial alternatives in the FS Report.

Assessments conducted for the IWCS and documented in several other TMs previously developed and published by USACE provide necessary information to support this TM. The *Waste Disposal Options and Fernald Lessons Learned Technical Memorandum* (USACE 2011c) examined the remedial actions taken at the Fernald Site in Ohio, which included the remediation of K-65 residues. Additionally, the Waste Disposal Options and Fernald Lessons Learned TM evaluated the potential off-site disposal facilities and costs associated with off-site disposal. The *Radon Assessment Technical Memorandum for the Niagara Falls Storage Site* (USACE 2012a, hereafter referred to as the Radon TM) estimated potential radon emissions from the IWCS based on several hypothetical intrusion and excavation scenarios. The *Preliminary Health Effects of Hypothetical Exposures to Contaminants from the Interim Waste Containment Structure Technical Memorandum* (USACE 2012b, hereafter referred to as the Health Effects TM) identified receptors and potential pathways for exposure to waste materials within the IWCS based on current land-use scenarios.

1.4 Report Organization

This TM is organized as follows:

Section 1.0 – Introduction discusses the status of the CERCLA RI/FS activities for the NFSS, discusses the purpose of this TM, presents a brief account of site historical use and prior remedial activities, and describes FS remedy process steps that are the objectives of this TM.

Section 2.0 – IWCS OU Description provides a detailed overview of the construction of the IWCS and identifies the contents, volumes, and radiological characteristics of waste materials in the IWCS. This information is used to define the breakdown of the IWCS into three subunits A, B, and C and the volume of waste in each subunit that must be managed for remediation.

Section 3.0 – Development and Screening of Remedial Technologies identifies the contaminants of concern (COCs) and presents the preliminary RAOs developed for the IWCS OU. This section also describes the various GRAs and presents the potential technologies and process options for each GRA. In addition, the technologies and process options are screened for implementability.

Section 4.0 – Evaluation of Technologies and Selection of Representative Technologies uses the results from the screening of technologies in Section 3.0 to evaluate each technology based on its effectiveness, implementability, and qualitative cost. Technologies that are expected to be most effective and have the highest implementability for the IWCS residues and wastes will be retained irrespective of cost.

Section 5.0 – Development of Remedial Alternatives assembles the technologies resulting from the evaluation in Section 5.0 into subunit actions for the IWCS. A general description of each action, along with descriptions of the components that will be required to implement the action, is also provided. This section also presents the assembly of the subunit actions that result in the IWCS alternatives. Remedial alternatives that are proposed in this TM will be carried forward to the IWCS OU FS for the detailed analysis of alternatives.

Section 6.0 –Recommendations identifies potential treatability, modeling, and other additional studies recommended for the development of the IWCS FS.

Section 7.0 – References contains the references cited throughout this report.

Appendix A includes a copy of the Development of IWCS Remedial Alternatives Technologies Development and Screening TM Fact Sheet from December 2010 and the public comments submitted to USACE during the public review period.

Appendix B presents an estimated inventory and radiological concentrations of the waste materials contained within the IWCS that were used as a basis for the evaluation of remedial technologies and alternatives.

Appendix C details the assembly of IWCS alternatives based on the technologies retained for each IWCS subunit.

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2.0 INTERIM WASTE CONTAINMENT STRUCTURE (IWCS) OPERABLE UNIT

This section presents background information important to the evaluation of the remedial technologies and alternatives that will be evaluated in this TM. A description of the wastes contained in the IWCS is provided for the potential alternatives that would include removal, treatment, and/or disposal of wastes. A discussion of the construction and integrity of the IWCS is necessary to support discussions of alternatives that may include engineering enhancements to the existing IWCS.

The NFSS is located in the township of Lewiston, Niagara County, New York, which lies in western New York State on the south shore of Lake Ontario (Figure 1-1). Land use in the vicinity of the NFSS is shown on Figures 2-1 and 2-2. The NFSS property is bordered on the north and northeast by the CWM Chemical Services, LLC hazardous waste disposal facility; on the east and south by the Modern Landfill, Inc. solid waste disposal facility; and on the west by a transmission corridor owned by National Grid (USACE 2007a). All of the aforementioned properties were once part of the original LOOW, including an 8.9-ha (22-acre) portion (former waste water treatment plant) located north of the NFSS that was transferred to the town of Lewiston (USACE 2007a).

Details of the construction of the IWCS, the characteristics and placement of the wastes within the IWCS, and studies conducted to evaluate the integrity of the IWCS are presented below and provide information necessary for the evaluation of remedial technologies.

2.1 IWCS Structure Design

The IWCS was designed as a waste containment system in accordance with the performance requirements of 40 CFR Part 192 and 10 CFR Part 40 Appendix A with an engineered cap, dike, sidewall, and natural clay bottom to inhibit radon emissions, infiltration from precipitation, and migration of contamination to groundwater. The IWCS containment system was designed with site-specific engineering parameters for addressing local weather patterns and geophysical concerns identified during design, as shown in Table 2-1. Table 2-1 also presents engineering parameters and requirements for a long-term cap design based upon site-specific information available at that time (DOE 1986b).

The IWCS measures approximately 300 m (990 ft) long by 140 m (450 ft) wide and covers approximately 4.0 ha (10 acres) at the NFSS (Figure 1-3). Once the various residues and wastes were placed in the former buildings and on the ground surface, the IWCS cap was constructed by first spreading stockpiled, contaminated soil and sediment over the residues and waste (Figure 2-4). A 0.9-m (3-ft) layer of compacted, low-permeability (maximum 1×10^{-7} centimeters per second [cm/s]) clay was then overlaid on the contaminated soil layer, forming the principal barrier to moisture and radon emanation, followed by applying 30.5 cm (12 in.) of loosely compacted soil to act as a protective cover to the clay layer. Fifteen centimeters (6 in.) of topsoil were then placed on the cap prior to adding a final cover of seeded, shallow-rooted turf to control erosion and minimize frost heave damage. The sides of the cap were constructed to a maximum slope of 3:1 horizontal to vertical ratio (33 percent [%] slope), and the top of the cap was constructed with a 5 to 10% slope to promote run-off while limiting moisture retention and erosion. The cap slopes at approximately 8% from the center to the vicinity of the clay dikes. At this point, the side slopes increase to 3:1 (33%). In all, this facility reaches a maximum height of 10 m (34 ft) above ground surface (DOE 1991, 1985b, 1986b).

The sidewalls of the containment system consist of a compacted clay dike and cut-off wall constructed around the waste containment area (Figure 2-3). The dike has a minimum width of 2.4 meters (8 feet) and extends approximately 1.5 meters (5 feet) above the original grade. It rests on the cut-off wall, which has a minimum width of 3.6 meters (12 feet) and extends at least 0.5 meters (1.6 feet) into the gray glaciolacustrine clay or Gray Clay Unit. A dike/cut-off wall also was installed in the center of the IWCS, immediately west and east of Building 411. The height of the cut-off wall beneath the dike ranges

Table 2-1. Summary of the IWCS Design Requirements (DOE 1986b)

Item No.	Description	Existing Interim Cap	Long-Term Cap	Dike and Cut-Off Walls	Bottom	Remarks
1	Design Services Life	25 to 50 years	200 to 1,000 years	200 to 1,000 years	200 to 1,000 years	
2	Safety Factor: Cut-Off Walls Slope Stability					
	Static Conditions	1.5	1.5	--	--	
	Earthquake	1.0	1.0	--	--	
3	Surface Drainage Slope					
	Top Surface	5 to 10%	5 to 10%	--	--	
	Side Slopes	Max. 3 ft H to 1 ft V	Max. 5 ft H to 1 ft V	--	--	
4	Surface Erosion Protection	Shallow-rooted grass	Shallow-rooted grass Rip-rap (compacted rock) to elevation 98.4 m (323 ft)	--	--	
5	Intrusion Barrier Required	No	Yes	--	--	
6	Frost Penetration	122 cm (48 in.)	122 cm (48 in.)	--	--	Assume bare ground
7	Radon Barrier Required	Yes (20 pCi/m^2/s [1.9 pCi/ft^2/s])	Yes (20 pCi/m^2/s [1.9 pCi/ft^2/s])	--	--	
8	Radiation Barrier Required	Yes (100 mrem/year)	Yes (100 mrem/year)	--	--	
9	Component Construction	Topsoil/clay	Topsoil/rock layer/clay	Clay	Natural clay strata	
10	Clay Permeability	10^{-7} cm/s	10^{-7} cm/s	Approx. 10^{-7} cm/s	Approx. 10^{-7} cm/s	
11	Clay Adsorption Coefficient (measurement of how tightly a material binds to another)					
	Natural Uranium	5 mL/g	5 mL/g	5 mL/g	5 mL/g	
	Radium-226	500 mL/g	500 mL/g	500 mL/g	500 mL/g	
12	Inspection and Maintenance Required	Yes (design life)	Yes	No	No	
13	Earthquake Pseudostatic Coefficient (force caused by a potential earthquake)	0.1 g	0.15 g	0.15 g	--	
14	DOE Concentration Guide for Radionuclide Migration (groundwater concentration, uncontrolled areas)					
	Natural Uranium	--	--	600 pCi/L	600 pCi/L	
	Radium-226, -228	--	--	30 pCi/L	30 pCi/L	
15	Temperature Extremes	-29 to 34°C (-20 to 94°F)	-29 to 34°C (-20 to 94°F)	-29 to 34°C (-20 to 94°F)	--	

Table 2-1. Summary of the IWCS Design Requirements (DOE 1986b) (continued)

Item No.	Description	Existing Interim Cap	Long-Term Cap	Dike and Cut-Off Walls	Bottom	Remarks
16	Rainfall per Year	74 cm (29 in.)	74 cm (29 in.)	--	--	
17	Wind Speed and Direction	(80 mph) southwest	(80 mph) southwest	--	--	
18	Annual Deep-Infiltration Rate (the speed at which water enters into the soil)	2.54 cm (1.0 in.)	2.54 cm (1.0 in.)	--	--	
19	Design Floodplain Elevation	Elevation 96.6 m (317 ft) above mean sea level 100-year flood	Probable maximum flood 98.4 m (323 ft)	Probable maximum flood 98.4 m (323 ft)	--	
20	Groundwater Elevation (high)	--	--	--	Elevation 96 m (315 ft) above mean sea level (exclusive of probable maximum flood)	
21	Snowfall per Year	2.4 m (93 in.)	2.4 m (93 in.)	--	--	
22	Internal Cap Drainage Layer	None	Yes	--	--	
23	Waste Containment Consolidation	Minimize settlement (95% compaction)	Minimize settlement (95% compaction)	95% compaction	--	
24	Shrinkage, Swelling, and Frost Action Requirements	Yes (3 to 5% in volume expansion)	Yes (3 to 5% in volume expansion)	Yes (3 to 5% in volume expansion)	No	
25	Migration Limits	Not to exceed EPA primary drinking water standards in off-site groundwater	Not to exceed EPA primary drinking water standards in off-site groundwater	Not to exceed EPA primary drinking water standards in off-site groundwater	Not to exceed EPA primary drinking water standards in off-site groundwater	
26	Buffer Zone (minimum distance measured from lateral limit of waste)	30.5 m (100 ft)	30.5 m (100 ft)	--	--	
27	Groundwater Hydraulic Gradient (saturated zone) (change in hydraulic head divided by the change in distance)	--	--	--	0.0015	

Source: *Addendum to the Design Report for the Interim Waste Containment Facility at the Niagara Falls Storage Site*, Lewiston, New York, Table 3-1 (DOE 1986e).

°C = Degrees Celsius.
cm = Centimeter.
cm/s = Centimeter per second.
DOE = U. S. Department of Energy.
EPA = U. S. Environmental Protection Agency.
°F = Degrees Fahrenheit.
ft = Foot.
g = Acceleration of gravity.
H = Horizontal.
in. = Inch.
IWCS = Interim Waste Containment Structure.
m = Meter.
mL/g = Milliliters per gram.
mph = Miles per hour.
mrem/year = Millirems per year.
% = Percent.
pCi/L = Picocuries per liter.
pCi/m^2/s = Picocuries per square meter per second.
V = Vertical.

between 3 and 7 meters (10 and 22 feet) varying with changes in the elevation of the top of the Gray Clay Unit (DOE 1986b). In general, the cut-off wall is not centered beneath the dike; its location varies according to subsurface conditions.

Below ground surface, the IWCS containment system consists of 1.8 to 7 m (6 to 23 ft) of naturally occurring brown clay underlain by 3.3 to 8.8 m (11 to 29 ft) of gray glaciolacustrine clay (Figure 2-4) (DOE 1986b, 1994). The Gray Clay Unit and the dike/cut-off wall function as adsorption barriers to vertical and horizontal migration of constituents from the IWCS (DOE 1986b, 1994). A full description of the IWCS containment system is detailed in the *Design Report for the Interim Waste Containment Facility at the Niagara Falls Storage Site, Lewiston, New York* (DOE 1986b), the *Addendum to the Design Report for the Interim Waste Containment Facility at the Niagara Falls Storage Site, Lewiston, New York* (DOE 1986e) and the *Failure Analysis Report for Niagara Falls Storage Site, Lewiston, New York* (DOE 1994).

The suitability of the structure for longer-term use was evaluated in the *Failure Analysis Report* (DOE 1994). The period of interest for this suitability evaluation was 10,000 years. A few recommendations on longer-term design modifications or upgrades to the IWCS are presented in the 1994 analysis. These recommendations primarily focus on modifying the interim cap to include a rock-fill penetration barrier (rip-rap layer) between the clay cover and vegetation layers and reducing the maximum side slopes from 3 horizontal/1 vertical (33%) to 5 horizontal/1 vertical (20%). These two cap modifications, coupled with the existing integrity of the natural clay bottom and the constructed dike and cut-off walls, are considerations toward the development and assessment of any leave-in-place alternatives for residues and other waste materials currently within the IWCS as they would reduce the maintenance requirements and failure modes associated with erosion and penetration of the cap. The 1994 study also noted that the concrete foundations and walls of Building 411 and other structures within the IWCS would not be expected to last 10,000 years, but that the remaining concrete rubble may provide an alkaline buffer against the solubility of the stored residues, which are more soluble under acidic conditions.

2.2 Contaminant Sources in the IWCS

A variety of radioactive wastes and contaminated materials are contained within the IWCS and are identified as source media evaluated for the IWCS OU. For the purposes of this study, waste streams associated with the IWCS have been organized into the following major categories:

- K-65 residues,
- Other IWCS residues/wastes,
- Tower Soils,
- Contaminated rubble/waste,
- R-10 residues and soil, and
- Contaminated soil.

Descriptions of the origin and physical characteristics of each waste are provided in the following subsections.

Section 312 of the Energy and Water Development Appropriations Act for the Fiscal Year Ending September 30, 2004 (Public Law 108-137) states:

> *"SEC.312. Notwithstanding any other provision of law, the material in the concrete silos at the Fernald uranium processing facility currently managed by the United States Department of Energy and the ore processing residual materials in the Niagara Falls Storage Site subsurface waste containment structure managed by the United States Army Corps of Engineers under the Formerly Utilized Sites Remedial Action Program will be considered "byproduct material" as defined by section 11e.(2) of the Atomic Energy Act of 1954, as amended [42 U.S.C. 2014(e)(2)].*

> *The Nuclear Regulatory Commission or an Agreement State, as appropriate, will regulate the material as "11e.(2) byproduct material" for the purpose of disposition of the material in an NRC-regulated or Agreement State-regulated facility."*

The K-65, L-30, L-50, F-32, and R-10 residues are designated as 11e.(2) byproduct materials. Assumptions regarding the waste classifications of the remaining wastes in the IWCS as 11e.(2) or low-level radioactive waste (LLRW) were made in the Waste Disposal Options/Fernald Lessons Learned TM (USACE 2011c) and are discussed below. These waste classifications will be further evaluated in the FS as part of the detailed analysis of alternatives. Table 2-2 provides the calculated average source term and associated waste volumes for the residues, soil, and wastes associated with the IWCS. Table 2-2 is based on information provided in Appendix B.

2.2.1 K-65 Residues

The K-65 residues contain very high concentrations of radium-226. The K-65 residues resulted from the development of uranium-processing techniques and the production of uranium metal as part of the MED/AEC work conducted by Mallinckrodt Chemical Works located in St. Louis, Missouri. The main uranium ore processed by Mallinckrodt originated from the Belgian Congo (Africa) region, which contained uranium oxide concentrations up to 65%. The digestion of these high-grade uranium ores (the term "high-grade" indicates that the ore yields a relatively large amount of the metal for which it is mined) provided the feed material (uranium) required for the Manhattan Project.

Table 2-2. Average In-Situ Radium-226 Concentrations in Materials Stored in the IWCS at the NFSS and Associated Waste Volumes

IWCS Material	Radium-226 (pCi/g)[a]	Total Waste Volume[b]	
		(m^3)	(yd^3)
K-65 Residues	520,000	3,080	4,030
Other IWCS Residues			
L-30 Residues	12,000	6,090	7,960
L-50 Residues	3,300	1,640	2,150
F-32 Residues	300	340	440
Tower Soils	10,400	3,150	4,115
Contaminated Rubble/Waste	6,181[c]	35,650	46,610
R-10 Residues and Soil	95	45,500	59,500
Contaminated Soil	16	189,680	248,100
Total Waste Volume		**285,130**	**372,905**

[a] Radium-226 concentrations as reported in Table B-2, Appendix B.

[b] Waste volumes as reported in Table B-1, Appendix B.

[c] Radium-226 concentrations for contaminated rubble/waste were estimated from the weighted average of the volume and source-term concentrations presented in Appendix B for each of the wastes in Building 411 (L-30, F-32, Tower Soils, and contaminated soil excluding the K-65 residues) as a conservative estimate (USACE 2011c).

IWCS = Interim Waste Containment Structure.
m^3 = Cubic meters.
NFSS = Niagara Falls Storage Site.
pCi/g = Picocuries per gram.
yd^3 = Cubic yards.

The uranium extraction process resulted in K-65 residues, which still contained natural uranium decay products: actinium (actinium-227), bismuth (bismuth-210 and bismuth-214), protactinium (protactinium-231), lead (lead-210 and lead-214), polonium (polonium-210), radium (radium-226), thorium (thorium-228, thorium-230, and thorium-232), and uranium (uranium-234, uranium-235, uranium-236, and uranium-238). Several metal hydroxides (iron, aluminum, and manganese) and other impurities, such as precious metals, are also present in these residues. Some precious metals (e.g., gold, platinum, palladium, and silver) were extracted from some shipments of the ore prior to processing for uranium. The K-65 residues are a mixture of oxides (60%), carbonates, and sulfates (DOE 1981a) and have much less cobalt, nickel, and copper and more rare earth elements (e.g., palladium, molybdenum, and lead) than do the other residues stored at the NFSS.

In or around 1949, these K-65 residues were transported to the LOOW facility in drums (DOE 1986c). Some of these drums were stored outdoors along existing roads and rail lines; others were stored in Building 410 (Figure 1-3). From 1950 to 1952, the K-65 residues were transferred to an above-ground silo (Building 434) in the northeast portion of the site (DOE 1986b). Once the storage silo had reached capacity, the remaining drums of K-65 residues were transported to the Feed Materials Production Center in Fernald, Ohio (DOE 1993; National Research Council 1995).

Between 1983 and 1985, the K-65 residues were hydraulically slurried from the storage silo (Building 434) and placed in the substructure of former Building 411 (Figure 1-3). A majority of the radioactive residues are stored in four bays (designated as Bays A, B, C, and D) formed within the reservoir. The K-65 waste has been documented as being placed in Bays A and C (Figure 2-4) (DOE 1986c).

The estimated volume of the K-65 residues in the IWCS is 3,080 cubic meters (m^3) (4,030 cubic yards [yd^3]). The average radium-226 concentration is approximately 520,000 picocuries per gram (pCi/g) in its current state (Table 2-2 and Table B-2). The K-65 residues also represent approximately 95% of radium-226 activity and 77% of thorium-230 activity, with these two constituents being the primary contributors of the radioactivity present at the site (DOE 1996). This waste stream has been deemed to be 11e.(2) byproduct material.

2.2.2 Other IWCS Residues

Other residues stored in the IWCS were designated as L-30, L-50, and F-32 residues. These were residues resulting from the processing of ore, with uranium concentrations ranging from 0.4% up to 10%, at the Linde Ceramics Plant, Tonawanda, New York (L-30 and L-50 residues), and residues from the Middlesex Metal Refinement Plant (F-32 residues) in Middlesex, New Jersey.

The L-30 residues were transported to the NFSS in 1944 and were stored in the east and west bays of Building 411 (Figure 2-4) (DOE 1981a; EA 1999). Approximately 6,090 m^3 (7,960 yd^3) of L-30 residues are stored in the IWCS. Gamma-ray spectral analysis of the L-30 residues indicates that the uranium-238 concentrations in the L-30 residues vary greatly, ranging from 280 to 1,660 pCi/g (DOE 1986a, DOE 1981b). The average radium-226 concentration (dry weight) is about 12,000 pCi/g (DOE 1986a). In addition to these radiological constituents, the L-30 residues also contained 10,000 milligrams per kilogram (mg/kg) or more of lead, barium, iron, cobalt, and nickel (DOE 1981a).

The L-50 residues derived from uranium extraction from African pitchblende ores, containing approximately 7% uranium oxide, at the Linde Ceramics Plant in Tonawanda, New York (DOE 1981a). Approximately 1,640 m^3 (2,150 yd^3) of these residues were transported to the NFSS starting in 1944 and were stored in clarifier tanks at the water treatment plant (Buildings 413 and 414) (Figure 1-3) (EA 1999; DOE 1994). The average radium-226 concentration is about 3,300 pCi/g (DOE 1986a).

The F-32 residues resulted from the Linde Ceramics Plant’s extraction of Q-20 pitchblende ore from the Belgian Congo. Approximately 340 m^3 (440 yd^3) of material was stored in the recarbonation pit (Bay A) of Building 411 (Figure 2-4) (DOE 1981a). The average radium-226 concentration is about 300 pCi/g (DOE 1986a). These residues are 11e.(2) byproduct material.

2.2.3 Tower Soils

Tower Soils consist of soil that was originally located outside the K-65 residues storage silo (Building 434) at the NFSS. This soil was contaminated as a result of facility operations, transfer of the K-65 residues to Building 411, and decommissioning of the silo. The Tower Soils were placed in Bay D of Building 411 (Figure 2-4). The broad radium-226 characterization categorizes this material as 10,400 pCi/g (approximately 2% of the K-65s). Because the soil was contaminated with K-65 residues, it is 11e.(2) byproduct material.

2.2.4 Contaminated Rubble/Waste

The Contaminated Rubble/Waste category includes construction debris, concrete, rebar, piping, equipment, and machinery and has an estimated volume of 35,650 m^3 (46,610 yd^3) (Table 2-2). This waste category includes debris from the demolition of Buildings 410, 415, and 434 (see Section 2.2.3.7) as well as other structures previously located within the footprint of the IWCS. This category also includes the K-65 slurry transfer piping, the Thaw House Foundation, and the Hittman tanks (Table B-1, Appendix B). A portion of the total volume of contaminated rubble/waste is the “miscellaneous materials” added to Buildings 413 and 414 (see Section 2.3.6), which total approximately 11,470 m^3 (15,000 yd^3).

The majority of the contaminated rubble/waste has either previously been in direct contact with the residues or was placed within Buildings 411, 413, and 414. The remainder of the contaminated debris/waste is currently stored in the southern portion of the IWCS and outside of Buildings 411, 413, and 414 but may have come in contact with other wastes that were used to transfer or store the K-65 residues or the other residues (L-30, L-50, and F-32) during placement activities. Due to potential extended contact with residues or material used to transfer or store the residues, this waste stream will be considered 11e.(2) byproduct material.

Another waste type identified in this group is the Middlesex Sands. Inventory records show that approximately 180 m^3 (230 yd^3) of sand, resulting from sand-blasting activities at the Middlesex Sampling Plant located in New Jersey, were transported to the NFSS sometime prior to 1953 and were stored in a bin in Building 410. Precipitation entering through holes in the roof of the building eroded the bins, and the sand was spread through a significant portion of the lower floor of Building 410. The original concentration of uranium was reported to be 3%. Measurements made in 1979 showed that the sand contained less than 100 mg/kg of uranium and less than 0.01 micrograms per kilogram (μg/kg) of radium-226 (DOE 1981a).

In addition, approximately 230 m^3 (300 yd^3) of miscellaneous contaminated debris were placed in a 100-by 60-m (325- by 192-ft) waste containment cell that was excavated within the northern portion of the IWCS (see Section 2.3.8).

2.2.5 R-10 Residues and Soil

The R-10 Residues and Soil category includes R-10 residues from the processing of ore containing approximately 3.5% uranium oxide at the Linde Ceramics Plant in Tonawanda, New York (DOE 1981a). These residues and iron cake associated with the same extraction process were shipped to the NFSS sometime between 1944 and 1949 and were stored in a pile on open ground north of Building 411 (Figure 2-5). Additionally, soil from the 1972 remedial action (pre-IWCS construction) was placed on top of the original R-10 pile (DOE 1982a). Information from previous reports (DOE 1986a, 1986b) indicates that the R-10 soil pile consists of approximately 7,000 m^3 (9,500 yd^3) of original residues and approximately 11,500 m^3 (15,000 yd^3) of contaminated soil from remedial actions conducted in 1972. The resulting R-10 soil pile, while under historic open-ground storage at the NFSS, subsequently leached into the underlying soil, contaminating an approximately additional 26,500 m^3 (35,000 yd^3) of below-grade soil for a total volume of 45,500 m^3 (59,500 yd^3) (Appendix B, Table B-1).

The R-10 residue pile was stabilized as part of the initial construction of the IWCS. Stabilization included clearing and grubbing the surrounding area, moving contaminated soil near the R-10 pile onto the cleared area, and constructing a clay dike and cut-off wall around the R-10 pile. The clay cut-off wall was keyed into the underlying gray clay. The top of the pile was graded and covered with an ethylene propylene diene monomer liner, which was removed during construction of the IWCS (USACE 2007a).The reported concentrations of radionuclides in the R-10 pile are from the data results of sampling of the soil pile and subsurface. This soil and residue were estimated to contain 5 curies (Ci) of radium-226 and 5 Ci of thorium-230 (DOE 1996). The average radium-226 concentration is 95 pCi/g. The R-10 residues and soil are 11e.(2) byproduct material.

2.2.6 Contaminated Soil

The contaminated soil includes materials resulting from the cleanup of several on- and off-site remedial actions over the years between 1982 and 1991 (see Appendix B, Table B-1). This category also includes materials that may be contaminated by proximity to the IWCS residues and/or wastes, including the volume of material that comprises the sand/clay separating layers in Building 411 and portions of the containment system (dike material, cap material, and the soil beneath the IWCS) (Figure 2-5). The average radium-226 concentration is 16 pCi/g.

The volume estimates include soil located beneath the structures containing the uranium ore processing residuals (Buildings 411, 413, and 414) that may be considered 11e.(2) byproduct materials due to radiological contamination associated with the 11e.(2) residues. A majority of the volume of contaminated soil is located in the northern portion of the IWCS and is considered LLRW because of limited contact with uranium ore processing residuals (see Appendix B, Table B-1). Given the presence of potentially hazardous materials at the NFSS, it is assumed that some of this soil may be characterized as low-level mixed waste (LLMW). For volume estimation purposes or for evaluation of alternatives, it is assumed that 10% of the waste volumes of residuals not associated with uranium ore processing should be considered LLMW (USACE 2011c).

2.3 IWCS Waste Placement

Information regarding the placement of wastes within the IWCS is important in determining the effectiveness and implementability of any potential remedial technology. Some residues and wastes were placed into the IWCS within the former freshwater treatment buildings (Buildings 411, 413, and 414), which were constructed on original grade (i.e., the Brown Clay), or on the ground surface. Site-specific factors play a significant role in the ability to successfully utilize certain remedial strategies. Figures 2-3 through 2-5 show cross-sectional views of the IWCS, which indicate the general locations of the IWCS residues and wastes.

2.3.1 General Waste Placement Activities at Building 411

Building 411 is a reinforced concrete structure with a bottom thickness of 30 cm (12 in.) and sidewalls approximately 50 cm (20 in.) thick. The bottom elevation of Building 411 is 95 m (312 ft) above mean sea level (Figure 2-4). The overall building spans an area of approximately 60 by 53 m (200 by 180 ft) and is 5.8 m (19 ft) deep with a usable capacity of approximately 18,100 to 18,900 m^3 (23,700 to 24,700 yd^3) (DOE 1982b).

Building 411 is separated into two large vats by a poured concrete center dividing wall that served as a catwalk. These walls form the boundaries of what are referred to as the bays of Building 411, which include Bays B, C, and D (Figure 2-4). The western vat of Building 411 has been identified as Bay D. The eastern vat has a baffled wall made of concrete block that was open on the northern end leaving a space between the baffled wall and the outer wall of the building. The baffle wall divides the eastern vat into Bays B and C. During construction of the IWCS, this baffled wall was extended to reach the full length of the building (DOE 1981a). Bay A is a small concrete structure, historically referred to as the recarbonation pit that is attached via spillway to the southwest corner of Bay D (Figure 2-4). Bay A was divided into two compartments via a wall with openings at the bottom; a smaller western compartment and a larger eastern compartment. Concrete columns, with concrete purlins (struts) between them, provided structural support within each vat in a lattice-like pattern, as shown in Figure 2-6. IWCS construction documentation indicates that many of these concrete purlins were removed and dropped into Bay D as part of the remediation activities (DOE 1981-1986, 1986d).

Most of the residues were in a saturated and unconsolidated condition prior to placement in the IWCS (DOE 1985b). Stabilization of the residues involved dewatering and consolidation. The dewatering process was expected to reduce the residues to approximately two-thirds of their original volume. Even though the residues placed in the IWCS were dewatered, they are not expected to be dry. The residues stored within the IWCS are extremely fine-grained and become thixotropic (forming a gelatinous-like material that is flowable when agitated) when sufficiently wetted (USACE 2003).

Approximately 1,100 vertical drainage wicks were placed within Bays B and C to act as conduits for a dewatering system for the wastes (DOE 1985a). A 0.3-m (1-ft) layer of sand was then placed on top of the residue to accelerate the dewatering process. Contaminated clay soil was then placed on top of the sand in each bay, creating additional surcharge (Figure 2-4).

Building 411 was connected to Building 410 through a 0.9-m (36-in.) diameter pipe, which was eventually sealed with concrete from the bottom of the southwest end of Bay A. Underground piping in the general area of Buildings 409, 410, and 411 was either plugged with fillcrete or removed (DOE 1986b). Fillcrete is a low-strength, cementitious material consisting mainly of cement, sand, and water. Fillcrete can be used to backfill excavations in place of traditional compacted fill and, because it is flowable and self-compacting, can be used to fill various construction or excavation voids.

Residues and wastes were placed in the IWCS with the goal of preventing subsidence within the completed structure. In general, residues and wastes were placed in layers and compacted to 90% of maximum dry density. Rubble materials were deposited in layers and voids were grouted with fillcrete to create a consolidated, dense mass. Contaminated organic material was not placed within the IWCS but was buried in a separate on-site area where subsidence was not a consideration (DOE 1986b).

2.3.2 K-65 Residues in Building 411

Prior to construction of the IWCS, the K-65 residues were stored in Building 434, a renovated concrete water tower (silo) located in the northeast corner of the NFSS. The complex process of removing the moist, clay-like K-65 residue from Building 434, and the subsequent transport and placement of the residue into Building 411, was conducted in 1984 and 1985. Approximately 1.6 km (1 mile) of pipeline was created using a 10-cm (4-in.) steel pipe between Building 411 and a pond constructed on the south end of the Thaw House adjacent to Building 434. The pipeline supplied water from Building 411 to the pond that would be used for the hydraulic mining process (DOE 1981-1986) and to transfer the K-65 slurry to Building 411.

Two 10-cm (4-in.) pipelines went into Building 434. One pipe was used to supply high-pressure water from the pond to the mining unit that was used to dislodge the K-65 residue and mix it with the water to create a slurry. The second pipe was used to remove the K-65 residue slurry from the tower and transport it through the 1.6-km (1-mile) pipeline into Bay C of Building 411 (Figure 2-4) (DOE 1981-1986). After placement in Bay C, the K-65 residues were covered with strips of unspecified synthetic material specifically placed for demarcation and to separate it from other residues that would eventually be placed above it (DOE 1985a).

All but approximately 500 m^3 (675 yd^3) of K-65 residue and rubble were removed from Building 434 by the hydraulic mining process (DOE 1986c). The remaining residue and rubble from the inner and outer domes of Building 434 that could not be removed by hydraulic mining were removed mechanically the following year through an enlarged opening at the base of the tower and loaded into steel bins. The steel bins were then transported via truck to Building 411, and the K-65 residue material was emptied from the steel bins into Bay A (DOE 1985b, 1986c, 1986d).

2.3.3 F-32 and L-30 Residues in Building 411

Prior to construction of the IWCS, F-32 residues were stored in the recarbonation pit (Bay A) associated with Building 411 and L-30 residues were stored in areas of Building 411 now designated as Bays B and C. When construction of the IWCS commenced, the F-32 and L-30 residues were consolidated and transferred to Bay D using a crane with a 0.4-m^3 (0.5-yd^3) clamshell bucket. Bays B and C were then cleaned by lowering a Caterpillar/Case 450B front-end loader into each bay when no more than 0.3 m (1 ft) of material remained. The residue was moved and piled against the common wall between Bays B and C to where the clamshell bucket could remove the material (DOE 1985a). The remaining residues were dumped over the common wall by the front-end loader. Upon completion of cleaning activities, 20 cm (8 in.) of fill concrete was placed on the floor of Bay A to level the floor area, and the baffled dividing wall between Bays B and C was extended using plywood and steel so that each bay was completely divided (DOE 1985a). A sand filter drain system was then installed in Bays A, B, and C. It included a layer of fine sand followed by a layer of coarse sand with slotted polyvinyl chloride pipes placed horizontally along the bottom of each bay, covered by filter fabric and a gravel layer (DOE 1985a).

From 1984 through 1985, portions of the consolidated F-32 and L-30 residues in Bay D of Building 411 were transferred back into to Bays B and C in phases, starting with the northern end of the bays and working southward (DOE 1986c). As seen in Figure 2-4, the consolidated F-32 and L-30 residues lay above the K-65 residues in Bay C. A layer of about 1.5 m (5 ft) of consolidated F-32 and L-30 residues was left at the bottom of Bay D after the residue transfer (DOE 1986c).

2.3.4 Tower Soils and Other Wastes in Building 411

Waste placed within Building 411 includes the Tower Soils excavated from an area around Building 434 where the K-65 residues were previously stored as well as the Thaw House. Earth excavated to a depth of 0.3 m (1 ft) from a 370-square meter (m^2) (400-square feet [ft^2]) area around Building 434 and from the bottom of the Building 434 pond was placed in Bay D. A total of 77 m^3 (100 yd^3) of the contaminated soil from around the Thaw House also was placed in Bay D. Contaminated soil placed in Bay D also originated from “hot spots” excavated during on-site cleanup of the area near Building 434 (DOE 1986d).

Additionally, unspecified amounts of contaminated water, mud, and residue from Pond 434, which was used during the K-65 slurry transfer process, were placed in Bay D (DOE 1981-1986). Dewatering activities were later completed for Bay D. Within the northern end of Bay D in Building 411, a berm comprised of contaminated soil was constructed to contain K-65 residues and sediment from Pond 434. The residues and sediment were collected at the pond using a large vacuum truck (DOE 1986d) and placed within the berm (DOE 1981-1986). The pond liner also was placed in the northern end of Bay D (DOE 1986d). Residue sediment from Pond 434 was reported to be 0.22 m (9 in.) deep totaling 191 m^3 (250 yd^3) (DOE 1986d). The total volume of materials identified as Tower Soils placed in Bay D has been estimated as 3,150 m^3 (4,115 yd^3), assuming half of the interior of Bay D is filled with 4 m (13 ft) of Tower Soils (Table B-1, Appendix B).

An uncertain volume of contaminated rubble and debris was added to Building 411 during the construction of the IWCS. However, rubble and debris include underdrain and dewatering system material, various pumps, geosynthetic vertical drainage strips (Bays B and C), standpipes (Bay A), concrete beams, demarcation layers between residue types, geotextile layers, pieces of geomembrane liner, and contaminated tools (DOE 1984a, 1985a, 1986d, 1987, 2003).

2.3.5 Contaminated Soil in Building 411

Sand and clay layers contaminated due to their proximity to the residues are present in Building 411. As shown on Figure 2-4, a 0.3-m (1-ft) layer of sand was placed on top of the residues as part of the dewatering process for the residues, and then contaminated clay soil was placed on top of the sand in each bay. The volume of contaminated sand and clay separating layers in Building 411 is estimated to be 2,980 m^3 (3,900 yd^3) (see Table B-1, Appendix B).

In 1986, before the final stage of the cap completion over Building 411, cleanup was required for six water retention ponds. Contaminated material was removed from the ponds prior to their demolition and placed in the IWCS. Two disposal trenches were excavated in the contaminated clay soil above Bay D. The trenches were in the western sections of Bay D and extended down into the bay itself. The dry contaminated soil excavated from the trenches was taken to the temporary water retention ponds (North Pond and Pond 3) to be mixed with the wet residue sludge that had settled out during the dewatering process. Bentonite was added to the ponds to promote mixing. The wet mixture was spread out over the area to dry before being transported back to Building 411. At Building 411, the contaminated mixture, along with the contaminated pond liners, was placed in the trenches and compacted. The material that would not fit into the trenches was spread over Bays B, C, and D and compacted to establish the grade before the cap could be installed (DOE 1987, 1981-1986).

2.3.6 Buildings 413 and 414

Buildings 413 and 414 are cylindrical reinforced concrete tanks used to store the 1,640 m^3 (2,150 yd^3) of L-50 residues. These structures are located southeast of Building 411 (Figure 2-3) and were built in 1942. Each of these cylindrical structures has a diameter of 19 m (62 ft) and a usable volume capacity of 1,075 m^3 (1,407 yd^3). Each cylinder extends approximately 3 m (10 ft) above the original (pre-IWCS) ground level and 2.7 m (9 ft) below the original ground surface (bottom elevation 95 m [311 ft] above mean sea level) for a total cylinder depth of 5.8 m (19 ft) (DOE 1982b).

Actions at Buildings 413 and 414 were taken by DOE in 1982 to reduce emissions of radon gas from the L-50 residues stored in these buildings. Roof materials were removed, and the troughs that encircled the inside of the building near the top of the residues were filled with concrete. Several layers of miscellaneous materials (i.e., sand, synthetic rubber, clay, and pea gravel) were placed over the residues and resulted in the reduction of radon emanations from the buildings (DOE 1993, DOE 1986c).

2.3.7 Wastes Within the South End of the IWCS

As part of the construction of the IWCS, other buildings once used as part of the water treatment plant for the LOOW located within the IWCS footprint were demolished in place. Demolition activities for Building 415 and the upper portion of Building 410 were completed in 1984 to allow for the development of the southern portion of the IWCS (Figure 2-3). This included the demolition of Building 410 down to the ground surface and the demolition of Building 415 to the top of the first floor. Demolition started with the removal of the roof panels, which contained small amounts of asbestos. This material was loaded and transported to an on-site burial area. Most of the rubble from the demolition, which consisted of walls, floor slabs, the venturi vault roof, walkways, canals, and concrete compartments, was placed in 0.9-m (3-ft) lifts within the east section of Building 410 and the first floor section of Building 415 (DOE 1985a). The major cause of contamination in Building 410 was due to the storage of the Middlesex Sands on the second floor and the presence of leachate from the sand on the floor below. The Middlesex Sands were transferred into Building 410, and the building was further demolished with consolidation/transfer of rubble to this building with remaining voids fillcreted. The voids within each 0.9-m (3-ft) lift were filled by vibrating a 35-kilogram (kg)-force per square centimeter (cm^2) (500-pounds per square inch [psi]) concrete mix into the voids (DOE 1985a).

Decontamination and demolition of other buildings were conducted on-site throughout the DOE remedial action between 1982 and 1986, which resulted in the transfer of rubble, debris, and machinery to the IWCS. Rubble wastes were placed in thin layers, filling the voids with fillcrete, to create a consolidated, dense mass. Voids between machinery and piping also were grouted with fillcrete to prevent subsidence.

Upon completion of the K-65 transfer, the Building 434 storage silo and its foundation were demolished using a crane and wrecking ball. The rubble from the demolition activity, consisting of concrete and rebar (DOE 1986d), was placed at the south end of Building 411 in the south containment area (DOE 1985a). The 10-cm (4-in.) steel pipeline used for the K-65 slurry transfer was cut into 6-m (20-ft) sections and placed into a trench located outside of Building 411 on the northwest corner (DOE 1986d) where it was subsequently covered with fillcrete to minimize subsidence.

In 1985, the K-65 slurry manifold that was located on top of the Building 411 catwalk was cut into 3- to 6-m (10- to 20-ft) sections and placed in the weir section along the south end of Building 411 and finished with fillcrete (DOE 1986d). The foundation of the Thaw House adjacent to Building 434 was demolished, and the concrete rubble was placed in the south containment area adjacent to Building 411 (DOE 1986d). Additionally, several small structures located in the vicinity of Building 434 were found to be contaminated and were demolished; these structures include two concrete thrust blocks on 0.61-m (24-in.) pipes, one valve house, and one concrete slab. Rubble from these structures was placed in the IWCS south of Building 411 (DOE 1986c). Polyvinyl chloride piping used in the slurry transfer process was crushed and placed, along with the Building 434 rubble, in the south containment area to be finished with fillcrete. Additionally, the Caterpillar/Case 450B front-end loader that was used to clean out Bays B and C of Building 411 was buried and fillcreted in the area south of Building 411 (DOE 1981-1986). Additional sand was placed in the area south of Building 411 where placement of fillcrete was insufficient (DOE 1981-1986).

The estimated volume of contaminated rubble/debris described in this section is further detailed in Appendix B, Table B-1.

2.3.8 Wastes Within the North End of the IWCS

The wastes located within the north end of the IWCS include the R-10 residues and associated soil, contaminated soil from on-site areas and off-site vicinity properties, and miscellaneous debris. As described in Section 2..2.5, the R-10 pile located north of Building 411 (Figure 2-3) includes the R-10 residues, soil from the 1972 remedial action that was placed on top of the original R-10 residue pile, and underlying soil, for a total waste volume of 45,500 m^3 (59,500 yd^3).

Contaminated soil from several remedial actions taken at the NFSS and the vicinity properties were placed in the north end of the IWCS (see Appendix B, Table B-1). In 1982, remediation activities associated with the stabilization of the R-10 residues included remediation of the work areas outside of the centerline of the proposed R-10 dike. Approximately 12,000 m^3 (15,700 yd^3) of soil were excavated and placed inside the R-10 dike area (DOE 1983).

In 1983, remediation of additional on-site soil areas, the West Drainage Ditch, and both on- and off-site portions of the Central Drainage Ditch was conducted. Approximately 41,290 m^3 (54,000 yd^3) of material was excavated and placed north of Building 411 (DOE 1986c).

In 1984, an additional 21,330 m^3 (27,900 yd^3) of contaminated material were generated from continued on- and off-site decontamination activities that included off-site portions of the Central Drainage Ditch and vicinity properties identified as L, M, R, NN’ South, Q, H’, and X (DOE 1985a). A total of 2,750 m^3 (3,600 yd^3) of this material was stockpiled and later used for covering the IWCS in 1985. The remainder of the contaminated material was placed in the R-10 spoils area (DOE 1985b).

From the 1985 remedial actions, approximately 9,400 m^3 (12,300 yd^3) of additional contaminated soil from on- and off-site locations was placed in the IWCS. The west and south portions of the dike and cut-off walls were closed, completing the placement of additional waste into the IWCS (DOE 1986c).

In 1991, approximately 2,450 m^3 (3,200 yd^3) of contaminated soil and 230 m^3 (300 yd^3) of miscellaneous contaminated debris were placed in a 100- by 60-m (325- by 192-ft) waste containment cell that was excavated within the northern portion of the IWCS (DOE 1991). The miscellaneous debris included 64 drums of contaminated soil and resins, 4 steel tanks from the dismantled Hittman water treatment system, 900 boxes of soil samples, rolled tarps, geotextiles, and other miscellaneous debris (DOE 1991). The Hittman water treatment system was used to remove radium-226 from contaminated water processed during the IWCS construction (BNI 1982-1986).

2.4 IWCS Subunit Designation and Waste Volumes

The wastes within the IWCS exhibit a wide range of properties that must be addressed through the screening and evaluation of technologies and the development of alternatives. It was determined to be more useful to define areas and volumes of wastes for evaluating potential remedial alternatives based on contaminant level and waste placement within the IWCS. For this reason, the IWCS OU has been divided into three subunits called Subunit A, Subunit B, and Subunit C. The areas of the IWCS that comprise each subunit designation are shown in Figure 2-7.

Table 2-3 presents the preliminary volume estimates of the materials in the IWCS. These volume estimates are calculated to define and evaluate the feasibility of technologies considered for the IWCS OU. The waste volumes presented in Table 2-3 are based on the volumes and activity levels found in Tables B-1 and B-2 of Appendix B. The volume estimates for this TM include the contents of the IWCS as well as the volume of soil beneath the IWCS (3 m [10 ft]). An additional volume estimate was calculated for the structures of Buildings 411, 413, and 414 and foundations that may potentially be removed as part of any removal actions conducted for the IWCS (Table 2-3). There are several uncertainties associated with the volume of contaminated soil and the volume of contaminated rubble/debris associated with wastes particularly in the south end of the IWCS (Subunit B). A waste inventory and volume estimate will be conducted for the FS.

2.4.1 Subunit A: Residues and Commingled Wastes Within Buildings 411, 413, and 414

This subunit includes all residues (K-65, L-30, L-50, and F-32) placed in Buildings 411, 413, and 414 (Figure 4-1). The average radium-226 concentrations of the residues range from 300 pCi/g for the F-32 residues to 520,000 pCi/g for the K-65 residues (Table 2-3). The residues (K-65, L-30, F-32, and L-50) have a higher specific activity and may warrant immobilization for risk reduction (DOE 1984b). Therefore, treatment technologies will be evaluated for the residues.

This subunit also includes the Tower Soils because of its placement in Building 411, because the soil became contaminated as a result of the handling and transfer of the K-65 residues, and because of its average radium-226 concentration (Table 2-2). Additionally, there are sand layers that separate the Tower Soils, the residues (Figure 2-4), and the contaminated soil that was placed on top of Buildings 411, 413, and 414, which would require handling if any residues are removed. Some contaminated rubble/debris also is present in Building 411. The weighted average radium-226 concentration in the residues and soil in Building 411 is assumed to be a conservative estimate of what could be in the building materials (6,181 pCi/g) (Table 2-3). Miscellaneous materials were placed inside Buildings 413 and 414 to reduce radon emissions (Section 2.2.3.6) and include sand, clay, synthetic liners, and gravel (DOE 1983). The radium-226 concentration in the L-50 residues (3,300 pCi/g) is assumed to be a conservative estimate of what could be in the miscellaneous material in Buildings 413 and 414 because of the extended contact with the L-50 residues (Table 2-3). Because of the radium-226 concentrations and the commingling of these wastes within Buildings 411, 413, and 414, the Tower Soils, sand/clay layers, and contaminated soil placed within the buildings also are defined as wastes that should be considered for treatment as part of the remedy selection process.

Table 2-3. Radium-226 Concentrations and Volumes of Materials in the NFSS IWCS

NFSS IWCS Subunit	Radium-226 Concentration (pCi/g)	Volume[a,b]	
		(m^3)	(yd^3)
Subunit A – High-Grade Residues and Commingled Wastes Within Buildings 411, 413, and 414			
K-65 Residues	520,000	3,080	4,030
L-30 Residues	12,000	6,090	7,960
L-50 Residues	3,300	1,640	2,150
F-32 Residues	300	340	440
Tower Soils	10,400	3,150	4,115
Sand/Clay Separating Layers in Building 411		2,980	3,900
Contaminated Soil (1982-1991 on- and off-site remedial actions, miscellaneous soil)[c]	16	6,080	7,950
Miscellaneous Materials and Materials Added to Buildings 413 and 414[d]	3,300	9,840	12,870
Total Volume Subunit A		*33,200*	*43,415*
Subunit B – Debris and Wastes in the South End of the IWCS			
Building 410 and Grouted Piping		3,220	4,210
Building 415		80	100
Building 434		1,070	1,400
Thaw House Foundation		150	200
K-65 Slurry Transfer Piping		130	170
Middlesex Sands		180	230
Existing Structures Prior to the IWCS	Building 411 – 6,181[e] Buildings 413 and 414 – 3,300[e]	11,470	15,000
Contaminated Soil (1984-1985 on- and off-site remedial actions, miscellaneous soil)[c]	16	6,080	7,950
Miscellaneous Materials[d]		9,270	12,130
Contaminated Dike Material[f]		1,100	1,440
Contaminated Cap Material[f]		12,230	16,000
Soil Beneath the IWCS[f]		26,760	35,000
Total Volume Subunit B		*71,740*	*93,830*
Subunit C – R-10 Residues and Wastes in the North End of the IWCS			
R-10 Residues and Soil (includes 1972 remedial action soil and sub-grade contaminated soil)	95	45,500	59,500
1982 Remedial Action – placed on the R-10 pile		12,000	15,700
1983 Remedial Action (on- and off-site) – placed north of Building 411		41,290	54,000
1991 Miscellaneous Soil – placed north of Building 411		2,450	3,200
1991 Hittman Tanks, Miscellaneous Debris – placed north of Building 411		230	300
Contaminated Soil (1984 on- and off-site remedial actions)[c]	16	18,580	24,300
Contaminated Dike Material[f]		1,650	2,160
Contaminated Cap Material[f]		18,350	24,000
Soil Beneath the IWCS[f]		40,140	52,500
Total Volume Subunit C		*180,190*	*235,660*
Total Inventory Volume		**285,130**	**372,905**

[a] The results presented in this table were derived from the tables contained in Appendix B.

[b] The volume in the table represents the in-situ volumes.

[c] Of the approximately 27,900 yd^3 of contaminated soil excavated in 1984, 3,600 yd^3 were stockpiled and later used for covering the IWCS in 1985. The remainder of the contaminated material (24,300 yd^3) was placed in the R-10 spoil area (DOE 1985b). Since the interim cap on the north portion of the IWCS was begun in 1984 and completed in 1985, it is assumed for volume estimates that the 12,300 yd^3 of contaminated soil excavated during 1985 was placed in the southern portion of the IWCS. Due to the uncertainty of the placement of the 3,600 yd^3 of 1984 soil and the 12,300 yd^3 1985 soil, 50 percent (%) of this total volume is assumed to be placed in Subunit A and 50% is assumed to be placed in Subunit B. Therefore, it is assumed that 7,950 yd^3 was placed in each subunit (A and B).

[d] It is assumed from the reported useable capacity of Buildings 413 and 414 (1,407 yd^3 each, total capacity of both buildings = 2,814 yd^3) that the buildings contain 2,150 yd^3 of L-50 residues and approximately 664 yd^3 of additional material was placed in the buildings. Adding a 10% uncertainty to this volume to account for concrete added to the building structures (such as filling of troughs), this estimate is approximately 730 yd^3. Assuming the remaining miscellaneous materials volume listed in Appendix B (25,000 yd^3 – 730 yd^3 = 24,270 yd^3) is split evenly between Subunits A and B results in approximately 12,870 yd^3 of material being placed in Subunit A and 12,130 yd^3 of material being placed in Subunit B.

[e] The radium-226 concentrations are not known for the contaminated rubble/debris within the IWCS. Therefore, an estimated concentration was made based on the weighted average of the volume and source-term concentrations for each of the wastes as a conservative estimate. It is expected that building surfaces of Buildings 411, 413, and 414 would be contaminated. For the contaminated rubble/debris and building surfaces of Building 411, an estimated radium-226 concentration was calculated based on the wastes placed inside Building 411 (L-30, F-32, Tower Soils, and contaminated soil) but excluding the K-65 residues as a conservative estimate. Therefore, the radium-226 concentration of the debris and the Building 411 structure would equal (12,000 pCi/g x 7,960 yd^3) + (300 pCi/g x 440 yd^3) + (10,400 pCi/g x 4,115 yd^3) + (16 pCi/g x 6,000 yd^3 [approximation of soil in Building 411]) divided by the total volume (22,415 yd^3) of the non-K-65 residues material in Building 41,1 including the volume of the clay/sand layer (3,900 yd^3). The estimated radium-226 concentration of the contaminated structures of Buildings 413 and 414 is assumed to be equal to the concentration of the L-50 residues.

[f] Based on the linear footage of the dike/cut-off wall for Subunits B and C, 60% of the contaminated dike/cut-off wall and cap material and the soil beneath the IWCS is assumed to be associated with Subunit C (North End of the IWCS); the other 40% of these volumes is assumed to be associated with Subunit B (South End of the IWCS). The actual dike and cut-off wall are assumed to be part of the Balance of Plant Operable Unit.

IWCS = Interim Waste Containment Structure.
m^3 = Cubic meter.
NFSS = Niagara Falls Storage Site.
pCi/g = Picocuries per gram.
yd^3 = Cubic yard.

2.4.2 Subunit B: Debris and Wastes in the South End of the IWCS

The wastes comprising Subunit B are defined as the wastes placed south of the IWCS dike/cut-off wall that abuts Building 411 on both its east and west sides (Figure 4-1), except for those wastes defined as part of Subunit A, as well as the strictures of Buildings 411, 413, and 414. It also includes other contaminated rubble/debris that was placed outside of Buildings 411, 413, and 414, including the debris associated with storage, handling, and transfer of K-65 residues; contaminated rubble/debris from the former K-65 storage silo (Building 434); the Thaw House Foundation; Building 415, Building 410, and the Middlesex Sands that were placed into Building 410 (Table 2-3). Additionally, Subunit B includes contaminated soil that was placed surrounding the debris within the south end of the IWCS. No characterization of the contaminated rubble and debris (transfer piping, equipment, etc.) in Subunit B (Table 2-3) was conducted.

The radium-226 concentration of the structural materials of Buildings 411, 413, and 414 (based on the extended contact with residues) was estimated. The weighted average radium-226 concentration in the residues and soil in Building 411 is assumed to be a conservative estimate of what could be in the building materials (6,181 pCi/g) (Table 2-3). The broad radium-226 concentration of Buildings 413 and 414 is associated with extended contact with the L-50 residues and is estimated at 3,300 pCi/g. As a result of extended contact with the radioactive residues, the structural surfaces of Buildings 411, 413, and 414 also are defined as wastes that should be considered for surface treatment as part of the remedy selection process.

2.4.3 Subunit C: Residues and Wastes in the North End of the IWCS

This subunit includes the R-10 residues and soil, some miscellaneous waste, and the majority of the volume of waste categorized as contaminated soil located north of the IWCS dike/cut-off wall that abuts Building 411 on both its east and west sides (Figure 2-7). The broad radium-226 concentrations of wastes in the north end of the IWCS range from 16 to 95 pCi/g (Table 2-3). Subunit C also contains 230 m^3 (300 yd^3) of contaminated debris, including 64 drums of radioactive material, 4 steel tanks from the dismantled Hittman water treatment system, 900 boxes of soil samples, rolled tarps, geotextiles, and other miscellaneous debris, that were placed in a 100- by 60-m (325- by 192-ft) waste containment cell that was excavated within the northern portion of the IWCS in 1991 (DOE 1991).

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3.0 DEVELOPMENT AND SCREENING OF REMEDIAL TECHNOLOGIES

This section presents a summary of the IWCS COCs that were identified for the IWCS OU. In addition, remedial action objectives (RAOs) for the IWCS OU, which are established to protect human health and the environment, are defined. The RAOs support the development of general response actions (GRAs), which in turn allow for the identification and screening of remedial technologies and the development of remedial alternatives.

3.1 Contaminants of Concern

Although the wastes within the IWCS are currently safely contained, potential exposure to contaminants in the IWCS was evaluated to support the development and screening of remedial alternatives in the FS. Pathways evaluated include (1) airborne releases due to a hypothetical cap breach and (2) migration to groundwater due to infiltration of precipitation through the cap and the leaching of contaminants beyond the IWCS containment structure.

The potential impacts to groundwater due to leaching of constituents beyond the IWCS containment structure were presented in the *Groundwater Flow and Contaminant Transport Modeling* (USACE 2007b, 2011b). One objective of this evaluation was to support the FS evaluation of the long-term effectiveness of any remedial alternative that considers leaving the wastes in the IWCS in place. Some of the selected contaminants of potential concern (COPCs) were those contaminants that were determined to be most prevalent in the residues and expected to be mobile in the environment if water percolated through the IWCS cover.

Potential airborne releases were evaluated in the *Preliminary Health Effects for Hypothetical Exposures to Contaminants from the Interim Waste Containment Structure Technical Memorandum* (Health Effects TM) (USACE 2012b). The Health Effects TM conducted an evaluation of risk conditions relevant to the near term (i.e., on the order of 10 years). The evaluation was not intended to address all constituents in the IWCS; rather, it focused on a set of constituents considered to reflect those of primary concern if the IWCS cap were breached (whether by excavation or other events that could uncover the wastes) and contaminants were released to the air and subsequently deposited where on-site workers or the general public could be exposed (USACE 2012b).

A total of 22 constituents (11 radionuclides and 11 chemicals) were evaluated as COPCs for the wastes within the IWCS.

These evaluations confirmed that the principal COCs for the IWCS are radium-226 and its short-lived decay products due to its high concentrations in the residues and its potential to emit substantial gamma radiation and to release radon-222 gas. Among the wastes stored in the IWCS, the K-65 residues contain the highest concentration of radium-226.

3.2 Remedial Action Objectives

An RAO is a qualitative goal developed to specify the requirements that remedial alternatives must fulfill to be protective of human health and the environment. RAOs provide the basis for selecting applicable remedial technologies, and developing and evaluating remedial alternatives.

The RAOs for the IWCS OU are designed to provide short- and long-term protection of human health and the environment based on plausible future land uses for the NFSS. CERCLA requires that any action taken be protective of human health and the environment as well as be compliant with identified applicable and relevant and appropriate requirements (ARARs).

The preliminary RAOs for the IWCS OU are as follows:

- Prevent unacceptable exposure of receptors to the hazardous substances associated with uranium ore mill tailings (e.g., radium-226 and its short-lived decay products) inside the IWCS.
- Minimize/prevent the transport of hazardous substances within the IWCS to other environmental media (e.g., soil, groundwater, surface water, sediment, and air) outside of the IWCS.
- During implementation of the remedial alternatives(s), minimize/prevent releases and other impacts that could adversely affect human health and the environment, including ecological receptors.

3.3 General Response Actions

GRAs are defined as broad response actions that satisfy the RAOs for the IWCS residues and wastes. GRAs include several remedial categories such as containment, removal, disposal, and treatment, and general categories of remedial technologies such as capping, subsurface barriers, or vertical trenches. Remedial technologies are further divided into process options, which are specific processes within each category of remedial technology. As indicated in Figure 3-1, several broad types of remedial technologies may be identified for each GRA and numerous process options may exist for each category of remedial technology.

This section describes each GRA and then screens each GRA to determine if it can meet the RAOs established for the IWCS OU. Individually, GRAs may meet the RAOs; however, they also can be grouped together to form alternatives that have the potential to meet RAOs. GRAs are assessed in a general nature on their ability to reduce the volume, toxicity, or exposure to the waste materials within the IWCS. GRAs that satisfy the RAOs for the IWCS OU are carried forward to Section 3.4 where remedial technologies and process options for the IWCS residues and wastes are identified.

3.3.1 Land-Use Controls

The term ‘land-use control’ is defined as “any restriction or control, including institutional controls and engineering controls, arising from the need to protect human health and the environment, such as the restriction of access or limitation of activities at a site that has residual contamination.” Land-use controls (LUCs) do not actively clean up the contamination at a site, but they can control future access to the site and limit exposures to existing contamination; therefore, they are considered to be limited actions (1990 NCP Preamble at 55 *Federal Register* 8710). There are two basic types of LUCs: institutional controls and engineering controls.

Institutional controls are “non-engineered instruments, such as administrative and legal controls that help to minimize the potential for human exposure to contamination and/or protect the integrity of a response action” (EPA 2010). Previous efforts to address uncertainties related to the potential for human intrusions into radioactive waste sites with long-lived radionuclides have acknowledged that, “neither experimentation, observation, nor modeling can resolve such uncertainties” (Hora, et.al. 1991). In one of the most robust efforts to address this issue to date the government relied on “expert judgment analysis” to study the reliability of government controls, possible modes of intrusion, and quantitative measures of probabilities for human intrusion (Hora et.al. 1991). Since the study was primarily performed for a single waste site (the Waste Isolation Pilot Plant in Carlsbad New, Mexico), the conclusions represented reasonable intruder scenarios for that site. However, the general conclusions are applicable to the potential for future intrusion at the NFSS and include:

- The facets of society that most directly impinge upon inadvertent human intrusion include the rate of technological development, population growth, economic development (including the price of natural minerals and energy resources), water availability, information and records, and the level of government continuity

- The experts agreed that there is a small likelihood of continued U.S. government controls for the periods studied because “governments are seldom stable for long periods of time, certainly not for the period of time covered for this study.” The study concluded that the amount of time required to achieve safe levels of radioactivity (due to the long half-lives of the radionuclides in the waste being considered) is longer than the anticipated “continuity and stability of governments.” As a result, there is no assurance that the government will maintain active control of the site for the necessary length of time.

- The probabilities for intrusion into the Waste Isolation Pilot Plant were very low. The key reason for intrusion was found to be for purposes of “mining” natural resources (oil, water, etc.). However, the methods of intrusion at the Waste Isolation Pilot Plant were different than the types of intrusion that would be expected at the IWCS since the Waste Isolation Pilot Plant is a deep geologic repository.

A variety of engineering controls could be used in conjunction with institutional controls to control access to contaminated areas at the NFSS. Engineering controls are engineering and physical barriers, such as fences, berms, and warning signs, placed on or around a contaminated site to prevent unauthorized access. Each of these engineering controls is designed to minimize the potential for direct human contact with contaminated media. For the purposes of this TM, barriers such as asphalt or concrete pavement are included as a type of engineering control. More complex capping in place, such as enhancement or replacement of the current engineered cap over the IWCS, has been included as a technology option under the containment GRA. When engineering controls are used to supplement institutional controls and other GRAs, engineering controls could achieve the RAOs for the IWCS OU by reducing the potential for human exposure to contamination and by ensuring the continued integrity of a response action.

In addition to institutional controls and engineering controls, environmental monitoring is included under the LUC GRA because it provides information concerning the contamination present in site media, similar to informational tools (a type of institutional control). For sites where LUCs will be relied upon, environmental monitoring is essential to confirm that LUCs are performing as intended. It also may be conducted to provide information to allow an assessment of the continued effectiveness of the selected remedy and to determine if releases of contaminated materials from the site could present an unacceptable risk to potential existing and future receptors. Although monitoring can be a stand-alone action, it is more typically used in conjunction with other technologies, such as institutional controls. Environmental monitoring also could be conducted in combination with other remedial technologies, such as containment, to evaluate contamination concentrations and impacts on the environment during and after implementation of the remedial action.

Environmental monitoring would not achieve the RAOs for the IWCS OU as a stand-alone option. However, when used in combination with other GRAs, it would support attainment of the RAOs by providing information on any contaminant releases, if they occurred, thus allowing corrective action as needed.

Surveillance and maintenance activities also could be conducted in support of LUCs to ensure that the LUCs remain effective in protecting human health and the environment over the long term. Surveillance and maintenance activities would include maintenance of institutional controls, routine site inspections and site walkovers, and the maintenance and repair of the physical components of the remedy (i.e., fences, signs, and landfill cap). The surveillance and maintenance activities would not achieve the RAOs for the IWCS OU as a stand-alone option but, when used in combination with other GRAs, would support attainment of the RAOs.

3.3.2 Containment

Containment may refer to any process whereby the waste is left in place and contained by a combination of natural and engineered structures. The containment GRA for the IWCS confines contaminants to their current location and media but does not reduce their volume or toxicity. Containment actions are used to reduce or prevent the mobility of the contaminants and the potential for exposure by providing a barrier between contaminated and uncontaminated media that prevents contaminants from migrating into groundwater, surface water, air, or other media, or acting as a source for direct exposure. Containment actions can reduce the mobility of contaminants if the contaminated medium is isolated from transport mechanisms such as wind, erosion, surface water, groundwater, etc. Containment technologies may include subsurface migration control, surface capping, run-on/run-off control, and modifications to existing containment structures. Subsurface migration control, surface capping, and run-on/run-off control are all containment practices applicable to site soil, and many of these practices are already in place at the IWCS.

Containment actions do not reduce contaminant volume or toxicity and, therefore, often require other actions, such as environmental monitoring, to ensure that the protectiveness of the containment action meets the RAOs. Certain actions may be applied to the entire site, while other actions would be tailored to specific areas or specific contaminants within the NFSS.

3.3.3 Removal

The removal GRA for the IWCS includes moving the contaminated media from its current location for treatment and/or disposal either on- or off-site. Physical removal of contaminated media is applicable to almost all situations. The selection of a specific removal technology depends on the physical characteristics of the contaminated media, the location of the media, and potential risks associated with the COCs. Removal actions can be implemented mechanically, hydraulically, pneumatically, or manually (by hand). Physical equipment modified with robotics to allow remote handling may be more appropriate for portions of the IWCS. Additionally, a combination of removal processes may be applicable to the IWCS. Removal of contaminated media reduces the long-term potential for human and environmental exposure at the NFSS; however, by itself, it does not reduce toxicity or volume. Removal of wastes from the IWCS would need to be combined with another GRA (e.g., disposal) to meet the RAOs.

3.3.4 Treatment

Treatment as a GRA is defined as a physical, chemical, biological, or thermal means to permanently or substantially eliminate or reduce the toxicity, mobility, or volume of hazardous substances by the use of in-situ (treatment in place without excavation and/or removal) or ex-situ (excavation and/or removal of contaminated media and materials for treatment at an approved on- or off-site treatment facility) remedial technologies (EPA 2007). In-situ treatment can be appropriate as a stand-alone GRA or may serve as one of several components of a remedial alternative. Ex-situ treatment is not a stand-alone GRA because excavation and/or removal of contaminated media would be required. Treatment may be conducted on-site or at an off-site treatment facility. Disposal of treatment residuals also may be required as part of this GRA.

Technologies and process options are being evaluated primarily for the radioactive residues placed within Buildings 411, 413, and 414. Treatment of the residues is being evaluated to reduce the mobility of the residues if they were removed from the IWCS. Additionally, no off-site disposal facilities can currently accept the K-65 residues for disposal without some form of treatment, and U. S. Department of Transportation (DOT) requirements for transportation of the K-65 residues also require some form of treatment (USACE 2011c). The Tower Soils and other contaminated waste placed within Buildings 411, 413, or 414 are included in the wastes that will be considered for treatment as part of any alternatives where the wastes from Subunit A would be removed. Treatment of contaminated rubble/debris and the building structures of Buildings 411, 413, and 414 also is evaluated to reduce the mobility of radioactive particulates if these surfaces are exposed during implementation of the selected remedy. Treatment also would be considered for other wastes contained within the IWCS as part of any alternatives that included removal of wastes if it was determined that their radioactivity would warrant immobilization. Treatment of the residues and other Subunit A wastes will be done to primarily address radionuclides but will address collocated metals concentrations as well. The preferred treatment option would be able to address both the COCs and any other collocated hazardous substance(s).

During any removal actions associated with Subunit C, it is possible that there could be isolated encounters with hazardous wastes in contaminated soil, drums, etc. Such hazardous wastes will be removed and shipped off-site for treatment and disposal as LLMW. Wastes that are LLMW would have to comply with RCRA (40 *CFR* 261-268). Because RCRA (40 *CFR* 268) requires hazardous wastes to meet land disposal restrictions prior to disposal in a land-based unit, treatment may be required to immobilize the hazardous constituent(s) and meet the concentration standards. Given the small quantity of mixed waste expected in the IWCS, it would likely be more cost effective to transport this waste to a licensed off-site mixed waste treatment facility rather than to develop a treatment process specifically to address it. Therefore, treatment or disposal of LLMW must consider shipment off-site for treatment/disposal and RCRA requirements.

This GRA would achieve the RAOs for the IWCS OU by reducing the mobility and/or toxicity of the waste, thus minimizing the potential for long-term impacts to human health and the environment. It also would enhance the long-term effectiveness of other alternatives where treatment is a component of that alternative.

3.3.5 Disposal

Disposal is a GRA for final disposition of excavated wastes, affected soil, treatment residuals, or waste generated by the remedial action process. In comparison to the containment GRA, disposal relocates contaminants from one area or place to another for long-term containment in a permitted or licensed facility. Disposal does not reduce the toxicity or volume of contaminated wastes but it may reduce the mobility and/or exposures to wastes. Disposal options are dependent on the waste classification, the characteristics of the contaminant(s), and the physical properties of the waste media. For the IWCS waste, disposal would need to be combined with the removal GRA to be implemented.

The options for disposal following removal include a newly constructed on-site disposal facility and an off-site landfill disposal facility. On-site disposal enables the treated media to be handled on-site without the need for off-site transportation. Off-site disposal would require obtaining all necessary permits for transportation and disposal.

Transportation options for off-site disposal include truck, railcar, barge, or bimodal (i.e., a combination of two or more transportation modes). Transportation will require compliance with regulations controlling the radioactivity level of the soil and residue. Wastes will have to be containerized appropriately to provide shielding requirements and to comply with applicable DOT requirements and disposal facility waste acceptance criteria (WAC) of the receiving facility.

This GRA would achieve the RAOs for the IWCS OU by either placing the waste into a newly constructed engineered disposal facility on-site or transporting the wastes to a permitted or licensed off-site disposal facility. On-site disposal would need to be combined with other GRAs, including removal actions, to be implemented and for LUCs to be effective. These actions would minimize the mobility of and exposure to COCs and collocated hazardous substances, thus reducing long-term impacts to human health and the environment.

3.4 Identification and Screening of Technology Types and Process Options

In this step of the FS process, appropriate remedial technology types and process options that are capable of addressing the contaminated media are organized under each GRA. In accordance with the NCP

(40 *CFR* §300.430[e][3][i]), USACE will develop a range of remedial alternatives through the FS process that reduce the toxicity, mobility, or volume of the contaminant. Although technologies for radiologically contaminated media can effectively reduce the volume or mobility of contaminated material, very few of the treatment technologies change the radioactivity of the radiological COCs. Instead, the level of radioactivity emitted from the immobilized radionuclides reduces itself over time through the process of radioactive decay. Therefore, the main focus for identification and screening of technologies is to reduce the volume or mobility of the radiological contaminants or to reduce exposures to radiological contaminants in the media of concern.

The identification and screening of remedial technologies and process options was conducted using several available technology reference guides and screening tools, including the *Remediation Technologies Screening Matrix and Reference Guide* (FRTR 2009), the *Technology Screening Guide for Radioactively Contaminated Sites* (EPA 1996a), and the *Technology Reference Guide for Radiological Contaminated Surfaces* (EPA 2006a). Available literature on remediation technologies and process options also was researched to determine the innovative technologies that may be feasible for implementation for the IWCS. The categories of institutional controls presented here are based on information presented in EPA's *Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites* (EPA 2010) and *Institutional Controls: A Site Manager's Guide to Identifying, Evaluating, and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups* (EPA 2000).

Additionally, remedial technologies and process options identified for the K-65 residues at the Fernald Site in Ohio were considered for evaluation in this TM. The presence of the K-65 residues at both the Fernald Site and the IWCS provided an opportunity to identify numerous aspects of the Fernald Site remediation that may be appropriate to future IWCS remedial activities including retrieval, treatment, shipping, and disposal of the K-65 residues and other wastes. USACE has prepared the Waste Disposal Option/Fernald Lessons Learned Technical Memorandum (USACE 2011c), which details and discusses remediation decisions and actions during the Fernald Closure Project that have relevancy to the IWCS OU FS process and have been included here.

The remedial technologies and process options identified for the IWCS OU are presented in Figure 3-1 and described below. Each of the technologies and process options are evaluated and initially screened based on technical implementability. In accordance with EPA guidance, remedial technologies and process options may be eliminated during the screening phase on the basis of technical implementability (EPA 1988). This initial screening is broad, assessing the suitability of a particular technology for addressing the COCs and types of waste materials in the IWCS. The information presented in Section 2.0 regarding the physical characteristics, radiological concentrations, and locations of waste materials within the IWCS was used to determine which technologies could be effectively implemented.

A technology or process option will be eliminated from further consideration on the following basis:

- If available information indicates that the technology or process option is incompatible with site conditions, waste characteristics, or COCs or cannot be implemented effectively due to physical limitations or constraints at the site, or
- If some of the process options are technically implementable on a small-scale basis for a specific location but there is not a large-scale, site-wide basis for use of the process options for the contaminated media.

The process options for the IWCS wastes eliminated from further consideration in this TM (with the rationale for elimination) are indicated on Figure 3-1 using gray shading. Although the purpose of this TM is to conduct the screening of technologies for the IWCS OU FS, technologies may be added or eliminated, as needed, based on availability of new information or new or emerging technologies.

3.4.1 Land-Use Controls

This section describes some of the types of LUCs (both institutional and engineering) that may be appropriate for remedial alternatives that result in hazardous materials remaining in the IWCS above levels that allow for unrestricted use. LUCs would be applicable for use at Subunits A, B, and C.

3.4.1.1 Institutional Controls

Institutional controls are “non-engineered instruments, such as administrative and legal controls, that help to minimize the potential for human exposure to contamination and/or protect the integrity of a response action” (EPA 2010). Institutional controls are generally used in conjunction with, rather than in lieu of, active response measures such as containment, removal, treatment, or beneficial use of source material. However, where active response measures are determined not to be practicable, the NCP allows the use of institutional controls to supplement engineering controls for short- and long-term management of hazardous substances, pollutants, or contaminants (40 *CFR* 300.430[a][1][iii][D]). There are four categories of institutional controls.

- Proprietary controls, which would involve placement of restrictions on land use through actions such as the use of easements and covenants.
- Governmental controls on land use.
- Enforcement and permit tools with LUC components.
- Informational tools (e.g., state registries of contaminated properties, deed notices, and advisories), which provide information or notification that contamination exists on-site.

Institutional controls include administrative and legal controls that help to minimize human exposures to contamination and/or to protect the integrity of a remedy. The use of different types of institutional controls (i.e., layering) helps to mitigate the risk should any single control fail. Therefore, because institutional controls are generally more effective if they are layered or implemented in series, it is likely that multiple types of institutional control mechanisms would be established for the IWCS. The different categories of institutional controls and their applicability to the IWCS are presented below.

The NCP cautions against the use of institutional controls as the sole remedy unless active response measures are determined to be impracticable. In addition, there are uncertainties regarding the ability of institutional controls to maintain protectiveness over long time periods. Therefore, institutional controls will generally be considered a component of a remedial action rather than a stand-alone measure.

3.4.1.1.1 Proprietary Controls

A proprietary control is a private contractual mechanism contained in the deed. Proprietary controls involve placement of restrictions on land through the use of easements, covenants, and reversionary interests. These controls would be used to ensure that unauthorized land uses do not occur at the IWCS to prevent exposures to contaminated media and to prevent any activities that could reduce the effectiveness of the remedy. An example of proprietary controls that could be considered for the IWCS follows:

- Restrictions on intrusive or construction activities (e.g., drilling, digging, or other use of heavy equipment) that could result in unacceptable exposures to contaminants or could compromise the integrity of the remedy (e.g., damage the cap or containment system).

The NFSS is a Federally owned property and, therefore, proprietary controls are not allowed for the NFSS as long as Federal ownership is maintained.

Proprietary controls would typically only be used for remedial alternatives for the IWCS if the IWCS is transferred to a non-Federal entity and contamination remains above levels that allow for unlimited use and unrestricted exposure. CERCLA 120(h) places certain requirements on the deed transfer of Federal Government-owned property to other parties. CERCLA 120(h) requires the Federal Government to:

- Give notice of hazardous substance activity to the grantee, including a due diligence obligation to provide detailed, accurate information on all reportable quantities of hazardous substances stored, released, or disposed on the property.
- Include a covenant in the deed that "all remedial action necessary to protect human health and the environment with respect to any such substance remaining on the property has been taken before the date of such transfer."
- Include a deed covenant that the United States will return and perform any additional response action that may be required in the future.
- Retain a perpetual right of access necessary to do such additional response actions (GSA 2006, 2010).

In this case, these requirements only apply to fee conveyances of real property out of Federal ownership but not to interagency Federal real property transfers or to leases, licensees, or easements granted for the use of Federal land (GSA 2006).

3.4.1.1.2 Governmental Controls

Governmental controls use the authority of an existing governmental unit to impose land or resource restrictions. Zoning restrictions, building codes, and permit programs are examples of governmental controls. In many cases, Federal landholding agencies, such as DOE, possess the authority to enforce institutional controls on their property.

Zoning use restrictions are imposed through a local zoning authority to place restrictions on the types of land use allowed. Zoning restrictions may prohibit activities that could disturb certain aspects of a remedy or control certain exposures not otherwise protected under a remedy. Zoning restrictions have inherent shortcomings. Zoning laws can be repealed or exceptions to them can be granted by the government. Also, they are not effective unless a government commits the resources to monitor and enforce the restrictions over the long term. Property zoning for the NFSS presently excludes residential use.

The NFSS is a Federally owned property, giving the Federal Government the authority to impose LUCs on the IWCS. The governmental controls include site access procedures that prevent unauthorized entry and provide for any worker access necessary for continued maintenance, monitoring, site inspections, and repairs. These procedures also ensure adequate training for workers who must enter hazardous areas and prevent exposures to contaminated media. Prior notification and approval of intrusive activities are required to prevent unnecessary disturbance of contaminated areas and to protect workers from potential exposures to hazardous materials. Current controls resulting from Federal ownership are in place to limit contact with contaminated groundwater. Groundwater use on-site is restricted, except for the purposes of monitoring. The installation of any new water supply wells of any kind is subject to Federal agency review. There are no drinking water wells on-site.

Assuming continued Federal ownership of the IWCS and associated buffer zones, the governmental controls currently in place would likely be continued, and procedures would be implemented to ensure their continued protectiveness in the event of a change in land use or property ownership. In the event that the Federal Government transfers property to another entity, USACE will suggest to GSA that the appropriate use restrictions will be attached to the real estate transaction to ensure that specific institutional controls will remain in place.

For those alternatives involving on-site disposal, a buffer zone or area of restricted access will need to be maintained. The government would have to maintain ownership or purchase any properties needed to establish a buffer zone of sufficient area surrounding the facility operations to allow environmental monitoring to be carried out; to allow contingency measures to be carried out in an emergency; and to ensure that, during site operations, there is an adequate distance between the facility and any area used by, or accessible to, members of the public. Governmental controls could be used to restrict access to the buffer zone and to require notification prior to any intrusive activities.

3.4.1.1.3 Informational Tools

Informational tools provide information or notification that residual contamination exists on-site. Common examples include state registries of contaminated properties, deed notices, and advisories. Informational tools also may include posted signs around the perimeter of the NFSS with project contact information and ongoing educational efforts that could include briefings, pamphlets, and websites that provide information regarding site contamination and status. Informational devices are most likely to be used as a secondary “layer” to help ensure the overall reliability of other institutional controls.

3.4.1.2 Engineering Controls

Engineering controls are physical barriers or other measures (security systems and signs) that limit exposure to contamination or access to a site. Some common engineering controls include low-permeability barriers such as concrete or asphalt pavement and physical access barriers such as fences and berms. These types of access barriers may not be effective in the long term unless they are regularly inspected and maintained.

Engineering controls limit the potential for inadvertent public or worker exposure to the IWCS and waste materials by restricting entry to the IWCS area or the NFSS. The following engineering controls are currently in place at the NFSS and are expected to be maintained if wastes remain on-site:

- Public access is restricted through the use of site perimeter fencing and site security measures.
- Areas of the NFSS are restricted to on-site workers by access gates, internal fences, ropes, and warning signs and markers.

3.4.1.3 Environmental Monitoring

Environmental monitoring of air, groundwater, surface water, and sediment could be conducted at the IWCS to determine if residual contaminants are migrating and if unacceptable concentrations could reach potential receptors. Proper use of monitoring data can alert property managers to impending exceedances of ARAR-based guidelines as well as health and safety parameters.

Environmental monitoring currently conducted at the NFSS includes monitoring of air, groundwater, surface water, and sediment for radiological and chemical analysis. The monitoring helps to ensure that the IWCS is functioning as designed and is fully protective of human health and the environment. It is expected that these types of monitoring activities would continue if waste remains in the IWCS. The monitoring activities would be modified as necessary to address specific requirements related to the selected remedial action to be taken at the IWCS. The media samples, the number of locations sampled, the frequency of sampling, and sampling collection and analysis methods would be determined based on the remedial action implemented and the contaminants remaining on-site.

Four process options for the environmental monitoring GRA (air, groundwater, surface water, and sediment monitoring) are equally technically implementable based on their current use at the site and have been retained as viable options for use at the IWCS. The following elements of the current monitoring program at the NFSS may be retained as part of a long-term monitoring (LTM) program for those IWCS OU alternatives that involve leaving waste on-site:

- Measuring external gamma radiation;
- Measuring radon gas concentrations in air (combined contributions from radon-220 and radon-222);
- Monitoring radon-222 flux;

- Sampling and analyzing surface water and sediment for radioactive constituents, metals, and organics; and
- Sampling and analyzing groundwater (UWBZ and LWBZ) for radioactive constituents, metals, and water quality parameters.

During remediation activities, portable and fixed monitors could be utilized to measure radon emissions. Air particulate monitoring could be conducted to measure fugitive particulate emissions.

3.4.1.4 Surveillance and Maintenance

Surveillance and maintenance activities conducted as part of long-term institutional controls are designed to identify potential problems before they develop into a need for corrective action. Site surveillance and inspection activities may include observing real-time activities to verify conformance of the physical and institutional controls with their specified regulatory requirements. Surveillance activities would include responding to unexpected conditions and emergencies. Inspections are generally conducted routinely to determine whether the LUC remains in place and whether it meets the stated objectives. Maintenance and repair activities are performed on physical components (e.g., caps, fences, signs, etc.) to keep them functioning as designed.

The current site inspection and maintenance program for the IWCS includes the following:

- Routine inspections and walkovers;
- Watering and maintaining the grass, grass mowing, and brush clearing; and
- Monitoring well, fence, sign, and cap maintenance and repair as needed.

These types of activities are expected to continue if waste remains in the IWCS. The surveillance and maintenance activities would be modified as necessary to address specific requirements related to the selected remedial action to be taken for the IWCS.

3.4.1.5 Summary of Potential LUCs for the IWCS

When used to supplement other GRAs, LUCs are implementable and, if properly implemented and maintained, would help achieve the RAOs for the IWCS OU. The LUCs applicable to the IWCS would be designed to minimize human and environmental exposure to hazardous substances remaining at the site and also to prevent activities that could impact the effectiveness of the remedy. Because institutional controls are more effective when layered, multiple types of institutional control mechanisms have been retained for potential use at the IWCS. The process options for institutional controls that have been retained include proprietary controls, governmental controls, and informational tools (Figure 3-1). These types of controls are commonly used at CERCLA sites and are technically implementable. The engineering controls that have been retained include fences, signs, and other engineered site security measures. These engineering controls are currently used at the site and have been demonstrated to be technically implementable. Environmental monitoring and the surveillance and maintenance program for the IWCS also are retained. If a final remedy is selected that includes institutional controls as one of its components, an Institutional Controls Plan would be prepared after the final remedy for the IWCS OU is approved in the ROD. The plan would document the approach for implementing and maintaining the institutional controls.

3.4.2 Containment

Containment technologies are used to isolate contaminated material to effectively reduce contaminant mobility and the potential for exposure to human health and the environment. However, containment actions generally do not reduce contaminant volume or toxicity. Some containment technologies are designed to prevent vertical migration while others are designed to prevent horizontal migration. Combining multiple containment technologies can prevent contaminant migration in any direction (e.g., landfill). When consolidation is used in conjunction with containment, the overall area of contamination is reduced, thereby reducing the area of potential exposure to individuals. Air, gas, water, and soil containment technologies are considered for Subunits A, B, and C of the IWCS.

3.4.2.1 Engineered Caps

Engineered caps are used to cover a contaminated area with a low-permeability material to reduce infiltration of water and to retard the vertical migration of contaminants, including upward migration of gases or other emissions and transport associated with infiltration. Capping materials can include naturally occurring, low-permeable soil and clay, asphalt, cement, and synthetic membrane liners, such as flexible geomembranes, which are made of high-density polyethylene. In general, a cap can be comprised of one layer or a complex multi-layer system using a combination of capping materials. Proper maintenance and monitoring LUCs are required to ensure its long-term effectiveness. Maintenance requirements can be reduced through proper design, which would impact long-term effectiveness and operating costs. Monitoring requirements may be optimized through design but are generally required throughout the design life of the containment structure and are directly related to the confidence associated with the long-term efficacy.

3.4.2.1.1 Single Layer

A single-layer cap is generally used to contain areas of surficial contamination (e.g., contaminated soil hot spot) and to provide some level of protection. A cap would reduce direct contact exposure to contaminated soil and may reduce leaching to underlying soil and groundwater but would not eliminate future leaching. The capped area would require LUCs, such as perimeter fencing, to ensure that the cap is not breached or disturbed in any way. A single-layer cap may be appropriate in areas other than the IWCS where LUCs would be considered adequately protective. Although technically implementable, use of a single-layer cap is not retained for further consideration as a viable technology process option for the containment GRA for Subunits A, B, or C because a multi-layer cap is already in place.

3.4.2.1.2 Multi-Layer Engineered

Multi-layer engineered caps consist of different materials that, when used together, provide a composite barrier to liquid- and gas-phase transport, as well as provide intrusion protection. A typical cap for radioactive material might consist of compacted clay over the waste; a cobble/rock layer to act as a barrier to plant roots, burrowing animals, surface erosion, and as a warning to the inadvertent intruder; and a sand drainage layer, several feet of topsoil, and shallow root vegetation for erosion control. The level of radioactivity and radon gas must be considered in designing a cap for radioactive material to provide adequate shielding.

The IWCS cap is currently an engineered cover consisting of two relevant soil components: a vegetated layer and a barrier layer. A vegetated soil cover layer overlying the clay barrier layer performs an important function by storing soil water, thereby allowing for evapotranspiration by plants. This layer accounts for a significant volume of water removed from the capping system each year. The clay barrier layer retards downward movement of infiltrating rainfall, causing more soil moisture storage and run-off.

Additional enhancements to the existing IWCS cap could be incorporated to improve the integrity of the cap. Cap enhancements could include increasing the clay layer thickness of the cap or adding a geomembrane directly above the clay layer to provide an additional barrier against rainwater infiltration through the waste. Other enhancements could include adding a rock layer to restrict inadvertent intrusion through the cap and to act as root penetration and burrowing animal restrictions.

Multi-layer cap enhancements are retained for further consideration as a viable technology process option for the containment GRA for Subunits A, B, and C.

3.4.2.2 Vertical Barriers

Vertical barriers are used to separate the contamination source from any surrounding groundwater or surface water sources. Most vertical barriers are intended to prevent contaminant transport by reducing or eliminating potential contact with water; however, some vertical barriers are designed to allow water to flow through them while using reaction potential to mitigate contaminant migration. The existing design of the IWCS is intended to minimize potential contact with water and includes sidewalls consisting of a compacted clay dike and cut-off wall constructed around the waste containment area that form the perimeter of the containment system. Several other vertical barriers are considered as part of potential enhancements to the existing IWCS containment system. Six potentially applicable technologies are discussed below.

3.4.2.2.1 Trench Walls

A number of different materials can be used to create a wall in a trench that will inhibit or prevent groundwater movement or retard transport. These materials include clay, various slurries, and synthetic and reactive materials. Trenches are excavated using mechanical earthmoving equipment and are later backfilled. A trench designed for a slurry wall can be lined with a geosynthetic liner, such as high-density polyethylene, before the slurry is put into place. The addition of the liner increases the impermeability and chemical resistance of the barrier wall. When clay is used for the low-permeability wall, the trench is backfilled with clay of optimal compaction and moisture content. When reactive materials are used, the wall is designed to allow groundwater to pass through the barrier.

Most slurry walls are constructed of a soil, bentonite, and water mixture. The bentonite slurry is used primarily for wall stabilization during trench excavation. A soil-bentonite backfill mixture is then added to the trench, displacing the bentonite slurry, to create a cut-off wall. This type of barrier wall construction is low cost with low permeability and is chemically resistant. If greater structural strength is necessary or chemical incompatibilities exist between site contaminants and bentonite, other wall compositions, such as cement/bentonite, pozzolan/bentonite, attapulgite, organically modified bentonite, or slurry/geomembrane composite, may be used. When a strong wall is required, diaphragm walls can be constructed with cast-in-place or pre-cast concrete panels.

Trench walls could be installed to provide an additional barrier surrounding the structures containing the residues (Subunit A wastes) or for providing redundant control for the existing vertical barriers surrounding the IWCS; however, the 2007 Groundwater Flow and Contaminant Transport Modeling report indicated that groundwater contamination is not migrating (laterally) (USACE 2007b). Therefore, additional barriers would provide no benefit over the existing containment already in place and the use of trench walls is not retained for consideration as part of the containment GRA (containment enhancements) for Subunits A, B, and C. Trench walls would be considered viable as a component of any new on-site disposal facility at the NFSS.

3.4.2.2.2 Grout Curtains

A grout curtain is a narrow vertical wall of grout installed into the ground that forms a hard barrier to inhibit or prevent horizontal migration of groundwater. Grout curtains are installed by either jetting or pressure-injecting grout into the soil around the contaminated media. They can be installed downgradient of the contamination zone to retard contaminant migration or upgradient to prevent clean groundwater from migrating through the contamination and are typically installed at shallow depths of no more than about 12 m (40 ft).

Jet-grouted walls are constructed by injecting columns of a grout mixture into the ground at high pressure at closely spaced intervals such that each “pillar” of injected grout intersects the next as it cuts and mixes with the soil, thereby forming an impermeable barrier wall. Most grout material consists of cement, clay, bentonite, or chemicals such as silicates. However, these grouts are not recommended for containing higher levels of radioactively contaminated media as they are not durable and may crack over time. Polymer grouts are used for applications where radioactive contamination exists because they are impermeable to gases and liquids and resist degradation due to radiation. The subsurface contamination outside the IWCS typically contains low levels of radioactive compounds, thus degradation due to radiation is not a major concern.

Pressure grouting, also called permeation grouting, is a process by which a viscous liquid is permeated through boreholes into the soil pores using low pressure. With time, the liquid gels to form a barrier to subsurface water flow. Substances that can be used include particulate cement grouts and chemical grouts like colloidal silica and urethane.

Use of grout curtains is not retained for further consideration as a viable technology process option for containment enhancements around structures containing residues in the IWCS. Although technically implementable, the use of grout curtains for horizontal control would have no benefit over the existing cut-off and dike walls currently in place for containment in the IWCS. Grout curtains also would be less practical than other engineered barrier options available for construction of cells for on-site disposal.

3.4.2.2.3 Sheet Piling

A series of overlapping sheets of an impermeable material such as metal, pre-cast concrete, or vinyl would be driven into the subsurface to block subsurface flow. The joints between sheets can be sealed to prevent seepage.

Use of sheet piling is not retained for further consideration as a viable technology process option for containment enhancements around structures containing residues in the IWCS. Although technically implementable, the use of sheet piling for horizontal control would have no benefit over the existing cut-off and dike walls currently in place for containment in the IWCS. A sheet pile also would be less practical than other engineered barrier options available for construction of cells for on-site disposal.

3.4.2.2.4 Vitrified Barrier Walls

The vitrification process of melting soil at high temperatures can be applied in situ to form glass-like barrier walls around the area of contamination to prevent migration. Benefits of the process include superior barrier wall strength (5 to 10 times that of concrete), long-term durability, and being unaffected by wet/dry or freeze/thaw cycles. In-situ vitrification may be applied to fully saturated media because the thermal gradient in front of the advancing melt simply dries out the media before melting it. However, water can be a limitation if site conditions allow recharge to the treatment zone at a rate faster than the drying and melting rate. Water removal consumes about the same amount of energy as melting soil. Due to the shallow depth to groundwater at the NFSS, this technology is expected to consume large amounts of energy. An additional disadvantage of the technology is that multiple melts may be required to achieve the depth required to limit lateral migration of groundwater.

Use of vitrified barrier walls is not retained for further consideration as a viable technology process option for containment enhancements around structures containing residues in the IWCS. Although technically implementable, the use of vitrified barrier walls for horizontal control would have no benefit over the existing cut-off and dike walls currently in place for containment in the IWCS. Vitrified barrier walls also would be less practical than other engineered barrier options available for construction of cells for on-site disposal.

3.4.2.2.5 Cryogenic Barrier

In this option, a barrier of ice is created by freezing soil around the contaminated area. Two rows of freeze pipes are installed in an array around and beneath the contaminated area using standard drilling methods. The first row of freeze pipes is installed around the contaminated zone and at angles to extend below the contaminated zone. The second row of freeze pipes is installed at a carefully placed distance away from the first row of pipes to ensure a complete frozen barrier formation. The array of pipes is then connected to a refrigeration plant by way of manifold to create a closed system carrying coolant that freezes the inner volume of soil/groundwater between the two rows of pipes. The frozen soil acts to prevent groundwater migration into or out of the confined waste and, therefore, contain the soluble radionuclides. The coolant used in this process is environmentally safe and typically consists of benign brines such as salt water, propylene glycol, or calcium chloride. The optimum soil moisture content is roughly 14 to 18%, and injection pipes can be installed within the barrier to achieve proper moisture content. Cryogenic barriers can be used to a maximum depth of 305 m (1,000 ft) with barrier thickness ranging from 4.6 to 15 m (15 to 50 ft) thick. The temperature required to achieve a cryogenic barrier varies with site conditions, and heat generated from high-level radioactive waste can increase the electrical power needed to sustain the system. Cryogenic barriers can be designed to decrease both horizontal and vertical subsurface flow. This technology would require long-term maintenance and continued energy input for chiller operation.

Use of cryogenic barriers is not retained for further consideration as a viable technology process option for containment enhancements around structures containing residues in the IWCS. Although technically implementable, the use of cryogenic barriers for horizontal control would have no benefit over the existing cut-off and dike walls currently in place for containment in the IWCS. Cryogenic barriers also would be less practical than other engineered barrier options available for construction of cells for on-site disposal.

3.4.2.2.6 Permeable Reactive Barrier

A permeable reactive barrier (PRB) is a variation of the trench technology discussed above but, in this process, the trenches are filled with a permeable material designed to treat groundwater contaminants flowing horizontally through the PRB. A variation of a PRB could include pneumatically fracturing the soil in the vicinity of the filled trench and injecting dissolved or nano-scale particles as a slurry into the fractured material to improve the treatment efficiency of the PRB. As water flows through the trench, contaminants are chemically altered, attenuated, or physically bound as a result of chemical reactions that take place within the PRB. These mechanically simple systems can be installed as permanent, semi-permanent, or replaceable units. The permeable trenches may contain metal-based catalysts for degrading organics; chelators for immobilizing metals; and nutrients, oxygen, or other agents used to enhance bioremediation. Potential configurations include funnel and gate systems, continuous wall systems, injection well configurations, or passive collection with reactor cells.

Several options for a reactive material used to treat uranium include fly ash, hydrated lime, barium chloride, iron oxide, ferric oxyhydroxide, bone-char phosphate, peat and lignite, and nano-scale zero valent iron. These same reactive materials also will treat or bind metals such as chromium, lead, radium, and selenium.

Organic compounds, including tetrachloroethene, trichloroethene, dichloroethene isomers, and vinyl chloride, have been successfully treated with PRB technology. For chlorinated solvent applications, the PRB should be keyed into an underlying, low-permeability barrier to avoid the potential for underflow of contaminants. Groundwater velocity and flow gradient are major considerations in determining the applicability of PRBs; as groundwater velocity increases, reactive cell thickness increases to achieve the necessary residence times, which increases costs. In addition, groundwater modeling is recommended to aide with PRB design. If the groundwater velocity is too high, the major component of flow is vertical and not perpendicular to the PRB, or the depth to a low-permeability layer to allow the trench to be keyed is too great.

Use of PRBs is not retained for further consideration as a viable technology process option for containment enhancements around structures containing residues in the IWCS or around other wastes within the IWCS. Because of the existence of a clay cut-off dike surrounding the IWCS and primarily vertical (not horizontal) flow within the IWCS, PRBs will provide little benefit. Soil and groundwater data evaluated for the RI indicate that the IWCS is performing as designed. Unlike the existing containment system, a PRB would result in additional costs, would require periodic media replacement, and would be less practical than other engineered barrier options available.

3.4.2.3 Horizontal Barriers

Horizontal barriers are used to separate the contamination source from the groundwater below. Horizontal barriers are intended to prevent percolation of groundwater to the water table or to prevent the water table from rising into contact with the contaminants. Retrofitting the IWCS with a continuous bottom barrier of engineered consistency and verifiable permeability is attractive in theory but difficult to implement due to the size of the IWCS and the current state of technology. Three potentially applicable technologies are discussed below; however, none has been implemented on the scale required for the IWCS.

3.4.2.3.1 EarthSaw Block Displacement

The EarthSaw Block method was developed to create a horizontal barrier to serve as a confining layer beneath buried waste in situ. A trench is installed to beyond contamination depth around the contaminated area and backfilled with a bentonite slurry for stability. A cutting cable is laid in the trench, and pulling units begin to pull the cable underneath the block of waste inside the trench. As the cable is being pulled, a specially formulated, high-density grout is poured into the trenches. The grout displaces the slurry and flows behind the cutting cable underneath the soil block. After the bottom cut is complete, the soil block "floats" on top of the dense grout, which continues to be added until the desired grout barrier thickness is reached. Several different types of grout material can be used to form the horizontal barrier: hard, rigid grout; molten, pliable, wax-like grout; or non-hardening clay-based grout. The clay-based grout sets to be similar to a natural clay layer and offers the advantage of resistance to cracking. EarthSaw Block displacement has not been tested or applied at the scale required for the IWCS and is, therefore, not retained as a containment technology for vertical control at the IWCS.

3.4.2.3.2 Horizontal Excavation Method

A horizontal slot is excavated beneath in-situ waste using specialized cast-in-place barrier placement machines and conventional trenching equipment. As excavation proceeds, a cementitious grout material is injected into the space created by removing the soil. The soil is excavated by mini-discs and used to backfill the trench after the grout has been injected. A grid of fiber optic sensors and sensor tubes can be installed with the grout for LTM. The option also exists to insert pre-cast blocks and a geopolymer liner underneath the waste. A disadvantage of this technology is that the mini-discs are less effective in wet soil and it is difficult to move soil saturated with water. Additionally, this technology has been employed mostly on trenches measuring 6 m (20 ft) wide by 9 m (30 ft) deep by 305 m (1,000 ft) long. Designs to accommodate trenches 30.5 m (100 ft) wide exist but not for the 122 m (400 ft) needed for the IWCS. Horizontal excavation has not been tested or applied at the scale required for the IWCS and is, therefore, not retained as a containment technology for vertical control at the IWCS.

3.4.2.3.3 Grouting and Permeable Reactive Barrier by Horizontal Directional Drilling

A horizontal or trough-shaped grout (or reactive) barrier is installed underneath waste through the use of directionally drilled boreholes. The borings are made by drilling equipment that can be steered through the soil. Grout (or reactive material) is injected into the subsurface using high pressure and speed, mixing the grout (or reactive material) with the soil to form a relatively homogenous mass. Systems can be designed to mix the soil with a grout (or reactive material) or nearly replace it. Two types of grout can be layered on one another: a cement grout and a high molecular weight polymer grout. Alternatively, a PRB layer may be installed in conjunction with a grout layer(s). Technically, implementation depth is unlimited. The application of a horizontal PRB in an area the size of the IWCS would generate a large amount of spoils that likely would require management (processing or treatment due to potential radiological contamination and saturation with groundwater) and disposal. The application of a horizontal PRB in an area the size of Building 411 would have similar disposal requirements for spoils as treating the IWCS but on a much smaller scale. Implementation would require placement of several side-by-side rows beneath the IWCS that could potentially have gaps between them that would allow groundwater to pass. The potential for misalignment with directional drilling at the depths and angles required for the IWCS exists. This uncertainty could compound problems with gaps between the overlapping grouted boreholes.

Horizontal directional drilling is not appropriate for a project sized as large as the IWCS and is, therefore, not retained as a containment technology for vertical control at the IWCS.

Use of horizontal barriers is not retained for further consideration as a viable technology process option for the containment GRA for vertical control at the IWCS. Although some of the horizontal barrier technologies are potentially implementable on a small scale for containment enhancements, none would be more effective than the existing vertical control provided by the existing natural clay barriers already present beneath the IWCS.

3.4.3 Removal

Various types of removal actions are available. This section describes these methods and identifies those that are technically implementable for the removal of contaminated media from the IWCS. Manual removal actions using small, handheld tools would not be applicable by itself due to the relatively large size of the IWCS; however, all other removal actions would have manual components applicable to the small quantity detail work not suited for mechanized methods. Manual actions will be limited to maintain worker exposure levels that are as low as reasonably achievable.

As presented in the Radon Technical Memorandum (USACE 2012a), removal actions involving the residues and wastes contained within Building 411 (i.e., Subunit A) would require radon control measures as part of the removal and handling of these residues and wastes. The Health Effects Technical Memorandum (USACE 2012b) estimated the radiological dose and risk for exposures to radon-222 in the IWCS residues during removal. The results indicated that stringent engineering controls will be needed to minimize exposures to workers and other on-site individuals at the NFSS if the remedy selected for the IWCS OU involves excavating the K-65 residues and other residues. Therefore, evaluation of the specific removal technologies takes into consideration the need for a radon control system (RCS) during the removal of Subunit A residues. The RCS may require the construction of a containment structure over the work area and associated air handling systems.

3.4.3.1 Mechanical Removal

Mechanical removal actions include the use of equipment to excavate contaminated media from its current location and place it for subsequent transport to another location. This section describes several types of equipment and their implementability for removal actions for the IWCS, including the demolition of concrete building structures. Generally, mechanical removal actions include very efficient means for moving bulk media; however, an increase in efficiency typically equates to an increase in dust and airborne COCs. Dust mitigation must be considered as various mechanical removal actions are ultimately screened.

It must be noted that mechanical methods that may be appropriate for removal of residues and construction debris from Buildings 411, 413, and 414 are only appropriate for removal of unconsolidated and appropriately sized bulk waste; other methods (e.g., downsizing of concrete columns and joists and washing and pumping remaining residues) would be required to effect complete removal of the building contents.

3.4.3.1.1 Conventional Earthmoving Equipment (Excavator/Loader/Bulldozer)

Conventional earthmoving equipment includes bulldozers, scrapers, excavators, loaders, and backhoes. This equipment is readily available. With the exception of scrapers, earthmoving equipment is generally applicable to any contaminated soil and small debris media removal actions that would be conducted for the IWCS outside of Buildings 411, 413, and 414 (Subunits B or C). Scrapers are not suited for removal of construction debris that is mixed with other contaminated media. While scrapers could be used to remove portions of the IWCS cover and the native soil below the contaminated media, a combination of bulldozer and excavator/loader would work well on this relatively small area.

Excavators are significantly more effective than loaders in removing compacted material. Because a removal action would be conducted over many days, the cap should remain in place until the waste below it can be quickly transferred. Therefore, bulldozers and loaders are removed from further consideration as primary technologies. Rubber-tire backhoes may ultimately be used as a small component of a removal action; however, larger track-mounted excavators would be used to perform the bulk of the excavation work. Grapple attachments also can be readily fixed to excavators to pick up construction waste for placement and subsequent transport. Removal of bulk residues and construction waste within Buildings 411, 413, and 414 (Subunit A) by excavators is technically implementable.

3.4.3.1.2 Overhead Removal Equipment (Crane and Clamshell)

Overhead removal equipment, specifically a crane and clamshell bucket, consists of opposable scoops clamping together via cables to scoop bulk media. This equipment was used, along with a front-end loader, to transfer L-30 and F-32 residues between the Building 411 bays during the IWCS construction. Therefore, this method has proven its ability to remove bulk L-30 and F-32 residues present in the IWCS. A dredging clamshell may be more effective in residue removal than the conventional clamshell used during construction (USACE 2003). This method also would be applicable for removing debris such as the 20-ft sections of steel pipe and other debris associated with historic K-65 slurry transfer activities. It can be used for excavating other bulk contaminated media outside the buildings. Removal of bulk residues and construction waste within Buildings 411, 413, and 414 (Subunit A) by overhead removal equipment is technically implementable.

3.4.3.1.3 Conveyor System (Excavation Buckets and Belt)

Various types of conveyor systems could be used to excavate and/or transfer contaminated media from portions of the site outside the buildings to a loading point. Due to the relatively small size of the site, systems such as bucket-wheel excavators and associated conveyors would not be applicable and are, therefore, not retained for further consideration. However, conveyor systems may be incorporated into on-site contaminated media handling or size-reduction measures (e.g., concrete crushing) that may be needed.

3.4.3.1.4 Dragline System

Dragline systems are similar to crane and clamshell systems in that a bucket is manipulated with a boom and cables; however, the media are scooped into the bucket by dragging it towards the equipment. This equipment could be used to excavate bulk contaminated media, except some debris such as large rubble and long pipe, from the site. As with the crane and clamshell method, additional equipment would be needed to remove smaller quantities from discrete portions of the IWCS. Removal of bulk residues and construction waste within Buildings 411, 413, and 414 (Subunit A) by a dragline system is technically implementable.

3.4.3.1.5 Remotely Operated Equipment

Remote-controlled machines with qualified operators offer a range of tooling for breaking, reducing, and handling, as well as disposing of, material and are capable of remote operation in confined environments that require limiting personal exposures such as during the removal of the residues from Buildings 411, 413, and 414 (Subunit A). Electrically powered radio-controlled machines, such as a Brokke (or similar), have operating weights from 500 kg to 2 tons and have conventional attachments including hydraulic breakers, jaws, digging buckets, and metal shears. These machines can travel up and down staircases, do not require exhaust ventilation, and are quieter and more powerful than most diesel machines. Removal of the bulk residues and waste within Buildings 411, 413, and 414 by remotely operated equipment is technically implementable.

3.4.3.1.6 Auger Mining

This is a mining method that utilizes an appropriately sized auger machine, which functions much like a carpenter's wood drill. The auger would bore into the residues or wastes and discharge product out of the spiral onto a waiting conveyor belt. This method of mining is usually employed to recover remotely handled products left in areas that cannot be reached safely by other types of retrieval. Removal of bulk residues within Buildings 411, 413, and 414 (Subunit A) by auger mining is technically implementable. Removal of construction waste and debris would require other mechanical methods, such as remotely operated equipment.

3.4.3.2 Hydraulic and Pneumatic Removal

Hydraulic and pneumatic removal actions include the use of liquid or air and pumps or vacuums to remove contaminated particulate and liquid media from its current location and transfer it to another location. This section describes several types of methods and their applicability to removal actions for the IWCS. Generally, hydraulic and pneumatic removal actions work well to mitigate dust and airborne COCs; however, the introduction of liquid and air results in the need for these introduced media to be managed and treated. The management and treatment aspects must be considered as these removal actions are ultimately screened. Due to the additional management and treatment requirements and lower contaminant concentrations outside the buildings, these methods will only be considered for the removal of the residues from Buildings 411, 413, and 414 (Subunit A). These methods are not applicable for the removal of structures or construction waste (e.g., liner or pipe).

3.4.3.2.1 Hydraulic Removal

Hydraulic removal includes the use of high-pressure water to physically break down the bulk residues, typically with water jets creating a slurry that can be pumped and sluiced in pipes to another location for subsequent handling. This method was proven effective in the removal of the K-65 residues at the Fernald Site and the transfer of the K-65 residues from the storage silos (Building 434) at the NFSS. Removal of bulk residues within Buildings 411, 413, and 414 (Subunit A) by hydraulic removal is technically implementable; hydraulic removal is not appropriate for other wastes present in the IWCS.

3.4.3.2.2 Pneumatic Dredging

Pneumatic dredging can be used to remove some contaminated media. Pneumatic dredgers are based on the evacuator principle. A chamber with inlets for media is pumped out with the inlets closed. The inlets are then opened and media are drawn in. The mixture is then pumped out and the cycle repeated. The equipment would be suspended from a crane. The dredging action is intermittent and suitable only for easily flowing material; therefore, this method is not retained for use in removing waste from Subunits A, B, and C.

3.4.3.2.3 Vacuum (with Cutterhead)

Vacuum systems can be used to suck media from its current location and transfer it to another location for subsequent handling. This pneumatic method has limited production rates and effectiveness when used to remove media that are consolidated and have any potential for interference from moisture content, as is the case with residues in the IWCS. This process option is more amenable to dry material (DOE 1994). This system was not implemented for the retrieval of Fernald Silos 1 and 2 materials due to the reduced effectiveness on materials with elevated moisture content (DOE 1994). The residues and other materials in the IWCS are not considered to be dry materials for the purpose of rating pneumatic removal options; therefore, this method is not retained for use in removing waste from Subunits A, B, and C.

3.4.3.2.4 Airlift Dredging

The airlift dredging removal action includes the use of compressed air injected at the mouth of a suction pipe to lift media from its current location such that it can be transferred to another location for subsequent handling. This method is not applicable for removal of residues in their current state; residues would need to be heavily saturated in situ before this method could be employed. The residues and other materials in the IWCS are not considered to be wet enough for the purpose of rating airlift dredge removal options; therefore, this method is not retained for use in removing waste from Subunits A, B, and C.

3.4.3.3 Demolition

Demolition techniques would apply to the contaminated building structures and contaminated rubble/debris in the IWCS. The structures of Buildings 411, 413, and 414 in Subunit B and contaminated rubble/debris within Subunits A and B could be remediated by demolition subsequent to residue removal and transferred for handling and disposal. Because of the potential classification of the materials in contact with the K-65 residues and other residues in Subunit A as 11e.(2) byproduct material for disposal purposes, the structures are assumed to not be decontaminated to free release levels prior to disposal or such that they could be left in place without LUCs. At the Fernald Site, the concrete silos that were used to store the K-65 residues, once emptied, were found to be contaminated with fixed or residual loose contaminants even after multiple flushing events. It is assumed that the residues stored within the IWCS are in contact with the concrete walls and supports of Buildings 411, 413, and 414 and, therefore, also would be contaminated with fixed or residual loose contaminants.

Prior to demolition, structure interiors could be pressure-washed as a surface treatment (see Section 3.4.4.1.5). Additionally, based on the Waste Disposal Options/Fernald Lessons Learned Technical Memorandum (USACE 2011c), surface barriers (e.g., grout) could be applied to the interior of the structures to fix any residual contamination to the concrete prior to demolition (see Section 3.4.4.1.6).

The building structures consist of reinforced concrete walls and foundations. Demolition in this case would generally include the downsizing of concrete structures to rubble such that it can be loaded into appropriate containers. Any concrete demolition methods would require cutting of the reinforcing rebar into manageable lengths and use of the mechanical removal methods listed in Section 3.4.3.1 to transfer resultant media to containers. Depending on waste container requirements, additional downsizing of concrete may be required via crushers. Crushing would require complete separation of rebar and concrete. Removal of building structures and contaminated rubble/debris for Subunits A and B by demolition is technically implementable, provided it is supported with other means for mechanical removal. Demolition is not appropriate for other waste materials within the IWCS.

3.4.3.3.1 Controlled Blasting

Concrete structures could be demolished by controlled blasting. While this method is generally effective in structure demolition actions, it would not be applicable to any demolition that would be required within a radon containment structure. In addition, the relatively low design strength of the concrete (i.e., 211 kg-force/cm^2 [3,000 psi] and less) and its age suggest that the structures could be mechanically demolished with relative ease. Any blasting operations also introduce additional safety considerations for explosives transportation and handling and increased worker exposure as explosives are set. Therefore, this method is not retained for Subunits A, B, or C.

3.4.3.3.2 Concrete Cutting

Concrete cutting is an effective method for precisely sizing concrete into sections for removal. Appropriately sized concrete could effectively be handled using mechanical equipment and would allow for efficient waste packaging (limited void space). Removal of building structures and contaminated debris in Subunits A and B by concrete cutting is technically implementable, provided it is supported with other means for mechanical removal.

3.4.3.3.3 Mechanical Demolition

Mechanical demolition includes the use of wrecking balls and hydraulic breaker attachments that can be used with most mechanical removal equipment mentioned above. Any combination of these methods could be used to initially downsize the material as needed in its current location for subsequent transfer to containers or crushers for additional downsizing. Mechanical removal methods with bucket and/or grapple attachments would be used to transfer the concrete and rebar waste. Removal of building structures and contaminated debris in Subunits A and B by mechanical demolition is technically implementable, provided it is supported with other means for mechanical removal.

3.4.4 Treatment

Technologies and process options will be evaluated according to their ability to treat the residues and other wastes comprising Subunit A. The waste/matrix types include the K-65 residues and other residues (including F-32, L-30, and L-50), soil (including Tower Soils), and contaminated rubble/debris. Additionally, surface treatment of the building structures (Buildings 411, 413, and 414) comprising Subunit B also is evaluated. The general assumption will be that the COCs will be used as the basis for evaluating technologies and process options.

For the Subunit A residues and commingled debris, physical treatment processes involve either physically binding the contaminants to reduce their mobility or the potential for exposure (e.g., solidification/ stabilization [S/S], polymer encapsulation, or vitrification), separating the contaminants from the wastes to reduce contaminated soil volumes (e.g., soil washing and flotation), or reducing the volume of contaminated waste (e.g., transmutation). Chemical treatment processes add chemicals (in situ or ex situ) to react with contaminants to reduce their toxicity or mobility (e.g., chemical extraction/recovery or hydrolysis). Extraction/resource recovery would be an ex-situ chemical treatment that involves extracting metals (e.g., radium) from the residues for other beneficial uses. Biological treatment involves using microbes or vegetation to degrade or concentrate contaminants (e.g., phytoremediation, composting, or bioslurry). Thermal treatment, such as incineration, uses high temperatures to volatilize, decompose, or melt certain contaminants. Decontamination is a treatment technology for removing or reducing radiological contaminants that have become adhered to the structural surfaces of buildings, equipment, tools, etc.

This technical memorandum evaluates the available physical, chemical, thermal, and biological treatment technologies and associated process options designed to reduce the toxicity, volume, and mobility of COCs and collocated hazardous substances. Treatment technologies and process options will be eliminated if they are determined to not be technically implementable for the IWCS.

For the purposes of evaluating treatment technologies and process options, 10% of the soil is assumed to be mixed wastes. The residues in the IWCS are statutorily excluded from the definition of solid and hazardous waste under RCRA per 40 *CFR* 261.4(a)(4) due to their status as 11e.(2) byproduct material.

Therefore, as long as they meet the WAC for the off-site disposal facility, they should be eligible for disposal as 11e.(2) byproduct material, not LLMW, and should not require treatment for other hazardous substances. Therefore, the potential for the treatment of other hazardous substances prior to disposal is considered to be minimal. Any non-residue waste that is considered to be a mixed waste will be shipped off-site for treatment and disposal as a component of any removal action.

An unknown quantity of perched groundwater may be encountered and be contaminated during potential remedial action. For the purposes of this technical memorandum, during any remedial actions, all perched groundwater is assumed to be handled in a manner consistent with any other residual wastewater produced from remedial activities and will not require evaluation of treatment processes as part of the FS.

The following subsections describe the treatment technologies and process options considered for the IWCS and whether or not they are retained for further evaluation in Section 4.0 based on technical implementability. The results of the screening process also are shown on Figure 3-1. Both in- and ex-situ treatment technologies and process options are being considered. This preliminary screening evaluates the ex-situ application of each technology/process option first, followed by the in-situ application.

3.4.4.1 Physical Processes

This section presents and evaluates in- and ex-situ process options used to physically bind the contaminants or extract them from the medium. All process options under the physical treatment technology are being considered for residues, Tower Soils, and contaminated soil in Subunit A. Physical treatment processes applicable to building surfaces and contaminated rubble/debris include decontamination methods.

3.4.4.1.1 Conventional Solidification/Stabilization

Conventional solidification/stabilization (S/S), also referred to as cement S/S, typically involves the addition of cement or a cement-based mixture, which limits the solubility or mobility of the contaminants. Physical treatment by stabilization changes the chemical properties of the treated material through chemical reactions. Solidification incorporates the contaminants into a solid matrix of high structural integrity. The goals of the S/S process are to limit the spread of radioactive material via leaching and to trap and contain radon within a densified soil mass. This process does not remove or inactivate contaminants but eliminates or reduces contaminant mobility.

The types of S/S agents available include Portland cement; gypsum; modified sulfur cement, consisting of elemental sulfur and hydrocarbon polymers; and grout, consisting of cement and other dry materials such as fly ash or blast furnace slag. Cement solidification immobilizes contaminants by trapping them in an impervious matrix of grout/cement. Solidification can be achieved using other chemical agents that include thermoplastic polymers (asphalt bitumen, paraffin, and polyethylene), thermosetting polymers (vinyl ester monomers, urea formaldehyde, and epoxy polymers), and other proprietary additives (EPA 1996a). Chemical grouts can be used as S/S agents; however, little information is available on this process. The resulting matrix has been shown to have low leachability for some radionuclides.

Conventional S/S can be accomplished in situ, either by injecting a cement-based agent into the contaminated materials or by introducing the agent into the soil or waste materials using large-diameter augers to create overlapping columns of mixed solidifier and soil/waste. Sufficient mixing must occur between the waste and the stabilization agent soil for solidification to be effective. Therefore, extensive treatability testing is required prior to the in-situ application of conventional S/S to determine the optimum mix of waste matrix and binding agent. Following application of the in-situ approach for conventional S/S, all waste will remain at the site (EPA 1996a). On-site burial of the solidified mass also may require a soil cover sufficiently thick to absorb gamma radiation.

The technical implementability of in-situ conventional S/S is considered to be low. Although the necessary amendments can be added to the K-65 residues, other residues, and Tower Soils, in-situ S/S would not be effective due to the presence of debris (i.e., concrete columns, drainage wicks from the residue dewatering system, and the Building 434 pond liner) in Buildings 411, 413, and 414 that would interfere with mixing equipment. The in-situ addition and/or mixing of amendments also would not be effective in Building 411 due to the compaction methods used to place the residues in Building 411 and the low porosity of the residues. In-situ solidification is better suited to highly porous, coarse-grained soil rather than the tight clay soil found outside of the IWCS. Therefore, in-situ conventional S/S is not retained for further evaluation.

Ex-situ treatment is accomplished by excavating the waste materials and machine-mixing the agent with the waste, and then placing the treated material in containers (i.e., for off-site disposal) or burying it on-site. Ex-situ treatment has several advantages over in-situ treatment. First, it provides for greater control over the mixing process for achieving homogeneity, thus resulting in greater reliability and effectiveness. Second, wastes can be separated or consolidated, as necessary, prior to treatment, which increases the cost effectiveness of most ex-situ treatment processes over in-situ applications. Third, ex-situ treatment allows for off-site disposal of the treated waste, if desired. Finally, the treatment technology is more advanced for ex-situ operations than for in situ, and more binding or treatment agents are available for ex-situ operations. Generally, waste transportation and disposal volume is increased as a result of conventional S/S. Ex-situ conventional S/S was successfully implemented for large-scale use on the K-65 residues at the Fernald Site and is, therefore, considered to be technically implementable for the IWCS. Ex-situ conventional S/S is being retained for further evaluation.

3.4.4.1.2 Encapsulation

Encapsulation is another type of S/S treatment that involves the addition of chemical reagents to waste materials to limit the waste solubility and mobility. Two approaches to encapsulation are considered for the Subunit A residues, contaminated soil and the Tower Soils: (1) microencapsulation, which involves the addition and mixing of chemical and polymer additives (e.g., polyethylene or polysiloxane) into and around the waste matrix; and (2) macroencapsulation, which involves application of polymer material (e.g., NuCap™) to the exterior of the waste (e.g., by spraying or solid sheeting), thereby forming a barrier around the waste.

Encapsulation limits the spread of radioactive material via leaching and traps and contains radon within a dense soil mass. Rather than inactivate contaminants, this process eliminates or reduces the contaminants' ability to migrate. Similar to conventional S/S, encapsulation is accomplished either in situ, by injecting or spraying the agent into contaminated materials, or ex situ, by excavating and machine-mixing the materials with the encapsulation agent and then placing the solidified soil in containers (i.e., for off-site disposal) or burying it on-site. Following application of the in-situ approach for polymer encapsulation, all waste will remain at the site (EPA 1996a).

Encapsulation can be achieved using a product known as NuCap™ (formerly known as EKOR™). This product is marketed for use in containment and encapsulation, stabilization, and as a shielding agent and has the potential of being a substitute for conventional S/S materials, with an added potential of being used as a spray or preformed sheet application for increasing radiological shielding. NuCap™ is a silicone block copolymer exhibiting high resistance to radiation and showing little degradation due to chemical exposure or aging. It has very low permeability, no measurable leachability, and contains no toxic components. NuCap™ has the potential to be used in a variety of ways, ranging from spray application to preformed sheets for radiological shielding. It can be used as a substitute for conventional S/S materials, such as cement and grout, and may offer much higher waste loadings than conventional S/S materials. The formerly trademarked product called EKOR™ was created by a team of nuclear scientists (I.V. Kurchatov Research Center in Russia and the EuroAsian Physical Society) to address the radioactive contamination from the 1986 accident of Reactor 4 at Chernobyl, Ukraine.

Encapsulation allows for higher waste loadings than conventional S/S techniques, provides greater shielding than conventional S/S, shows minimal degradation, exhibits very low permeability and leaching potential, and can be applied in both dry and slurry forms. Materials such as boron can be incorporated into the mixture to increase shielding. However, encapsulation requires specialized equipment, and full-scale use of the technology for treating radioactive waste is limited. Sufficient mixing must occur between the waste and stabilization agent soil for solidification to be effective. Therefore, extensive treatability testing is required prior to in- and ex-situ polymer encapsulation to determine the optimum conditions for application to the waste matrix.

Ex-situ polymer encapsulation is considered to be technically implementable; although, it requires higher temperatures and more specialized equipment than cement-based reactions. Particularly, encapsulation using the NuCap™ process (formerly EKOR™) has demonstrated the ability to encapsulate material with high-activity concentrations. These demonstrations include the following:

- Encapsulation or "cocooning" of the most critical radioactive fuel-containing masses resulting from the Chernobyl disaster. Coating the mass successfully prevented radioactive material from dusting or seeping into the environment.
- Encapsulation of wastes in both dry and slurry form.
- Encapsulation of radioactive debris at the Savannah River Site, a large DOE facility near Aiken, South Carolina.

Although there has been success in implementing ex-situ polymer encapsulation at the aforementioned DOE sites, it has not been implemented for use on wastes similar to residues contained in the IWCS. Therefore, the potential use of polymer encapsulation will require a robust treatability program to ensure the contaminants will not leach. Polymer encapsulation also may be used in conjunction with conventional S/S treatment and, therefore, ex-situ polymer encapsulation is retained for further evaluation as a potential component of conventional S/S treatment.

The technical implementability of in-situ polymer encapsulation, particularly microencapsulation, is considered to be low. Although the necessary amendments can be added to the K-65 residues, other residues, and the contaminated soil and Tower Soils, in-situ S/S would not be effective due to the presence of debris (i.e., concrete columns, drainage wicks from the residue dewatering system, and the Building 434 pond liner) in Buildings 411, 413, and 414 that would interfere with spraying and mixing equipment. The in-situ addition and/or mixing of amendments also would not be effective in Building 411 due to the compaction methods used to place the residues in Building 411 and the low porosity of the residues. Therefore, in-situ encapsulation is not retained for further evaluation.

3.4.4.1.3 Vitrification

Vitrification involves heating contaminated media to extremely high temperatures to reach a melting point, then cooling them to form a solid mass. Upon cooling, a dense, glassified mass remains, thus trapping radioactive contaminants. The process can be applied to contaminated soil, sludge, sediment, mine tailings, buried waste, and metal combustibles. Different devices may be used, such as plasma torches or electric arc furnaces. Vitrification technologies may be particularly useful for treating extremely high-activity radioactive or mixed waste. An off-gas system may be required for emissions during vitrification because some organic contaminants will likely be destroyed and some inorganics, including low melting-point radionuclides, will volatilize due to the high temperatures involved.

Production-scale vitrification efforts within DOE have been restricted to a single technology, Joule-heated melters (DOE 1999). Experiences and lessons learned from the use and testing of Joule-heated melters have been well documented by DOE (1999) for the following projects:

- Fernald Vitrification Pilot Plant,
- Savannah River Site Vendor Treatment Facility,

- Oak Ridge Transportable Vitrification System,
- Savannah River Site Defense Waste Processing Facility, and
- West Valley Demonstration Project Vitrification Facility.

The vitrification process can be performed both in- and ex-situ, as discussed below. Treatability studies are needed to determine the optimum operational parameters and effectiveness for both in- and ex-situ vitrification technologies.

Overall, vitrification is a proven technology that transforms wastes into a solid, glass-like matrix that reduces the toxicity, mobility, and volume of the waste. However, two drawbacks of vitrification heating by electric resistance are the production of off-gases that must be treated to remove radioactive and chemical pollutants and the large electric energy and power requirements (DOE 1986b).

In-situ vitrification uses an electric current to create extremely high temperatures (approximately 1,600 to 2,000ºC [2,012 to 2,552°F]) to melt contaminated soil, dewatered sludge, and/or sediment into a glass-like matrix. The vitrified glass, which is similar to naturally occurring obsidian or basalt, is chemically stable and leach-resistant, immobilizes radionuclides and other contaminants within it, and volatilizes most organic contaminants by pyrolysis. In the process, electrodes are inserted into an area and electrical resistance heats the material to a molten state. Small quantities of organics, heavy metals, and/or radionuclide contaminants may be volatilized during the melting process and require treatment through an off-gas system. Additionally, the system requires an on-site electrical distribution system. No excavation is required, but soil parameters must be evaluated. Only near-surface contamination (i.e., within 5 to 7 m [16 to 23 ft] of the surface) can be treated. Construction of an off-gas collection and treatment system is required.

As cited by DOE (1986a), in-situ vitrification of the NFSS residues was considered in light of bench- and pilot-scale studies performed by Battelle and the Pacific Northwest Laboratory (Battelle-Northwest) on zirconia/lime sludge. Although success was achieved in producing a vitrified mass, the study recommended movement of the sludge into a configuration that optimized conditions for maintaining an electric current across the molten sludge, while allowing for continuous top-feeding of the sludge and soil (soil used to maintain the proper level of electrical resistance during sludge volume reduction). This reconfiguration results in a treatment that technically becomes more of an ex-situ treatment, as opposed to an in-situ treatment. This defeats the cited advantage of in-situ vitrification, which is the avoidance of residue handling. Additionally, the study did not address the problem of interference by rubble/debris in Buildings 411, 413, and 414. The in-situ vitrified mass remains in place and may require additional radiation barriers to protect the public and environment (EPA 1996a).

In-situ vitrification is considered to be of limited compatibility with IWCS site conditions due to the presence of rubble and debris in Buildings 411, 413, and 414 that would interfere with treatment. Additionally, the entire thickness of the contamination may not be treated without (1) cap removal to allow for proper vertical placement of the electrodes; and (2) reconfiguration of the residues and wastes, along with debris removal, that would allow for optimum operating conditions. Both of these activities would, consequently, defeat the cited advantage of in-situ vitrification, which is the avoidance of residue handling. In-situ vitrification is not considered to be technically implementable due to incompatible site conditions and, therefore, is not retained for further evaluation.

During ex-situ vitrification, the waste is melted into a glass-like solid. The ex-situ vitrification process involves blending glass-making constituents with the waste and feeding the mixture into a furnace at high temperatures (1,100 to 1,400°C [2,012 to 2,552°F]). The waste materials are melted with the molten glass and, upon cooling, a solid mass forms that traps the contaminants within the glass matrix. A pre-treatment step may be required to reduce the moisture content or reduce the size of the feed material. Small quantities of inorganics may be volatilized during the process, and afterburners may be used to convert partially burned organics in the exhaust to carbon dioxide. Because vitrification is applicable to many different types of wastes, the process is convenient if extensive characterization cannot be performed.

Ex-situ vitrification processes are proven industrial technologies and were tested for treatment of Fernald K-65 wastes; however, the equipment failed during testing. A number of recommendations resulted from the failures that have been documented by DOE (1999). Successful ex-situ vitrification has been carried out at the Savannah River Site to convert radioactive high-level waste sludges to solid borosilicate glass for safe long-term geological disposal (Bibler and Fellinger 2001).

Although most ex-situ work within DOE has been done using the Joule-heated melter, a newer, innovative technology, called the cold crucible induction melter (CCIM) is currently being studied by the Idaho National Laboratory and the French AEC in Marcoule, France (INL 2009). Principal project components of CCIM testing at the Idaho National Laboratory, which is being done for the Advanced Remediation Technologies Program, include the following (INL 2009):

- Laboratory-scale studies and testing performed by the Savannah River National Laboratory and French AEC to determine a suitable, high-waste-loading glass matrix.
- Pilot-scale demonstrations using existing CCIM test systems operated by French AEC in Marcoule, France, and by the Idaho National Laboratory to assess CCIM design and operation for treating Savannah River Site sludge wastes that are currently being treated in the Defense Waste Processing Facility.
- Engineering studies by SGN (Société Générale des Techniques Nouvelles, a subsidiary of AREVA) to validate the feasibility of retrofitting CCIM technology into the Defense Waste Processing Facility Melter Cell.
- Development of a comprehensive plan (including cost and schedule) for laboratory testing, pilot- and large-scale demonstrations, and engineering activities to be performed during subsequent project phases.

Testing has been completed on Hanford, Washington; Savannah River, South Carolina; and Marcoule, France, stimulants. The possible advantages being reported for the CCIM over the Joule-heated melter include increased waste loading (50% versus 34 to 38%), higher waste throughput and melt rate, possible extended melter service life, and higher tolerance of noble metals.

Ex-situ vitrification using the Joule-heated melter technology may be technically implementable on a large-scale basis for the K-65 residues, other residues, and Tower Soils in the IWCS; although, matrix parameters would need to be evaluated for these waste types. Therefore, ex-situ vitrification using the Joule-heated melter technology is retained for further evaluation. However, ex-situ vitrification via CCIM technology is a relatively new technology and is unproven on a large-scale basis; therefore, CCIM is not considered to be technically implementable for the IWCS and is not retained for further evaluation.

3.4.4.1.4 Separation/Volume Reduction

CERCLA, as amended, favors processes that reduce contaminant toxicity, mobility, and volume. Generally, radioactive contaminants are not destroyed (except as discussed below under transmutation). However, the volume of contaminated media may be reduced, usually resulting in higher contaminant concentrations in the reduced volume. Physical separation is an ex-situ mechanical process that separates contaminated media into clean and contaminated fractions, based on the media’s physical properties. Typically, in soil and sediment, radioactive contamination is associated with fine-grain particles, such as clay and silt. By separating the contaminated media from the clean media, the volume of waste requiring further remedial action can be reduced. Four types of physical separation/volume reduction options are being evaluated for the IWCS: transmutation, dry sorting/screening, flotation, and soil washing.

Transmutation

Transmutation, also called photodeactivation or photoremediation, is an innovative process option that essentially changes one element into another. This technology relies on processes such as neutron activation, induced fission, and activation using linear accelerators to convert radionuclides with long half-lives to products with much shorter half-lives. For example, the 1,600-year half-life of radium-226 is transformed into radium-225, which decays to stable bismuth-209 in less than 26 days. Researchers are investigating the use of linear accelerator systems to produce neutrons for transmutation of target materials. Other programs are developing technologies that use nuclear reactors to transmute the actinides in spent nuclear fuel.

To date, no pilot plant studies have been conducted to induce photoremediation (transmutation). The plant would need numerous pieces of equipment that are not normally thought of as remediation equipment. A linear accelerator accelerates positively or negatively charged particles that are directed onto a high Z target, such as tungsten, to generate very high energy gamma rays of at least 8 million electron volts (MeV) in energy. These gamma rays are directed onto the target material such as radium-226. In addition to the reactor, a system for introducing the material to be irradiated into the beam and for handling and storage afterwards is needed. A method of dissipating or using the waste heat from the accelerator also would be needed. Additional equipment to monitor the process would be necessary so that the feed rates are optimized for transmutation.

Another challenge to the transmutation technology is the required waste partitioning, that is, radioactive waste must be sorted before being recycled back into nuclear reactors for transmutation. For example, actinide (e.g., uranium, thorium, and plutonium) and lanthanide (rare earth) elements are chemically similar and, for this reason, are difficult to separate efficiently. Lanthanides tend to absorb neutrons relatively efficiently and will prevent efficient transmutation of actinides if they are intermixed. Thus, improved methods of separating lanthanides from actinides are needed to reach the goal of actinide transmutation (IAEA 2010).

The separation and transmutation of actinides is generally considered to be an innovative technology for remediation of radioactive waste and is in the development stage. For this reason, it does not offer a near-term solution for the large-scale treatment of the residues or contaminated soil in the IWCS. Another drawback of transmutation is that the nuclear reactions can transform short-lived radionuclides into long-lived radionuclides, thereby defeating the purpose of transmutation (Zerriffi 2000). Therefore, transmutation is not considered to be technically implementable for the IWCS residues or soil and is not retained for further evaluation.

Flotation

This ex-situ process separates contaminated soil particles (usually the fine soil particles such as silts and clays) from uncontaminated particles (large granular soil particles and gravel) to reduce the contaminated soil volume needing further remedial action. The flotation process works by first creating a slurry mixture of water and contaminated soil after having removed large granular and gravel fractions. Then, a chemical flotation agent is added to the slurry that adheres itself to the contaminated soil particles, which creates a water-repellent surface and allows the contaminated soil particles to float. During the process, air bubbles are formed by air injection or chemically within the slurry and adhere to the floating contaminated particles forming foam. The surficial foam containing the radioactively contaminated particles can then be skimmed off the top or collected into a container for further remedial action, thus leaving the clean soil available for dewatering and potentially replaced back into the excavation.

This process is not effective where high organic content exists and requires a particle size of between 0.1 and 0.001 millimeter (mm) (0.004 to 0.00004 in.) to be most effective. Larger particles must be removed or ground up to allow flotation to occur. Further, efficiency of the process is reduced as radium buildup occurs in the recycled wash fluid; therefore, the solution used in the flotation process must be treated.

Flotation is not considered to be technically implementable due to incompatibility with waste characteristics of the K-65 residues, other residues, or the contaminated soil and Tower Soils. All materials are presumed to be contaminated, regardless of particle size, which would render this process option as being ineffective. Therefore, this process option is not retained for further evaluation.

Soil Washing

Soil washing is a physical separation process whereby water washes fine clay and silt particles off larger soil particles with water. In this process, water (sometimes enhanced with a surfactant) is mixed with the contaminated media to produce a slurry feed that enters a scrubbing machine to remove contaminated fine-grain particles, such as clay and silt, resulting in a liquid/sludge. The liquid/sludge is separated based on particle size by filtration, screening, or ion exchange, leaving contaminated fine clay and silt, clean soil (generally sand and gravel), and process wash fluid, each of which must be analyzed and further treated. Soil washing is applicable to wastes contaminated with radionuclides such as uranium, radium, thorium, plutonium, and cesium; however, this technology is only effective if the process transfers the radionuclides to the process wash fluid or concentrates the radionuclides in a fraction of the original soil volume. Additionally, because radium is present in the residues as radium sulfate, which is highly insoluble in water, soil washing will not be effective in the removal of radium from the residues. Contaminated media should consist of less than 25% silt and clay and at least 50% sand and gravel, with optimal particle size between 0.25 and 2 mm [0.01 and 0.08 in.] to be most effective.

Factors that may impact the effectiveness of this technology are organic content, the level of radioactivity, and the cation exchange capacity of the contaminated media. Separating contaminants from the media particles may be very difficult if the cation exchange capacity of the contaminated media is too high; however, the use of surfactants and heated wash fluid may aid in increasing the metal removal efficiency. The process is best when applied to low-level radioactive contamination and to contaminated media with low organic content.

This technology is not considered to be technically implementable for the K-65 residues and other residues in the IWCS due to the very high activity and fine particle size. The soil at the NFSS has a high content of fine particle sizes. Therefore, this technology is eliminated from further evaluation. Soil washing can be enhanced by using electrodes to superheat the wash water with an electrical current. The heat causes steam bubbles to form on the clay and silt particles to induce more vigorous scrubbing. However, this enhancement does not add enough benefit or improve effectiveness enough to make the technology applicable to NFSS soil or residues.

3.4.4.1.5 Decontamination

Decontamination is a physical method for removing or reducing radiological contaminants that have become adhered to the structural surfaces of buildings, equipment, tools, etc. Decontamination has been demonstrated to be effective in removing radiological contaminants on some structural surfaces and is being evaluated as two main categories: surface decontamination and surface removal.

The following option is an example of a surface decontamination technology (EPA 2006a):

- **High-Pressure Steam and Water:** Water-soluble contaminants are removed from the surface of the debris by spraying with water and/or steam at sufficient temperature and pressure over a period of time.

The following options are examples of surface removal technologies (EPA 2006a):

- **Abrasive Blasting:** This process removes contaminants from debris with the force of water and/or air pressure used to propel solid media such as plastic beads, steel shot, aluminum oxide grit, or dry ice at the debris.

- **Scarification, Grinding, and Planing:** These methods use saws or rotating grinding wheels to strip contaminated surficial layers off debris.
- **Spalling:** Spalling drills holes at appropriate locations and depths into debris, and then a tool is used to exert pressure on the sides of those holes so that the contaminated surface layer is removed.
- **Vibratory Finishing:** Vibratory finishing is a process that uses scrubbing, flushing fluid, and oscillating energy to remove contaminants or the contaminated surface layer.

All of the above could be considered applicable to the interior structural surfaces of Buildings 411, 413, and 414 that are in direct contact with the K-65 residues, other residues, and Tower Soils, as well as to the exterior surfaces in contact with other contaminated wastes. Both surface removal and decontamination would be considered more effective if applied in conjunction with another GRA.

Based on efforts at the Fernald Site, decontamination of concrete to remove contamination is not easily performed due to the difficulty in removing embedded contamination. The decontamination efforts at the Silos 1 and 2 structures after removal of the K-65 residues and multiple internal flushing operations made demolition of the silos more difficult. The residual radium-226 concentration in the silo, either fixed in concrete or partially loose, were determined to be approximately 3 Ci in each silo (Fernald Closure Project 2005). As a result, grout was applied to the inner surfaces, thus stabilizing potentially loose contaminants and providing suppression of radon emissions.

Due to its porous nature relative to metal and for the purpose of this report, all concrete generated is assumed to be contaminated. Decontamination of building structures, including Buildings 411, 413, and 414, could be done primarily to reduce inhalation hazards to remove loose contamination prior to demolition. The depth and extent of the migration of the COCs and collocated hazardous substances into the concrete and the ability of adequately decontaminating the concrete is uncertain. Based on the information presented in Table 6-6 of the Waste Disposal Options/Fernald Lessons Learned Technical Memorandum (USACE 2011c), decontamination of rubble/debris may not be necessary for meeting WAC at disposal facilities that accept 11e.(2) byproduct material waste. Decontamination of building structures and contaminated rubble/debris may be feasible to reclassify waste as LLRW or construction debris.

Although decontamination of the building structures can be done within the footprint of the IWCS, it can only be done after removal of all residues and wastes. Therefore, decontamination of the buildings in the IWCS is considered to be an ex-situ treatment. Likewise, surface decontamination of the smaller rubble/debris (e.g., by application of high-pressure steam and water) can only be done following removal of the residues/wastes; therefore, decontamination of rubble/debris is considered to be an ex-situ process.

Both the surface removal and decontamination options are proven technologies that have been widely used on large-scale remediation projects (EPA 2006a). Decontamination of structural surfaces and rubble/debris in the IWCS would have to be used in conjunction with other technology/process options. Nonetheless, decontamination for the purposes of either removing contamination from the structural surfaces of Buildings 411, 413, and 414 or the decontamination of rubble/debris (the latter of which may not be necessary for disposal purposes) is technically implementable and is retained for further evaluation.

3.4.4.1.6 Surface Barriers

Remediation technologies for building materials also involve applying a sealant or impermeable sheeting to the building surface to prevent direct contact with contaminants and to reduce mobility. Typically, these methods are most feasible for cases where controlled reuse of a facility is proposed or for interior surfaces where environmental wear is significantly reduced. The purpose of screening treatment technologies for Buildings 411, 413, and 414 in Subunit B would be to reduce radiological exposures associated with the demolition of the buildings. Therefore, the use of impermeable sheeting is not technically implementable. Surface sealants and fixatives can be used as a method to reduce exposures during waste handling and, therefore, are retained as a process option.

3.4.4.2 Chemical Processes

Chemical processes involve adding chemicals to react with contaminants to reduce their toxicity and/or mobility.

3.4.4.2.1 Chemical Separation/Electrodialysis

Chemical separation/electrodialysis is an in-situ technique that would essentially use the concrete structures of Buildings 411, 413, and 414 as an in-place chemical “reactor” to treat the K-65 residues, other residues, and the contaminated soil and Tower Soils to recover the metals contained therein. In essence, the structures would act as leach piles. This process would require a means to deliver reactant throughout the media and a means to recirculate the reactant. The process may be enhanced using electrodialysis, which is a process that uses electrodes to attract charged ions.

Chemical separation/electrodialysis is incompatible with site conditions and waste characteristics. Due to the compaction methods used to place the residues into the IWCS, as well as the thixotropic consistency of the K-65 residues, the porosity of the residues and soil is expected to limit effectiveness of this technology, even with electrodialysis. Additionally, no readily available documentation could be located discussing application of this technology under conditions similar to those at the IWCS. Therefore, chemical separation/electrodialysis is not considered to be technically implementable for the IWCS and, consequently, is not retained for further evaluation.

3.4.4.2.2 Chemical Extraction/Metals Recovery

Chemical extraction is an ex-situ process that separates hazardous contaminants from soil, sludges, and sediment to reduce the volume of hazardous waste that must be treated. Chemical extraction involves excavating, transferring and mixing soil with an extracting agent that separates the contaminant from the soil. Solvent extraction using an organic solvent has been shown to be effective in treating soil containing primarily organic contaminants, while acid extraction is suitable for treating soil contaminated by heavy metals. Chemical extraction of metals also is known as leaching. Solvent extraction could be used to remove the PCBs from contaminated media; whereas, a leaching process could be used for the removal of metals and radionuclides.

After the extraction process has sufficiently removed the hazardous contaminants from the soil, the extraction solution containing the extracting agent and concentrated contaminants is separated from the soil. The extraction solution then undergoes further treatment or disposal. Dissolved metals are removed from solution by processes such as precipitation and ion exchange. While not all radionuclides and chemical extractants will be removed from the contaminated soil, if it is sufficiently clean, it can be returned to its original location (EPA 1996a). Otherwise, it may require separate storage or disposal.

Chemical extraction has been used extensively to extract uranium from mineral ores (EPA 1996a). However, using this technology to treat soil contaminated with radionuclides or mixed waste requires further development. Extraction agents that could be used to remove radioactive waste include complexing agents, such as ethylenediamine-tetraacetic acid; inorganic salts; organic solvents; and mineral acids, such as sulfuric, hydrochloric, or nitric acid. Each extraction agent’s effectiveness in removing different contaminants depends on concentrations, pH, and solubility.

Chemical extraction has been used to effectively treat sediment, soil, and sludge containing such organic contaminants as PCBs, volatile organic compounds, halogenated solvents, and petroleum waste, as well as organically bound metals (EPA 1996a). This technology has been effective commercially in treating media containing heavy metals.

While it can sometimes be used as a stand-alone technology, chemical extraction is commonly used with other technologies, such as S/S, incineration, or soil washing, depending on site-specific conditions.

Careful treatability studies are recommended by EPA (1996a) prior to implementation of a chemical extraction process. Soil properties such as particle size, pH, partition coefficient, cation exchange capacity, organic content, moisture content, and contaminant concentrations and solubilities are factors that could affect the efficiency and the operability of chemical extraction. Soil with high clay, silt, or organic content may cause dewatering problems in the contaminated waste stream.

According to EPA (1996a), factors that may limit this technology's applicability and effectiveness include the following:

- Traces of chemical extractants may remain in treated soil; toxicity of the extractants is an important consideration.
- Some soil types and moisture content levels will adversely impact process performance.
- Multiple extraction agents may be needed for mixed waste and mixed radionuclides.
- Chemical extractants tend to dissolve a large portion of the soil matrix; if more than 2 to 3% of the matrix is dissolved, this technology may not be feasible.

Chemical extraction is a fully developed ex-situ technology for application on contaminated soil, sludge, and sediment. Bench-, laboratory-, and pilot-scale tests have been performed for soil contaminated with radionuclides (EPA 1996a). Pilot- and full-scale tests have been completed for application to soil contaminated with PCBs and other organics (EPA 1996a). Pilot- and full-scale tests on a commercial level have been performed for soil contaminated with heavy metals (EPA 1996a). However, extensive research and method development would be needed to determine the appropriate extractants and reaction conditions to be applied toward the targeted removal and/or recovery of radionuclides, metals, and PCBs from the K-65 residues, other residues, and the contaminated soil and Tower Soils. If the recovery of radium, uranium, thorium, and precious metals is the goal, cost-benefit considerations become a significant factor because recovery processes typically involve many steps and require extensive development testing. Ex-situ chemical extraction/metals recovery is considered to be technically implementable and is, therefore, retained for further evaluation.

3.4.4.3 Thermal Processes

Thermal processes use high temperatures to volatilize, decompose, or melt contaminants. Thermal processes can include drying/calcination, incineration, and thermal desorption. All three processes were eliminated from the Fernald FS evaluation for treatment of the K-65 residues because those options do not treat the inorganic or radionuclide contaminants present in the residues/wastes. Drying and calcination are weight/volume reduction techniques that are typically used to apply heat to remove bound water from sludges or solids and are usually used in conjunction with treatment technologies. Drying and calcination processes have limited applicability to the IWCS due to the probable difference in moisture content in the non-residue wastes. Therefore, because of this and the ineffectiveness of incineration and thermal desorption for treating radionuclides and metals in the IWCS residues, none of these thermal processes are retained for further evaluation.

3.4.4.4 Biological Processes

Biological organisms that can degrade, detoxify, extract, or immobilize contaminants through biological processes can be used to remediate contaminated media. Applications of bioremediation have been proven effective and are now widely accepted as a remedial alternative for explosives, fuels, and other organic contaminants because organisms can convert (through biodegradation) organic contaminants into non-toxic chemicals (EPA 2006b). While radioactive and metal contaminants cannot be biodegraded, biological organisms can be used to detoxify or immobilize these containments by altering the oxidation state. Altering the oxidation state of the contaminants may increase mobility, which allows for extraction or removal. Effective bioremediation often requires the addition and control of amending agents and nutrients, as well as oxygen, temperature, and pH.

3.4.4.4.1 Phytoremediation

Phytoremediation is the general name of the technology that uses vegetation for in-situ treatment or stabilization of contamination in water, soil, or sediment. Generally, phytoremediation can be either an ex- or in-situ process. There are several applications of phytoremediation depending on the target contaminants, which can include solvents, metals, radionuclides, pesticides, polycyclic aromatic hydrocarbons, explosives, and landfill leachates.

Phytoaccumulation (also known as phytoextraction) is the phytoremedation process whereby specialized hyperaccumulating plants are used to absorb comparatively large amounts of metals contamination through root uptake and to translocate the metals throughout the rest of the plant. Close consideration needs to be focused on whether concentrations of metals accumulated in the shoots and leaves of the plants can be recovered or, if not, how to dispose of the plant material with the concentrated metals. Phytodegradation (also known as phytotransformation) is the process of organic contaminant degradation, which can occur either by uptake and metabolized within the plant or externally by enzymes produced by the plant. In either case, the degraded organic contaminant is used as nutrients and incorporated into the plant tissues. This process is efficient in degrading chlorinated solvents; benzene, toluene, ethylbenzene, and xylenes; and some aliphatics but is not effective for radionuclides and metals. Phytostabilization is the process of using metals-tolerant plants to immobilize contaminants in soil to prevent migration to groundwater or air. This process is best used at sites where the best alternative is to leave below-risk-level metals in place or in very large areas of contamination where removal is infeasible.

No documentation could be located that demonstrates any large-scale ex- or in-situ application of phytoremediation on wastes contaminated with radiological levels similar to those associated with the K-65 residues, other residues, or Tower Soils in the IWCS. Ex-situ phytoremediation would require removal and placement of the residues and soil to a location outside of the IWCS to be treated. Consequently, ex-situ phytoremediation is not technically implementable for the K-65 residues, other residues, or the contaminated soil and Tower Soils because of the potential risk of exposing the environment, remediation workers, and possibly the public, to radiological contamination from these wastes throughout the long period of time needed for remediation. Additionally, the high levels of radioactivity would be toxic to any vegetation or organisms introduced into the wastes. Therefore, ex-situ phytoremediation is not retained for further evaluation.

In-situ phytoremediation would require the establishment and growth of vegetation in IWCS residues. To allow for the levels of oxygen needed to grow and maintain vegetation in the IWCS, the cap would have to be removed, thereby potentially exposing remediation workers, the public, and environment to radiological contamination throughout the long period of time needed for remediation. Otherwise, oxygen would have to be introduced into the closed IWCS environment, along with other nutritive amendments. Therefore, in-situ phytoremediation is not technically implementable and is not retained for further evaluation.

3.4.5 Disposal

3.4.5.1 On-Site Engineered Disposal Facility

This technology option includes construction of a disposal facility on the NFSS, designed and constructed for long-term disposal. The structure would be large enough to hold the treated and/or containerized residues and any associated waste materials designated for on-site disposal. The facility would be designed to be effective for up to 1,000 years, to the extent reasonably achievable, and in any case, for at least 200 years, as is required under 40 *CFR* 192.02(a).

The structure could either be an engineered disposal cell with subgrade components related to containment and LTM or a containment structure placed at the current grade surface. Under 10 *CFR* 40 Appendix A, Criterion 3, the "prime option" for disposal is placement below grade. Therefore, the evaluation of on-site disposal alternatives must reflect serious consideration of this technical requirement. If an above-grade disposal facility is recommended, it must be demonstrated that the above-grade disposal cell would provide "reasonably equivalent isolation… from natural erosional forces."

3.4.5.1.1 Engineered Disposal Cell

An engineered disposal cell would have all of the attributes of a primary containment structure with an engineered multi-layer cap and sidewalls plus the additional protectiveness of an engineered multi-layer bottom inclusive of a leachate collection system, leak detection system, and synthetic and/or natural barriers to vertical and horizontal migration. For example, the multi-layer cap could have the same components as those described for the multi-layer engineered cap in the containment GRA and would include a synthetic barrier, a clay layer with appropriate thickness for radon gas and external gamma radiation protection, a rock layer for penetration and erosion resistance, and side slopes and cover appropriate for long-term passive design. The structure could be equipped with instrumentation to monitor its structural and environmental performance. Secondary containment and additional protectiveness could be provided by existing dike and cut-off walls or new vertical barriers (trench walls) extending into the gray clay layer. Waste would be removed from the IWCS and placed directly into the engineered disposal cell after any required treatment or processing. LUCs such as LTM and long-term surveillance and maintenance would likely be required for the design life of the structure. The engineered disposal cell could be laterally sited inside of the current IWCS containment system, with any required vertical adjustments to accommodate disposal volumes, or at another location on-site.

Use of an engineered disposal cell is retained for further consideration as a viable technology process option for on-site disposal of wastes removed from the IWCS.

3.4.5.1.2 Containment Structure

An example of a containment structure comprised of an aboveground concrete vault could be constructed on a foundation composed of (1) compacted clay sloped to facilitate run-off, (2) a geotextile layer, (3) crushed stone as a drainage layer and a capillary break, and (4) a level concrete working surface for waste placement. The vault walls would be designed to provide weather protection and shielding. The structure could be equipped with instrumentation to monitor its structural and environmental performance. Waste would be removed from the IWCS and placed into appropriately designed, DOT-compliant shipping containers for on-site storage in a vault. In this example, the waste containers would likely remain in good condition and could be moved if necessary. The containment structure would be closely monitored, and waste removal and transfer to a disposal facility could occur before any deficient condition arises. LUCs, such as LTM and long-term surveillance and maintenance, would be required for the design life of the structure or until the wastes are permanently removed from the site.

Use of a containment structure for permanent disposal is not retained for further consideration as a viable technology process option for the disposal GRA because placing material in a containment structure for later shipping to another facility would likely require the same handling requirements as off-site disposal without the benefit of shipping the materials off-site. For this reason, use of containment structures for long-term disposal or storage is not retained as a viable disposal option. However, temporary containment structures would be constructed to support radon control and worker protection requirements for removal, processing, and treatment of wastes. These structures would likely require the same horizontal and vertical controls as a more permanent facility, but the design of the temporary structures would support removal, decontamination, and/or disposal of the structures at the completion of any removal activities.

3.4.5.2 Off-Site Disposal Facility

Disposal at an off-site landfill disposal facility (including any treatment under land disposal regulations) would be based on waste classification. Landfill options may include disposal in a waste disposal facility licensed for 11e.(2) byproduct material waste, LLRW, or LLMW. The licensing restrictions embodied in the WAC for the commercial disposal sites limit the ability of the facility to receive wastes above certain radionuclide-specific activity concentrations.

Off-site disposal will require design and testing of DOT-compliant packages and the packaging and transportation of waste materials to the off-site facility. Transportation of IWCS waste can be conducted using truck, rail, or bimodal (a combination of the truck and rail). Depending on the waste stream and the WAC, wastes may be transported in bulk (i.e., contaminated soil) or placed in appropriate containers (i.e., residues) prior to disposal. Because the waste must be shipped over public transportation routes, the waste must be shipped per DOT requirements.

Off-site disposal of radioactive waste has been successfully implemented at other DOE and USACE sites. The K-65 residues from the Fernald Site were disposed of in an 11e.(2) cell at Waste Control Specialists in Andrews, Texas. Several licensed commercial disposal facilities also are available to accept IWCS waste materials, including 11e.(2), LLRW, and LLMW (USACE 2011c). Disposal at an off-site licensed facility is considered implementable for the IWCS wastes and has been conducted on a large-scale use; therefore, it is retained for further evaluation. It is noted that in accordance with 10 *CFR* 40 Appendix A, Criterion 11 (C), “Title to the byproduct material licensed under this Part and land, including any interests therein (other than land owned by the United States or by a State) which is used for the disposal of any such byproduct material, or is essential to ensure the long-term stability of such disposal site, must be transferred to the United States or the State in which such land is located, at the option of such State.”

3.4.6 Summary of Technologies Retained

Figure 3-1 summarizes the technologies and process options retained for further evaluation in Section 5.0. For each of the specific GRAs and technologies, the process options retained are as follows:

- LUCs
  - Institutional controls,
  - Engineering controls,
  - Environmental monitoring, and
  - Surveillance and maintenance
- Containment
  - Engineered caps
    - Multi-layer engineered cap
- Removal
  - Mechanical Removal
    - Conventional earthmoving equipment,
    - Overhead removal,
    - Dragline systems,
    - Remotely operated equipment, and
    - Auger mining
  - Hydraulic and Pneumatic Removal
    - Hydraulic mining
- Demolition
  - Concrete cutting and
  - Mechanical demolition
- Treatment
  - Physical Processes

        - Ex-situ conventional S/S (including ex-situ encapsulation),
        - Ex-situ vitrification,
        - Decontamination (surface decontamination),
        - Decontamination (surface removal), and
        - Surface barriers (sealants)
    - Chemical Processes
        - Chemical extraction/metals recovery
- Disposal
    - On-site engineered disposal facility
        - Engineered disposal cell
    - Off-site disposal facility
        - Licensed disposal facility

4.0 EVALUATION OF TECHNOLOGIES AND SELECTION OF REPRESENTATIVE TECHNOLOGIES

Each of the technically implementable remedial technologies and process options retained from the initial screening presented in Section 3.0 is further evaluated using three qualitative criteria: effectiveness, implementability, and cost (EPA 1988). For each technology and process option, a rating of high, moderate, or low is determined for each criterion. Figure 4-1 summarizes the evaluation of technologies and process options.

4.1 Technologies Evaluation Criteria

The factors evaluated as part of each criterion are discussed below, and a relative ranking of high, moderate, or low is identified for each technology and process option. The evaluation of each process option is relative to the other process options within the same GRA. Remedial technologies or process options eliminated from further consideration are those that have been rated as having

- Low effectiveness, and
- Low implementability.

Technologies also were evaluated for elimination if the ratings for implementability and effectiveness were moderate and low, or low and moderate, respectively.

4.1.1 Effectiveness

Effectiveness is evaluated based upon the potential long-term effectiveness and permanence in meeting the goals identified in the RAOs, compliance with ARARs, reduction in the mobility or volume of contaminated materials, the adequacy and reliability of controls in handling the estimated volumes of contaminated waste, and the ability of the technology process to minimize risks and exposure levels to human health and the environment during construction and implementation.

Effectiveness ratings are high, moderate, or low. Those technology and process options that have demonstrated effectiveness in treating wastes and contaminants similar to the IWCS are rated high or moderate. Process options providing significantly less effectiveness than other more promising options, as well as those that do not provide adequate protection of human health and the environment, are rated as low.

4.1.2 Implementability

Technically implementable technologies and process options retained in Section 3.0 are further evaluated with respect to feasibility of implementing a remedial technology or process option. This subsequent evaluation places greater emphasis on the conventional aspects of implementability, such as the ability to construct and operate the technology; the availability and capacity of treatment, storage, and disposal services; the availability of necessary equipment and skilled workers; the ease of undertaking additional steps that may be required to implement a technology, such as pre-treatment or management of residual wastes and the ability to monitor remedial effectiveness. Implementability ratings are high, moderate, or low. Process options that are infeasible or require equipment, specialists, or facilities that are not available within a reasonable period of time are rated as low.

4.1.3 Cost

In accordance with EPA guidance (1988), cost plays a limited role in the screening of remedial technologies and process options. Relative cost may include capital costs and operations and maintenance costs based on readily published information rather than detailed cost estimates. Costs for each technology are rated qualitatively on the basis of engineering judgment and relative to the other process options in the same technology type (EPA 1988). For the IWCS evaluation, the average reported or estimated cost of a process option is rated as low (<150 United States dollars [$]/yd^3), moderate (between $150/yd^3 and $300/yd^3), or high (>$300/yd^3). Costs that are grossly excessive compared to the overall effectiveness of alternatives are rated as high.

4.2 Land-Use Controls

LUCs applicable to the IWCS would be designed to minimize human and environmental exposure to hazardous substances remaining at the site and also to prevent activities that could impact the effectiveness of the remedy. LUCs, as described in Section 3.0, are not considered effective when used as a stand-alone option and are considered more effective when layered. Therefore, multiple types of institutional control mechanisms have been retained for potential use at the IWCS. However, LUCs can increase the effectiveness of other GRAs when used in combination. This section evaluates LUCs when used to supplement other GRAs.

- **Effectiveness.** Three types of institutional control options (governmental, proprietary, and informational) are rated as moderate in effectiveness. Engineering controls (fences and signs) and maintenance and surveillance activities that would be required to maintain the effectiveness of the engineering and institutional controls also are rated as moderate when used in combination with other GRAs. Environmental monitoring is rated as moderate in effectiveness when implemented in conjunction with other GRAs because, although it does not directly address remediation of the waste, it does provide data necessary to identify and respond to issues that arise that could call into question effectiveness.
- **Implementability.** LUCs are readily implementable, especially on federally-owned property. Therefore, LUCs are rated as high.
- **Cost.** Costs associated with institutional controls would include the legal and administrative costs of setting up the institutional controls, material repair, replacement and maintenance costs of signage or fencing or other physical barriers, and costs associated with monitoring (i.e., installation of additional monitoring wells, periodic sampling, and reporting). While these initial costs of LUCs are low, the long-term costs involved with monitoring, surveillance, and maintenance activities are difficult to quantify. The relative costs of LUCs are rated as moderate.
- **Evaluation Summary.** LUCs are not retained for use as a stand-alone option. However, LUCs ar**e** retained for use in combination with other GRAs because, under these conditions, they are highly implementable and have moderate effectiveness over the long term. Three types of institutional controls (proprietary, governmental, and informational), as well as various types of engineering controls (e.g., fences or other physical barriers, signs, and security measures), are retained for further consideration in combination with other GRAs. Maintenance and surveillance activities and environmental monitoring are retained for further consideration as components of any remedial actions for Subunits A, B, and C where waste would remain on-site.

4.3 Enhanced Containment

The existing IWCS is a containment system which includes an engineered cap (interim multi-layer cap), vertical barriers (clay trench walls and dikes), and horizontal barriers (two natural clay layers). The additional containment technologies considered for potential use at the IWCS are enhancements to the existing structures and therefore this technology is evaluated as an Enhanced Containment action.

Under current conditions, the IWCS poses no risk. The NFSS is owned by the Federal Government and site access is controlled. The IWCS was designed and constructed to safely contain the stored materials until their final disposition could be determined. The site is routinely monitored, and periodic inspections are made for any damage to the IWCS cap that could compromise its integrity; any such damage would be repaired as it was identified. An extensive environmental surveillance program is in place to ensure the safety of the site (USACE 2012b).

Containment enhancements evaluated include an enhanced cap and sidewalls to minimize radionuclide migration, inadvertent intrusion, and soil erosion. Some of the enhancements to existing barriers may include previously evaluated design details for a longer-term cap such as an increase in multi-layer cap clay layer thickness from 0.9 to 1.5 m (3 to 5 ft), adding a geomembrane directly above the clay to further reduce infiltration through the water, adding a 0.9-m (3-ft)-thick rock rip-rap layer between the clay and topsoil layers to restrict inadvertent intrusion and to act as a biobarrier, and adding clay fill material to the existing side slopes to reduce the maximum slope from 3:1 (33%) to 5:1 (20%) (DOE 1986a, 1986b). Nearby roads and drainage ditches also may be adjusted to accommodate a larger footprint where required for the modified cap. Final IWCS cap enhancements will be determined as part of the FS.

Containment enhancements to the horizontal barriers of the IWCS also were evaluated. Directional drilling could be used to install leachate collection piping beneath the IWCS. These pipes could connect to pumps that would extract water from a zone immediately beneath the waste. However, due to the low permeability of the clay, numerous pipes would likely be required and at great cost. However, in the long term (assuming no human presence and without active pumping or maintenance out to 1,000 years), the pipes would clog, thus rendering the system useless. Therefore, the overall performance of the horizontal barriers would depend on the existing clay beneath the IWCS, and no performance gains from the piping system would be realized.

- **Effectiveness.** Enhanced containment would be designed to isolate the residues and wastes, which can effectively reduce contaminant mobility and the potential for exposure to human health and the environment. LUCs including regular inspections and environmental monitoring are required to ensure effectiveness. Because there is no reduction in toxicity or volume of contaminated materials and due to the requirement to demonstrate effectiveness for 1,000 years by requiring LUCs to be maintained for 1,000 years, this technology is rated moderate for effectiveness.
- **Implementability.** Enhanced containment is a conventional technology that is routinely used. Since enhanced containment is technically implementable, it is rated as high.
- **Cost.** Costs associated with containment would include capital costs (i.e., installation of an additional cap and wall materials) as well as operation and maintenance costs for periodic sampling and reporting. Construction costs associated with enhancements to engineered barriers are relatively low. The need to monitor on a long-term basis if wastes remain on-site exists; therefore, the overall costs are rated as moderate.
- **Evaluation Summary.** Enhanced containment is retained for further consideration for Subunits A, B, and C.

4.4 Removal – Mechanical and Hydraulic Removal

Removal technologies are used in conjunction with other GRAs, such as treatment technologies and on- or off-site disposal. Retained mechanical removal technologies include excavators, a crane and dredging clamshell, and a dragline system, all of which may be manually or remotely operated. Additionally, auger mining and hydraulic removal are considered for removal of Subunit A residues from Buildings 411, 413, and 414.

- **Effectiveness.** Overall, removal technologies are rated as highly effective in meeting RAOs because waste would be permanently removed from the IWCS and transferred to a different location that is designed to be adequate and reliable for the long term. However, it is necessary to evaluate the relative effectiveness of the various removal technologies for the specific subunit waste types.

  Conventional and remote-controlled excavators and overhead clamshells are rated as moderately effective for Subunit A. These techniques have been used previously to remove residues from buildings; however, some hydraulic washing and pumping or other treatment (surface coatings or surface removal) would likely be required to mitigate residues on the structure surfaces. For Subunits B and C, excavators and clamshells are rated high for removing demolished debris and contaminated soil.

Draglines are rated low for Subunit A due to the presence of debris in the residues and the dense, sticky characteristics of the residues. Draglines may be more practical for Subunits B and C soil excavation, but they would need to be supported by clamshells or excavators, which allow for more precise removal; therefore, draglines are rated as moderate for use in Subunits B and C. Additionally, draglines are rated low for large or long debris.

Hydraulic mining is rated moderately effective for residue removal in Subunit A because it has been effectively used to remove this waste both at the Fernald Site and the NFSS. The presence of construction debris commingled with the residues in Building 411 would require conventional remote-controlled or overhead removal equipment and could interfere with hydraulic methods. Hydraulic mining is not considered for Subunits B and C wastes due to the water management requirements.

Auger mining is rated as moderately effective for residue removal in Subunit A and has been deployed successfully in other material removal applications involving hazardous environments. The removal of the construction debris in Subunit A would require conventional remote-controlled or overhead removal equipment and, therefore, could interfere with auger methods. Auger mining also could support removal of waste materials from Subunits B and C; however, conventional remote-controlled and/or overhead equipment would provide more efficient removal in this case. Therefore, auger mining is rated low for Subunits B and C.

- **Implementability.** For all subunits, a clamshell should be more flexible for handling debris and residue than a bucket excavator. A dragline may offer more efficient removal in areas where there is bulk material with little debris. Remotely operated equipment would offer the most protection from worker exposures to the residues in Subunit A. For Subunits B and C, fugitive dust is the primary concern with regard to potential worker impacts during removal of contaminated soil. In this regard, excavators and clamshells would be more implementable than draglines due to greater bucket control. For the conventional, dragline, remote-operated, and overhead equipment described, implementability for mechanical removal methods is considered moderate. This equipment is readily available and should not require a significant investment in remediation waste management equipment beyond the RCS (i.e., water management requirements are relatively small compared to hydraulic methods).

  For Subunit A, hydraulic removal technologies would require construction of more infrastructure (e.g., process lines and hoist for the hydraulic head) than would be required for mechanical technologies and will require the use and treatment of process water. Remotely operated hydraulic equipment would require less worker involvement than required for mechanical equipment. Remotely operated auger equipment would require less water management than hydraulic mining. For this reason, hydraulic mining is considered to have low implementability compared to auger mining, which is considered to have moderate implementability.

- **Cost.** In general, removal is a higher-cost GRA then other GRAs. Costs associated with removal include capital costs (i.e., construction of temporary infrastructure associated with removal and handling of waste) and operations costs associated with direct removal and monitoring for fugitive dust, radon, and worker exposure.

  In a cost comparison between removal technologies for Subunits B and C, productivity is the primary consideration. When using comparably sized (1-yd^3 bucket) excavators and clamshells in this type of application, excavators are expected to remove and transfer 75 yd^3 of material per 1 hr while clamshells are rated for 35 yd^3 per 1 hr (CostWorks 2011). Therefore, the cost of these technologies is rated low for excavators and moderate for clamshells. Comparatively, the cost of using a dragline would be high. Even though the productivity of a dragline would be higher than the conventional equipment, the initial mobilization costs also would be higher.

For Subunit A, several factors must be considered, including the relative differences in the productivity rates, anticipated radon containment structure requirements, and waste handling infrastructure. Hydraulic removal has significantly higher productivity rates than mechanical removal or auger mining, as is widely recognized in the mining industry. Assuming that a radon containment structure is not required for debris removal after residues have been removed, the height of the containment structure could be shorter for hydraulic removal than would be necessary to accommodate the boom heights that would be required for debris removal using a clamshell. However, the additional cost of the hydraulic head hoist support would effectively consume more than the associated savings. Mechanical removal of residues is limited to bulk removal followed by washing and pumping using large volumes of water in the process; therefore, both methods require water collection and treatment infrastructure. It should be noted that after residues are removed, a particular treatment technology may require residues to have relatively high or low moisture content; therefore, hydraulic removal may be preferentially selected on this basis. In general, auger mining followed by mechanical removal and surface treatment (washing, removal, or coating) would likely require significantly less investment in water management and treatment infrastructure than hydraulic removal. Remote operation of any of the conventional earthmoving equipment would add an additional cost and, therefore, overall, this technology’s costs would be high. Collectively considering these factors for the removal of residues from the buildings, costs for hydraulic removal of the residues and remote operations are rated high and for mechanical removal of debris including conventional and auger-based methods are rated moderate.

- **Evaluation Summary.** For the removal of residues from Subunit A, both hydraulic removal and mechanical technologies are retained. For removal of contaminated media from Subunits B and C, all mechanical removal technologies are retained. Final selection will be determined by a more detailed analysis of these options.

4.5 Removal – Demolition

Demolition of Buildings 411, 413, and 414, which are concrete structures, may be implemented as part of a removal action for Subunit B. Additionally, demolition technologies also may be necessary to remove and process other contaminated rubble/debris within Subunits A and B. Retained demolition technologies include mechanical demolition by hydraulic breakers and concrete cutting.

- **Effectiveness.** All retained demolition technologies are rated high in terms of meeting RAOs because the waste is permanently removed and treated or transferred to a permitted or licensed disposal facility.

  In comparing specific methods for demolition of the buildings, the hydraulic breaker and concrete cutting methods are adequate for floors and walls and, likewise, offer good size control. This method will generate dust that can be easily mitigated by spraying a fine mist over the immediate area. However, use of remote-operated hydraulic breaker and concrete cutting equipment would provide better protection from worker exposures. The hydraulic breaker method is rated high. The concrete cutting method is slightly less reliable and significantly slower than the hydraulic breaker method. A relatively larger volume of water is required for the concrete cutting method to cool cutting blades. The concrete cutting method is rated moderate.

- **Implementability.** Both hydraulic breaker and concrete cutting technologies have been proven to be implementable. Two issues suggest the conventional hydraulic breaker method rates slightly higher compared to the conventional concrete cutting method: worker health impacts would be lower for workers using the hydraulic breaker method because the operator would remain in an enclosed cab and less mechanical maintenance is required. Remote-operated equipment would offer the highest protection from worker exposure and, therefore, the hydraulic breaker would be rated high for implementability as compared to concrete cutting (moderate). Whether conventional or remotely operated, both demolition technologies will be retained for further evaluation.

- **Cost.** Costs associated with demolition of building structures include operations costs of demolition and remnant removal as well as management and treatment of concrete cutting wastewater. The cost of wastewater would be incidental to the total cost of water treatment for hydraulic removal. Productivity is the primary consideration in the cost comparison of hydraulic breakers and concrete cutting. Given the thickness of walls and floors in the three buildings, hydraulic breakers are expected to remove 1 yd^3 per 1 hr and concrete cutting is expected to remove 0.1 yd^3 per 1 hr (CostWorks 2011). Therefore, the relative cost of these mechanical demolition technologies is low for hydraulic breakers and moderate for concrete cutting. Remote-operated equipment is traditionally higher in cost than conventional equipment; however, efficiency gains in this industry are closing the gap and merit attention where worker exposure risks may be high.
- **Evaluation Summary.** Conventional and remote-operated hydraulic breakers and concrete cutting are retained for further consideration as the demolition technologies for Subunits A and B.

4.6 Treatment

Treatment technologies were evaluated in Section 3.0 according to their ability to treat the residues (Subunit A). The waste/matrix types found within Buildings 411, 413, and 414 include the K-65 residues and other residues (including F-32, L-30, and L-50) and soil (including contaminated soil and Tower Soils). Additionally, the structures of Buildings 411, 413, and 414 (Subunit B) and contaminated rubble/debris were evaluated for surface treatment methods to reduce potential exposures during any removal. As stated previously, the general assumption will be that technologies and process options will be evaluated based on their ability to address COCs and collocated hazardous substances.

The following ex-situ treatment technologies/process options were retained: S/S, vitrification, and chemical extraction/metals recovery for Subunit A and decontamination (surface decontamination and surface removal) and surface barriers for building structures in Subunit B or any contaminated rubble/debris associated with Subunit A or B. No in-situ treatment technologies/process options were retained.

4.6.1 Physical Processes – Ex-Situ Conventional Solidification/Stabilization (including Ex-Situ Encapsulation)

S/S is a technology that physically binds or encloses contaminants within a stabilized mass (solidification) and/or induces chemical reactions between a stabilizing agent and contaminants to reduce their mobility (stabilization). Conventional S/S (using cement and/or fly ash), as well as encapsulation methods (polymers), are evaluated further as an ex-situ S/S treatment for the IWCS OU. S/S is feasible for the treatment of a wide range of contaminants including heavy metals and radionuclides (EPA 1996a). At the Fernald Site, conventional S/S was used successfully to treat the K-65 residues that were formerly contained in Silos 1 and 2, as well as the cold metals oxides that were contained in Silo 3 (USACE 2011c). Encapsulation using the NuCap™ process (formerly EKOR™) has demonstrated the ability to encapsulate material with high-activity concentrations at the Savannah River Site.

At the IWCS, ex-situ S/S is further evaluated for treating the residues and the contaminated soil and Tower Soils in Subunit A.

- **Effectiveness.** Although this technology does not reduce the toxicity or volume of contaminants, it has been proven to greatly reduce the mobility, thus reducing the risk of exposure. S/S processes have demonstrated the capability to reduce the mobility of contaminated waste by greater than 95% (FRTR 2009). Conventional S/S treatment, however, can significantly increase the total volume of contaminated material (up to double the original volume) that would require disposal because of the addition of stabilizing agents such as Portland cement or fly ash (EPA 2007). However, polymers can be used as a substitute for conventional S/S materials and offer much higher waste loadings.

Cement stabilization is best suited for highly porous, course-grained LLRW in permeable matrices (EPA 1996b). S/S is shown to be effective for radionuclides and metals; although, some organic constituents of mixed wastes can reduce the effectiveness of the technology for reducing leachability (EPA 1996a). Cement S/S was applied on a large-scale basis to the K-65 residues at the Fernald Site and successfully met DOT and off-site disposal requirements. The long-term effectiveness of cement S/S on the Fernald K-65 residues is yet to be determined.

By itself, S/S may not provide adequate shielding or eliminate external radiation effects (EPA 1996a), but it could provide a reduction in radon emissions. According to the Pacific Northwest Laboratory (1993), radon emanation rates of unsolidified K-65 residues stored in former Silos 1 and 2 at the Fernald Site ranged from 11,817 to 29,976 pCi/m^2/s. During treatability studies at the Fernald Site (OU 4), it was found that the radon emanation rates of S/S-treated K-65 residues were reduced to 200 pCi/m^2/s (USACE 2011c). However, it is likely that additional containment would be needed for S/S-treated residues to meet the 40 *CFR* 61 criterion (20 pCi//m^2/s). The use of polymer encapsulation materials has shown to increase the radiological shielding capabilities.

The concentrations of PCBs and other organics in the Fernald K-65 residues were not significant enough to warrant concern over the long-term effectiveness of this technology. Chemical composition data available for the NFSS residues do not indicate a significant presence of organic compounds and, therefore, the effectiveness of cement or polymer-based S/S in treating Subunit A wastes is rated as moderate.

- **Implementability.** Ex-situ S/S technologies are well demonstrated. Most reagents and additives are generally widely available and relatively inexpensive industrial commodities. Special concerns may be posed by certain types of hazardous waste (e.g., organic chemicals), but organics likely are not present. Inorganic acids can decrease the durability for Portland Type I cement (EPA 1996b).

  For S/S to be effective for the K-65 residues, which have thixotropic characteristics, the material would need to be removed and slurried to promote mixing with the solidifying agents. The slurrying of the K-65 residues, followed by cement S/S, was applied during remediation of Silos 1 and 2 at the Fernald Site.

  Certain waste matrices are incompatible with variations of the S/S process; therefore, treatability studies are generally required (FRTR 2009). The characteristics that influence whether the ex-situ application of the technology will contain the waste effectively include pore size of the waste matrix, which determines the size of the cement particles that can be injected, and the permeability of the surrounding soil, which determines whether water will flow preferentially around the solidified mass.

  According to EPA (1996a), during ex-situ processes, there are potential risks of exposures to workers during the excavation, mixing, and handling of waste. Radon and fugitive dust emissions would have to be controlled to protect the health of remediation workers and the surrounding community.

  No administrative issues are expected to be of concern for this option. The only residual would be water removed during dewatering to <20% moisture (EPA 1996b).

  For the above reasons, the technical implementability of S/S is rated as high.

- **Cost.** Costs can vary based on specific waste characteristics, volumes, contaminants, and the availability of solidification agents. In addition, costs for transportation and off-site disposal of the solidified material play a role in the overall cost. For ex-situ S/S processes (based on cement S/S), costs have been estimated to be approximately \$144/yd^3 based on assumptions provided by the Federal Remediation Technologies Roundtable (2009). Additionally, costs associated with removal and disposal would need to be considered. Consequently, the cost for S/S is rated as moderate.

- **Evaluation Summary.** Ex-situ S/S is rated moderate for effectiveness and costs and high for technical implementability; therefore, it is retained for further evaluation.

4.6.2 Physical Processes – Ex-Situ Vitrification

The ex-situ vitrification process involves blending glass-making constituents with the waste and feeding the mixture into a furnace at high temperatures (1,100 to 1,400°C [2,012 to 2,552°F]). The waste materials are melted with the molten glass and, upon cooling, a solid mass forms that traps the contaminants within the glass matrix. A pre-treatment step may be required to reduce the moisture content or to reduce the size of the feed material. Ex-situ vitrification using the Joule-heated melter technology is further evaluated for the treatment of the Subunit A residues and soil.

- **Effectiveness.** Vitrification is the internationally recognized best treatment approach of high-level radioactive waste sludges and liquids. It is highly effective in reducing the mobility and volume of radioactive wastes. Vitrified waste has generally been found to meet EPA Toxicity Characteristic Leaching Procedure requirements.

  As a result of treatability studies on the Fernald K-65 residues, vitrification was initially selected over cement S/S as the preferred remedy due to a higher reduction in leachability and radon emanation and less waste volume increase. During treatability studies conducted at the Fernald Site, radon emanation rates from the K-65 residues were reduced by factors ranging from 465,000 to 508,000 (Pacific Northwest Laboratory 1993). The radon emanation rate from the vitrified K-65 residues ranged from 0.01 to 0.06 pCi/m^2/s, which is more than two orders of magnitude less than the 40 *CFR* 61 criterion of 20 pCi/m^2/s. However, vitrification does not reduce the radioactivity of the contaminants within the vitrified mass and, therefore, requires additional shielding or containerization to reduce or eliminate potential human and environmental exposures. LTM is required after disposal of vitrified masses (EPA 1996a).

  On the treatability study level, vitrified waste has been found to meet EPA Toxicity Characteristic Leaching Procedure requirements. However, failure of a full-scale application on the actual waste form prevented understanding the effectiveness on a larger scale. As a result of this uncertainty in full-scale application, this technology is rated moderate for effectiveness.

- **Implementability.** DOE has built large vitrification facilities at West Valley, New York, and at the Savannah River Site (Defense Waste Processing Facility) in South Carolina and is building a facility at the Hanford site in Washington. Each of these cases involved high-level waste, high waste volumes, relatively homogeneous wastes, and mostly liquid wastes. All are based on joule-heated ceramic melter (JHCM) technology utilizing inconel 690 electrodes at a processing temperature of 1,150°C. JHCM technology also has been developed in Japan, Germany, China, and Russia for treatment of high-level waste.

  Low-temperature (1,150°C) JHCM technology is a viable and commercially proven approach suitable for some waste streams. It should be noted, however, that few cost models exist for the deployment of this process to treat lower-activity wastes such as the K-65 residues. A number of experimental and new vitrification technologies have been evaluated for use across DOE sites over the past 20 years; a listing of these is provided below.

  - Transportable vitrification system (JHCM with molybdenum electrodes),
  - Fernald Pilot Plant (high temperature, 1,400°C, JHCM with molybdenum electrodes),
  - Plasma torch melters for homogeneous and heterogeneous wastes,
  - In-can melters for Three Mile Island’s spent zeolite and other waste types,
  - Cyclone combustion (natural gas-fired) melters for Hanford’s low-activity waste,
  - Bulk vitrification melter (JHCM using graphite electrodes) for Hanford’s low-activity waste,
  - Stir melter (JHCM using a submerged impeller as an electrode) for the Defense Waste Processing Facility’s high-level waste,
  - Commercial JHCM (molybdenum electrodes) for various wastes,
  - CCIM (no electrodes) for the Defense Waste Processing Facility’s high-level waste, and
  - Hanford’s Waste Treatment Plant high-level waste and low-activity waste.

In each of the cases above, the technology failed to mature on a timeline suitable for project adoption. Lessons learned include the need for extensive electrical power and off-gas collection and cleaning systems that must be maintained during processing.

In addition to the different technologies that have been developed and tested at DOE facilities, there were studies involving development of different glass formulations for vitrifying K-65 residues. The purpose of the studies was to achieve melts at the lowest temperatures feasible, while maximizing waste loadings. Achieving melts at the lowest temperatures helps to minimize volatilization of radon-222, arsenic, and selenium. At the Fernald Vitrification Pilot Plant, surrogate melter testing was conducted at temperatures between 1,130 and 1,350°C using soda-lime-silicate and borosilicate formulations. A final transition to lower temperature operation at 1,150°C was planned when the pilot plant failed on December 26, 1996. According to the Westinghouse Savannah River Company (1999), a soda-lithia-lime-silica glass had been developed and tested at the Savannah River Technology Center in 1993 that not only achieved a lower melt temperature of 1,050°C but avoided phase-separation problems posed by metal oxides present in K-65 residues that had been observed in borosilicate formulations. However, indications are that the Savannah River Technology Center formula was never tested at the Fernald Vitrification Pilot Plant.

Based on the failures and lessons learned throughout the DOE complex (DOE 1999) and primarily regarding the failure to implement vitrification at the Fernald Site for the K-65 residues, this technology remains difficult to implement and would require extensive testing prior to implementation. Ex-situ vitrification is rated low in overall implementability relative to S/S.

- **Cost.** Based on data from West Valley, Savannah River, and Hanford, the capital costs for vitrification are high (the recent estimate-to-complete for the Hanford plant is $12.5 billion). As found at the Fernald Site, the costs associated with moving from treatability studies to pilot- and to full-scale studies are high and require significant schedule adjustments (USACE 2011c). Based on these considerations, costs are rated high.
- **Evaluation Summary.** Based on past experience, vitrification appears to be a cost-effective technology in cases only where there are large high-level waste streams. For this analysis, it is rated moderate for effectiveness on a waste stream like the K-65 residues, low for implementability, and high for cost. Ex-situ vitrification is not retained for further consideration.

4.6.3 Physical Processes – Decontamination

Decontamination is a physical method for removing or reducing radiological contaminants that have become adhered to the structural surfaces of buildings, equipment, tools, etc. Both surface removal and surface decontamination have been retained as treatments for the structural surfaces of Buildings 411, 413, and 414 in Subunit B. Similar techniques may be required for removal of contamination from rubble and debris in Subunit A.

- **Effectiveness.** Surface removal techniques (e.g., abrasive blasting, scarification, grinding, planing, spalling, and vibratory finishing) are technologies that physically remove contaminated surface media. Removal of contamination using these techniques is expected to be effective to greater depths than would be achieved using surface decontamination (e.g., high-pressure steam and water), which only removes surface contamination without removal of the surface material of the structure/debris. However, surface removal is not generally effective on irregular-shaped surfaces; whereas, surface decontamination is effective on most, if not all, types of surfaces. Both of these techniques are highly effective surface decontamination process options for use on Buildings 411, 413, and 414. The depth and extent of the migration of the COCs and collocated hazardous substances into the concrete and the ability of adequately decontaminating the concrete is uncertain. The overall effectiveness ratings of surface decontamination and surface removal for application to the buildings are both high.
- **Implementability.** Surface removal and surface decontamination technologies are generally easy to implement since materials, equipment, and manpower are available; although, there may be some

concerns over worker exposure within the IWCS if residual amounts of K-65 and other residues remain. Both process options would produce waste streams that would need to be captured and treated. Generally, surface removal is more implementable on large, flat surfaces (e.g., the surfaces of Buildings 411, 413, and 414) and requires more specialized equipment and more manual labor. One issue with surface removal is the potential to generate dust. Surface decontamination (e.g., using high-pressure steam and water) would be more implementable on most types of surfaces (e.g., small, large, irregularly shaped, etc.) and does not require specialized equipment and personnel.

The technical implementability is rated high of surface decontamination and moderate for surface removal.

- **Cost.** Unit costs have been estimated for surface removal and decontamination technologies and are presented by EPA (2006a). The total unit costs generally include costs associated with mobilization, decontamination, demobilization, and waste disposal. Available unit costs provided for the surface removal technologies range from \$14.00/ft^2 to roughly \$200/ft^2. The unit cost estimated for surface decontamination (high-pressure water/steam) is approximately \$3.63/ft^2. Based on these estimates, costs for ratings for surface decontamination and surface removal are both considered low.
- **Evaluation Summary.** The overall ratings for effectiveness, implementability, and cost of surface decontamination (i.e., high-pressure water/steam) technologies are high, high, and low, respectively. The overall ratings for surface removal technologies are high, moderate, and low for effectiveness, implementability, and cost, respectively. Therefore, both surface decontamination and surface removal are retained for further evaluations.

4.6.4 Physical Processes – Surface Barriers

Surface barriers would be used if Subunit B wastes are removed and would be applied to the structural surfaces of Buildings 411, 413, and 414 prior to demolition to prevent direct contact with contaminants and to prevent migration of contaminants. Surface barriers are proposed to be used if decontamination methods do not adequately reduce surface contamination prior to demolition.

- **Effectiveness.** Although sealing surfaces would reduce exposure to contaminants, it would not be effective for external gamma radiation and contamination would remain intact. Because the surface barrier would degrade over time and additional maintenance and/or future reapplications would be necessary, the effectiveness of this technology is considered only for short-term use for protection of human health and the environment. The sealing of the building surfaces may aid in the reduction of loose particulates during demolition, but additional methods to reduce air dispersion would be required. Therefore, the effectiveness of using sealants for containment of radiologically contaminated surface materials is rated as moderate.
- **Implementability.** Surface sealants are easily applied and are used extensively in the construction industry but generally on new or well-prepared surfaces. Poor condition of surfaces could involve repeated applications to be effective, but short-term use is the only application considered. The availability of products is extensive and, therefore, the technical implementability is rated high. No issues affecting the administrative implementability have been identified. Therefore, the administrative implementability of containment using surface barriers is high.
- **Cost.** The cost of using paint or grout as a surface barrier is low (<\$1.00/ft^2).
- **Evaluation Summary.** Containment using surface barriers was retained for worker protection based on its high implementability, moderate effectiveness, and low cost.

4.6.5 Chemical Process – Chemical Extraction/Metals Recovery

A potential component for remedial alternatives at the NFSS includes extraction and recovery of radium and other valuable metals that may exist in the residues stored within the IWCS. The K-65, F-32, L-30, and L-50 residues are the result of processing of high-grade pitchblende ores. In addition to uranium, the pitchblende ores were rich in precious metals such as gold, platinum, palladium, and silver. Most of the uranium was removed from the K-65 residues, and the radium was precipitated out as radium sulfate. Several metal hydroxides (e.g., iron, aluminum, and manganese) and other impurities, such as precious metals, also were precipitated. Some precious metals were extracted from some shipments of the ore prior to processing for uranium (DOE 1986a). Although these ores were processed for uranium and precious metals, the residues still contain appreciable quantities of these materials (DOE 1981a). The K-65 residues have much less cobalt, nickel, and copper and more rare earths, palladium, molybdenum, and lead than do the other residues. The L-30 residues have more uranium. All of the residues have a small amount of gold, platinum, and other noble metals (DOE 1986a).

Chemical extraction/recovery is a permanent treatment that separates metals contaminants from soil or waste material in the form of metal, metal oxide, or other useful products that have potential market value. This extraction/recovery process is typically preceded by physical separation processes to upgrade the metal content in a specific soil/waste volume or to recover larger metal fragments. The process selected would depend on the constituent or metal targeted for recovery. For example, the recovery of radium involves a complex set of unit operations requiring the addition of acids and salts and removal of precipitates (DOE 1997).

Chemical extraction/recovery is a retained technology for the radium and metals in the Subunit A residues. Extraction of these constituents would require additional pre-treatment to isolate the radium or valuable metals from the soil or waste medium. For this reason, extraction/recovery would be considered an alternative to disposal of waste along with a selection of a treatment technology that can be used to prepare the waste material for reclamation.

- **Effectiveness.** The effectiveness of the extraction/recovery is highly dependent upon the soil/waste material type and the available methods to separate and concentrate the metals into a reusable fraction. Generally, the process of extraction/recovery is rated high in effectiveness in removal of target metals/radionuclides from many waste matrices because the toxicity and volume of the remaining waste stream that has to be managed is reduced. However, extraction/recovery is rated low in effectiveness for not reducing the mobility of the remaining waste material without application of an additional treatment technology. Therefore, the overall effectiveness rating for the stand-alone application of extraction/recovery on the residues and Tower Soils in the IWCS is moderate.
- **Implementability.** A number of schemes for separation of radium from ore residues have been proposed and/or examined on a laboratory scale (DOE 1997). The earliest study was conducted by Mound Laboratories in 1951 (Vitro Corporation 1952). The Mound process was extremely complex and impractical on an industrial scale because it used repeated fractional crystallization of barium and radium salts. In 1974, Hazen Research, Inc. (Litz 1974) drew upon the Mound research and focused on removing the radium from the residues and then further treating the residues to recover the metals of interest. The Hazen approach was complex and utilized sodium carbonate to metathesize the barium and radium sulfates to their carbonates, which would then be solubilized in acid and isolated for subsequent separation. Due to the insolubility of both sulfates and carbonates of radium and barium, this proposed process would require the use of large volumes of water. This water would be contaminated and would require a substantial investment in evaporation equipment. Personal communication with the principal investigator of this work revealed that he did not consider chemical extraction to be a viable option for removal of radium from the residues (DOE 1997).

  A 1978 study published by the National Lead of Ohio, Inc. Feed Materials Production Center (Fernald) proposed a sodium carbonate leach process. Similar to the Hazen work, this process relied on the assumption that barium and radium sulfates, in the presence of a large excess of sodium carbonate, would be converted to carbonate. Treatment of the residue with nitric acid would then yield separable radium and barium nitrates. Chemical reactions required for this process do not occur to any appreciable extent under ordinary conditions, adding to the complexity of the process (DOE 1997).

The Denison Mines Corporation’s White Mesa Mill in Blanding, Utah, offered the greatest potential for providing resource recovery of the NFSS residues. Denison Mines Corporation, formerly International Uranium Corporation, is an NRC-licensed facility that has the capability to process natural uranium-bearing ores and alternative feed materials to extract the uranium, vanadium, and other valuable resources that may exist in the material. In 2002, radium and thorium recovery of metals from the high-grade uranium residues in the IWCS was discussed with International Uranium Corporation. The complexities associated with extracting these constituents contributed to the conclusion that it was infeasible to recover radium and thorium from the residues. In addition, the relatively recent addition of NRC and Agreement State license fees and related safety requirements for discrete sources of radium would significantly increase costs associated with the possession and use of radium.

Because implementation of this technology has never been demonstrated on a large-scale basis on the K-65 residues, a complex and time-consuming series of treatability studies would be needed to determine the optimum extraction/recovery reagents and conditions needed for the residues and Tower Soils. Technically, extraction/recovery is considered to be more complex and more difficult to implement than all the other treatment options evaluated thus far. Additionally, it is likely that the extraction processes would produce other waste streams that themselves may require treatment, storage, disposal, and, consequently, permitting. Therefore, the implementability of chemical extraction/recovery is rated low.

- **Cost.** If the revenues generated by the re-sale/reuse of the recovered radium or metals outweigh the costs of implementing the technology, or are comparable with other protective alternatives, then extraction/recovery should still be considered (EPA 1999).

  Economic viability of the recovered materials and vendor availability are key components in determining whether extraction and recovery is an effective technology to be used as a remedial alternative. Radium was important for radiation treatment of cancer; however, it has been replaced by other isotopes that can be produced at a lower cost and greater effectiveness in treatment (Reference for Business 2011). If recovery of radium for medical purposes was pursued, additional efforts would be needed to refine and purify the radium to be used as a medical therapy (Environmental Health Perspectives 1995). Extraction/recovery is not practicable for metals that lack economic viability, and the market value for the recovered material at the time of extraction cannot be predicted without potentially significant uncertainty. At the NFSS, off-site disposal of residues would result in significant costs for transportation, treatment, and final deposition of the material at a waste disposal facility. Extraction/recovery options could potentially reduce disposal costs.

  In summary, costs for extraction/recovery could be high and are outweighed by the economic benefits for extraction to be considered cost-beneficial.

- **Evaluation Summary.** The implementability of using extraction/recovery as a treatment technology was rated low because it has never been demonstrated on a large-scale basis on the K-65 residues, which necessitates a complex and time-consuming series of treatability studies to determine optimum extraction/recovery reagents and conditions needed for the IWCS residues and Tower Soils, and presently there is no commercial facility seeking these metals for recycling or has the technology to recycle these materials. Off-setting the potential value of radium or metal recovery is the cost of extraction and the increased exposures of workers. The concentrations of the precious metals in the residues are likely not great enough to ensure a significant cost recovery considering the complexity of the required extraction process. The extraction process for radium is similarly complex. Additionally, the use of radium as a medical resource has declined, and the future market for radium is uncertain. Therefore, the cost for implementing recovery/reclamation is rated as high.

In summary, chemical extraction/metals recovery is not retained for further evaluation as a treatment option for the residues and the contaminated soil and Tower Soils in Buildings 411, 413, and 414 of the IWCS.

4.7 Disposal

Disposal of wastes from all IWCS Subunits (A, B, and C) can be implemented using a newly constructed on-site engineered facility or by packaging and transporting to an off-site facility.

Wastes are categorized into classes to simplify waste management actions, rules, and regulations while protecting human health. The waste category is used to determine the requirements for treatment, storage, and disposal according to regulatory criteria established by Federal or state governments. In 2004, Congress designated the residues at the NFSS as 11e.(2) byproduct material. In Section 11e.(2) of the Atomic Energy Act, ‘byproduct material’ is defined as “the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content.” Therefore, the K-65, L-30, L-50, and F-32 residues (Subunit A) contained in Buildings 411, 413, and 414 are considered 11e.(2) material. Additionally, the R-10 residues in Subunit C also were considered as 11e.(2) byproduct material. Other wastes (i.e., contaminated rubble/debris) that have come in contact with the radioactive residues may be identified as 11e.(2) byproduct material (USACE 2011c). Otherwise, materials in the NFSS IWCS that are not residues (to include soil not mixed with residues) may be considered LLRW. LLRW is radioactive material not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or byproduct material (as defined in 42 U. S. Code 2014) and which NRC classifies as LLRW consistent with existing law. Based on the limited data and information associated with the materials placed into the IWCS, some of the waste in all subunits is expected to be classified as LLRW (USACE 2011c).

According to 40 *CFR* 261.4(a)(4), byproduct material is excluded from the RCRA definition of solid waste and is, therefore, not subject to these regulations in regard to transportation, treatment, or disposal of waste. However, if other hazardous waste materials not associated with ore processing are combined with the 11e.(2) byproduct material, the waste may not be acceptable at an 11e.(2) disposal cell due to restrictions in the disposal facility’s WAC (USACE 2011c), and instead, may be accepted only as a LLMW. There is a potential for other hazardous waste or radiological materials not associated with ore processing to be present within all of the IWCS subunits. (In the case of Subunit A, this material is contaminated soil that was collocated with the residues.) Any removal actions associated with the residues within the IWCS would need to be conducted in a manner that minimizes the potential for other non-11e.(2) byproduct material to be commingled with the residues. If LLRW is mixed with hazardous wastes, then it has a special status as LLMW and must meet treatment, storage, and disposal regulations both as LLRW and hazardous waste. Based on the limited data and information associated with the materials placed into the IWCS, there is potential for LLMW to be present in the IWCS, but the volume is considered to be minimal (USACE 2011c).

Disposal options for the IWCS waste are based on the current in-situ waste inventory and waste categories presented in Appendix B, Table B-1 and summarized in Table 2-3. The final volume of material to be disposed may vary significantly depending on the specific methods of treatment and/or handling methods evaluated for the FS. Additionally, the waste categorizations for some of the wastes (contaminated debris, soil, etc.) will be further evaluated based upon the detailed analysis in the FS.

4.7.1 On-Site Engineered Disposal Facility

On-site disposal of IWCS residues and wastes would require design and construction of a new on-site engineered disposal facility, excavation and processing of wastes, and may require treatment of wastes prior to placement in the new facility. The on-site engineered disposal facility would be designed as a primary containment structure with an engineered multi-layer cap and sidewalls plus an engineered multi-layer bottom inclusive of a leachate collection and monitoring system and synthetic and/or natural barriers to vertical and horizontal migration.

- **Effectiveness.** Disposal of wastes in a new on-site disposal facility is a relatively conventional containment technology used to isolate wastes. Engineering design features of the disposal facility and inspections and monitoring are necessary to ensure effectiveness. An engineered on-site disposal facility technology can be effective in preventing migration of contaminants to the environment. To prevent direct contact with the wastes, this technology has to include both engineered barriers and LUCs. The engineering design and materials and the LUCs would have to be durable and maintained to address potential long-term risks associated with this waste stream. As such, this technology is rated moderate for effectiveness.

- **Implementability.** Technical implementability concerns can be addressed through planning and engineering controls. Design requirements and construction materials are conventional and available. Appropriate mitigative measures would be necessary for handling and placing wastes within a new on-site engineered disposal facility to maintain exposures as low as reasonably achievable for both workers and members of the public. Because there would be minimal transportation requirements for on-site disposal, transportation controls would be necessary but not significant.

  There are administrative and regulatory challenges for constructing a new engineered on-site disposal facility. The requirements for siting radioactive waste cells under 40 CFR 192 would likely preclude the ability to construct a new engineered disposal facility on-site. Furthermore, Appendix A of 10 CFR 40 discourages the “proliferation of small disposal sites” for 11e.(2) byproduct wastes generated by an action and would only consider siting a new cell if “on-site burial clearly outweighs the benefits of reducing the perpetual surveillance obligations.” In addition, if wastes from all three subunits were disposed in the new on-site engineered disposal facility, this facility would have to be designed to accept both 11e.(2) byproduct material and LLRW. If it was determined that the IWCS contains hazardous waste, the facility also would have to meet RCRA-type design and waste acceptance requirements. Therefore, the facility could have to be sited and designed to 11e.(2), LLRW, hazardous, or LLMW requirements. 40 CFR 192, 10 CFR 40, and 10 CFR 61 require that the disposal facility be designed to be reliable for at least 1,000 years. Besides the regulatory hurdles, the physical constraints and residual contamination in the BOP area limit the possible location of a new on-site engineered disposal facility at the NFSS.

  Due to the regulatory challenges and constraints associated with siting a new on-site engineered disposal facility, implementability is rated low.

- **Cost.** On-site disposal cost is dependent upon a number of variables, including the geometry of the disposal cell area and waste height, the production rate of the waste removal and treatment process, and the materials of construction. The range of unit pricing for on-site disposal is between \$82/yd^3 and \$150/yd^3 for smaller volumes (Martin 2003a, 2003b). It becomes more economical from a unit cost perspective when larger waste volumes are involved. The actual volume of IWCS waste subject to disposal is fairly well known. Based on the significantly elevated radium-226 concentrations associated with the residues in Subunit A, additional materials would be added to the in-situ volumes of the residues. Overall, the costs associated with the on-site disposal technology relative to off-site disposal technology are rated moderate.

  Costs associated with this technology also cannot be analyzed without inclusion of treatment and removal costs for Subunit A and removal costs for Subunits B and C. Removal and treatment costs are analyzed in Sections 4.4 and 4.6, respectively, providing additional costs to any design and construction of a new engineered disposal facility.

- **Evaluation Summary.** Disposal of IWCS residues and wastes at a new on-site disposal facility is not retained for further analysis because of the administrative challenges related to implementability. For any alternative that requires excavation and generation of waste that would require treatment of some or all of the waste stream, the regulations and practical considerations suggest that disposal should take place at an existing off-site disposal facility.

4.7.2 Off-Site Disposal Facility

Off-site disposal of IWCS residues and wastes requires removal, treatment, packaging, and transport of excavated material pursuant to disposal at a properly licensed disposal facility. The classification of a particular waste limits the options for selecting facilities that can receive the waste for disposal as well as imposes constraints on the type(s) of treatment and packaging that may be used to transport and dispose of the wastes in question.

- **Effectiveness.** Disposal of wastes in an off-site disposal facility has been deemed effective through the licensing facility processes. However, without some treatment prior to disposal, it does not reduce the toxicity, mobility, or volume of the contaminants. To mitigate this, the location of viable off-site facilities (typically dry climates) and the engineering design features of the disposal facility (e.g., liner integrity, monitoring, and mitigation procedures) have been selected to ensure effectiveness. Viable disposal facilities have been designed to be reliable for at least 200 years, and potentially for 1,000 years or longer, with the appropriate maintenance activities. Based on results of performance assessments conducted to evaluate the long-term effectiveness of two off-site disposal facilities for the 11e.(2) material, the off-site disposal option is highly effective.

  Environmental and human health risks are of principal concern when residues are being excavated and handled. Potential health impacts to site workers also include exposure to fugitive dust emissions and fugitive gases. Appropriate mitigative measures must be implemented during excavation to maintain exposures as low as reasonably achievable for both workers and members of the public. Actions also must preclude or minimize contaminant migration. Transportation and disposal of the K-65 residues and other residues/wastes would likely require specially designed and tested packaging together with trucks, rail cars, or intermodal containers, which can be transported by truck or rail. Significant other requirements, such as route controls and emergency response, during transport also may apply.

  Because the use of a licensed engineered disposal facility would reduce the exposure and mobility of the IWCS wastes, the effectiveness of off-site disposal is rated high.

- **Implementability.** Off-site disposal of the hazardous materials has been performed with proven procedures and widespread use in cases where wastes cannot remain on-site. Due to the classification of the IWCS residues and a significant portion of other waste as 11e.(2) byproduct materials (Table 2-2), viable off-site disposal facilities that are authorized to accept 11e.(2) byproduct material currently exist. Commercial facilities located in Utah and Texas have been identified as potential disposal facilities to accept this waste stream. Modifications to the existing facilities' license may be required to accept the NFSS waste, but with appropriate notification, this factor should not result in any implementability issues.

  The majority of the contaminated soil within the IWCS is considered LLRW because it had limited or no contact with the residues; therefore, some soil can be disposed of in an LLRW facility. Options for potential disposal of LLRW include facilities in Utah, Idaho, Texas, Michigan, Nevada, and Idaho (USACE 2011c).

  Given the presence of potentially hazardous materials at the NFSS, some soil may require disposal in an LLMW facility. USACE has assumed that 10% of the non-11e.(2) byproduct materials may require disposal in an LLMW facility. Potential options for off-site disposal of LLMW include facilities in Utah, Idaho, and Nevada (USACE 2011c).

  Several factors affect the implementability of off-site disposal. Compliance with disposal facility WAC and DOT transportation requirements will be the focus of remedial waste characterization, pre-disposal treatment (if required), and final physical waste form. Requirements for packaging and transporting radioactive materials are contained in 49 *CFR* 173 (i.e., packaging, handling, marking, labeling, placarding, and paperwork). DOT also has established standards for personnel training, conveyance performance, and maintenance. Additional DOT criteria, such as weight limits and oversized load restrictions, also must be considered during the development of remedial alternatives in the IWCS FS.

Out-of-state shipment will require special coordination with appropriate state and Federal agencies.

Some variations in waste volume noted in Table 2-3 will not impact the identification of the viable disposal facilities because the overall currently available disposal capacity is more than adequate to accommodate the processed waste volumes that can be reasonably expected. (These volumes include the in-situ waste plus the volume added by processing.) Therefore, the technical implementability for disposal in an off-site landfill is rated high.

- **Cost.** The waste classification and quantity of material for disposal most influences the cost. The final volume of waste subject to disposal during potential remediation may increase due to the removal or pre-shipping waste treatment activities. Based on the significantly elevated radium-226 concentrations associated with several of the IWCS waste streams (see Table 2-3), additional materials are assumed to be added to the in-situ volumes to reduce the radium-226 concentrations to meet disposal facility WAC and/or DOT shipping requirements.

  Costs for commercial treatment, storage, and disposal of wastes can vary significantly depending, in part, on the proximity of properly licensed disposal facilities to the NFSS. Other considerations with respect to off-site disposal include the modes of transportation that a specific facility can accommodate.

  As presented in the WDO/Fernald LL TM (USACE 2011c), the average off-site disposal unit cost is \$1,340/m^3 (\$1,025/yd^3) for 11e.(2) byproduct material waste. The average cost for LLRW ranges between \$350/m^3 (\$266/yd^3) and \$440/m^3 (\$338/yd^3). The average cost for LLMW ranges between \$475/m^3 (\$364/yd^3) and \$1,750/m^3 (\$1,341/yd^3). These estimates do not include packaging or transportation to an off-site facility. Overall, the costs associated with off-site disposal are rated high.

- **Evaluation Summary.** Disposal of IWCS residues and wastes at off-site disposal facilities is retained because its effectiveness is rated high and its implementability is high.

5.0 DEVELOPMENT OF REMEDIAL ALTERNATIVES

In this section, the remedial technologies and process options evaluated and retained in Section 4.0 are combined to develop alternatives that encompass a range of remedial actions. At some CERCLA sites, GRAs that have been retained may meet RAOs as a stand-alone remedy but, in the case of the IWCS OU, the GRAs must be combined to provide a complete remedy or to meet NCP requirements. Additionally, the no action alternative is evaluated as part of the FS process as a baseline for comparison to the other alternatives being considered (40 *CFR* 300.430[e][6]). Using the retained GRAs and technologies, the remedial actions developed for each IWCS OU subunit are as follows:

Subunit A: High-Activity Residues and Commingled Wastes Within Buildings 411, 413, and 414

A1: No Action
A2: Enhanced Containment with LUCs
A3: Removal, Treatment, and Off-Site Disposal

Subunit B: Debris and Wastes in the South End of the IWCS

B1: No Action
B2: Enhanced Containment with LUCs
B3: Removal and Off-Site Disposal

Subunit C: Residues and Wastes in the North End of the IWCS

C1: No Action
C2: Enhanced Containment with LUCs
C3: Removal and Off-Site Disposal

Each remedial action identified for each subunit is described in further detail below and includes the key remediation components (e.g., waste handling and off-site disposal) that are required to successfully implement the action. Some elements of the component descriptions are general in nature pending detailed analysis in the FS. Specific details (e.g., treatment rates, size and configuration of process areas, and remediation durations) will be determined during the FS due to potential overlap among subunit remedial actions.

5.1 Description of Subunit A Remedial Actions

5.1.1 Action A1: No Action

In accordance with the NCP (40 *CFR* 300.430[e][6]), the no action alternative shall be developed. This action is considered by EPA to equate with baseline conditions and defines baseline conditions (and baseline risk) to be those “associated with a site in the absence of any remedial action or control” (NCP 55 *Federal Register* 8666 at). “No action” is intended to account for maximum potential exposure, which means that exposure could be experienced in the absence of any form of active control (Federal or otherwise). Therefore, the baseline maximum potential exposure would be compatible with unlimited use and unrestricted exposure (e.g., residential land use).

Under Action A1, no remedial actions would be implemented for the residues and wastes contained within Buildings 411, 413, and 414 of the IWCS. The IWCS, residues, and waste materials would be left as-is, without the implementation of any other GRA, such as LUCs or any containment, removal, treatment, or other mitigating actions. No action also would not provide other access controls (e.g., physical barriers and deed restrictions) to reduce the potential for exposure. All existing LUCs and routine environmental monitoring and maintenance activities would cease. Because no actions would be taken under Action A1, this action has no remedial components.

The residual risk for Action A1 would be the baseline conditions associated with no continued controls for the site. With no LUCs, land use would not be restricted, and the current IWCS configuration would result in unacceptable exposures to a resident that builds a home with a basement over the area where the residues are located (National Research Council 1995). Without further actions to contain or control the residues and waste, the long-term protectiveness of the IWCS cannot be assured. However, the Federal Government is committed to operating, monitoring, and maintaining the IWCS and, although no action is not a realistic scenario, it is being evaluated to understand the risk that may exist if no additional actions were in place to be protective to the public.

5.1.2 Action A2: Enhanced Containment with Land-Use Controls

Under Action A2, enhancements to the IWCS would be implemented to reduce potential long-term exposures and releases of Subunit A wastes. The containment enhancements would likely include upgrades to the existing cap on the IWCS to minimize radionuclide migration, rainwater infiltration, inadvertent intrusion, biotic protection, and soil erosion. Under Action A2, no wastes would be removed from the IWCS and no treatment of the residues or commingled wastes within Building 411 would be completed.

Action A2 would include the continued ownership of the IWCS by the Federal Government, access controls including site security (i.e., fencing), and surveillance (inspections). LUCs also would include institutional controls to restrict groundwater use, disturbances to the IWCS, and long-term environmental monitoring to assess the protectiveness to human health and the environment.

Although the same waste materials would remain within the IWCS with no treatment or enhancements to waste form, as is the case for no action, the residual risk would be significantly less for Action A2. The enhanced containment system would be designed to preclude/minimize the potential for receptors to come in contact with the wastes and to minimize the potential for releases from the unit to the environment. Enhanced containment would reduce the potential exposures to radon from the IWCS wastes by increasing the thickness of the cap layers to those required by a final cap design. The final cap design would reduce infiltration through the use of a sand drainage layer that maintains a low static head on the composite geomembrane/clay barrier layer and by using a high-density geomembrane placed on top of, and in contact with, the clay unit to further reduce infiltration of water through the cap. The enhancements made to the existing cap increase the performance (allowable infiltration of precipitation through the cap) by up to two orders of magnitude. In addition, by increasing the thickness of materials overlying the clay barrier layer, further frost protection is realized, thus increasing the longevity of the cap.

Components of Action A2 include the following:

- Remedial design plan and activities,
- Site preparation/construction,
- Containment enhancements,
- Waste handling,
- Water treatment,
- Site restoration,
- LUCs, and
- Five-year reviews.

5.1.2.1 Remedial Design Plan and Activities

Remedial design plans would be developed prior to implementing the selected remedy and would include details of site preparation activities, design of facilities, implementation and sequence of construction activities, decontamination, segregation, and disposal of any generated waste streams. Also, a site-specific health and safety plan would be necessary to address the safety of remediation workers, on-site employees, and the general public.

5.1.2.2 Site Preparation/Construction

Enhanced containment may require rerouting of existing roads and water conveyances (ditches) along the southeast corner of the IWCS so that the expanded footprint of the modified IWCS containment system would not be impacted by these resources. A soil staging area for clean cap materials may be established to manage topsoil, drainage sand, and clay materials that would be removed from the cap during cap reconstruction. Temporary stormwater management controls (ponds and conveyances) would be established for management of stormwater run-off from the IWCS where the cover has been exposed.

5.1.2.3 Containment Enhancements

The containment enhancements proposed as part of Action A2 would likely include upgrades to the existing cap on the IWCS to minimize radionuclide migration, rainwater infiltration through the cap, inadvertent intrusion, biotic protection, and soil erosion. Enhancements may include modifying the current engineered multi-layer cap as follows:

- Adding a geomembrane directly above the clay layer to further reduce infiltration through the waste.
- Increasing the clay layer thickness to provide an additional barrier against rainwater infiltration through the waste.
- Adding a rock layer to restrict inadvertent intrusion through the cap and to act as root penetration and burrowing animal restriction.
- Adding a drainage layer between the geomembrane and topsoil/subsoil layers to prevent water buildup on the top of the geomembrane.
- Adding geotextile between the drainage layer and rip-rap and topsoil/subsoil and rip-rap layers to act as a filter to prevent clogging of the designed, free-draining layers.
- Adding engineered outlets to the drainage layer to allow free drainage above the permeable layer and to reduce infiltration through the waste.
- Adding clay fill material to the existing side slopes to reduce the maximum slope from 3:1 (33%) to 5:1 (20%) to provide a more stable slope.
- Adding rip-rap to the surface of the IWCS at the toe of the slope to an elevation protective of the maximum probable flood level to prevent erosion of the cap.
- Adjusting nearby roads and drainage ditches to accommodate the larger footprint of the cap.

After site preparation, in which temporary controls would become operable, the capping materials would be removed in successive layers and subsections down to the top of the clay layer and staged. The existing clay layer would remain in place and would be scarified to promote adhesion between the existing and new materials, and then new clay fill would be brought in and compacted along the sides and top of the IWCS to meet clay thickness and side slope design. Subsequent layers would be installed to enhance the clay barrier for drainage, erosion, and penetration and subsoil and topsoil layers, which would then be re-vegetated. Additional details of the enhancements to the engineered multi-layer cap will be provided in the feasibility study.

5.1.2.4 Waste Handling

Enhanced containment would not include disposal requirements for the removal of the Subunit A waste. However, management of construction-related wastes generated as part of the enhanced containment action may require disposal in an appropriate off-site disposal facility.

5.1.2.5 Water Treatment

Stormwater that may collect during construction activities inside the IWCS would require appropriate management practices such as filtration, carbon treatment, construction and operation of temporary stormwater collection ponds, sampling of stormwater during the construction phase, discharging treated water to a publicly owned treatment facility, hauling treated water off-site, and managing associated wastes generated during construction associated with water treatment.

5.1.2.6 Site Restoration

Restoration of the IWCS cap is addressed under containment enhancements. Backfilling of temporary cap material storage areas and/or ancillary roads may be required. Site restoration can progress area by area to prevent the occurrence of large disturbed areas in an attempt to minimize erosion and dust generation and in an effort to limit stormwater management.

5.1.2.7 LUCs

Under Action A2, access to the Subunit A residues and wastes within the IWCS would be controlled through appropriate institutional and engineering controls. These controls would be designed to be effective for up to 1,000 years to match the requirements under 40 *CFR* 192.02(a).

The existing institutional controls at the NFSS would be maintained as part of Action A2 and would include the continued ownership of the IWCS by the Federal Government. Current controls resulting from Federal Government ownership include the following:

- Site access procedures that prevent unauthorized entry and ensure adequate training for workers who must enter hazardous areas to minimize their exposures to contaminated media.
- Restrictions on groundwater use except for the purpose of monitoring.
- Administrative procedures requiring prior government approval for intrusive activities such as excavation and drilling to prevent disturbances to the cap or other components of the remedy.

In addition to the existing governmental controls listed above, the current property zoning for the NFSS excludes residential use.

Additional institutional controls would be implemented at the IWCS to meet the RAOs, if needed. The objectives of the LUCs could include the following:

- Prevent construction activities involving drilling, boring, digging, or other use of heavy equipment that could disturb vegetation, disrupt grading or drainage patterns, cause erosion, or otherwise compromise the integrity of the cover or manage these activities such that any damage to the cover is avoided or repaired as necessary.
- Prohibit the extraction, consumption, exposure, or use in any way of the groundwater underlying the IWCS without the prior written approval of the Federal Government.
- Provide for access necessary for continued maintenance/repair, monitoring, and site inspections.
- Ensure continued protectiveness in the event of a change in land use or property ownership.
- Provide information concerning the presence and location of residual COCs. This could be accomplished through deed notices, state registries, LUC tracking systems, or advisories.

Maintenance of the site perimeter fencing, access gates, internal fences, ropes, signs, and site security measures would continue. Periodic site inspections and review would be required to verify the integrity of the landfill cap. The site inspection and maintenance program for the IWCS would be upgraded as necessary to ensure protectiveness of the remedy.

Site monitoring will be conducted to document the effectiveness of this remedial action. Environmental monitoring would consist of air, groundwater, surface water, and sediment sampling. Air monitoring would include measurement of external gamma radiation, measurement of radon gas concentrations in air, monitoring of radon-222 flux, and air particulate monitoring. Air monitoring would be conducted during the implementation of this action to allow for modification of ongoing remediation activities (i.e., increased dust suppression or other engineering controls) to ensure that worker and public health is protected during site remediation. Air monitoring would continue after completion of the remedy to demonstrate continued protectiveness (in support of the CERCLA five-year reviews) and compliance with ARARs (e.g., 40 CFR Part 61 Subpart Q). The environmental monitoring program may include the monitoring of surface water and sediment for radioactive, metal, and organic constituents and the monitoring of the upper water-bearing zone and lower water-bearing zone for radioactive constituents, metals, and water quality parameters. The monitoring results would be reviewed after each round of sampling to determine if changes in the monitoring program (e.g., analyte list, sampling frequency, and sampling locations) are warranted. The environmental monitoring data would be evaluated to ensure that the remedy continues to be protective.

An Institutional Controls Plan would be developed after the ROD is approved to document the approach for implementing and maintaining the institutional controls.

5.1.2.8 Five-Year Reviews

Under this action, five-year reviews would be conducted in accordance with CERCLA 121(c) for areas where hazardous substances, pollutants, or contaminants are left above levels that allow for unlimited use or unrestricted exposure. The five-year reviews would demonstrate that controls are maintained and that the remedy remains protective of human health and the environment. Five-year reviews would be discontinued when no hazardous substances, pollutants, or contaminants remain on-site above levels that allow for unlimited use and unrestricted exposure. It is assumed that five-year reviews would be conducted for 1,000 years, consistent with the performance period requirements of 40 *CFR* 192.02(a).

5.1.3 Action A3: Removal, Treatment, and Off-Site Disposal

Under Action A3, the radioactive residues, Tower Soils, and contaminated rubble/debris placed in Buildings 411, 413, and 414 would be removed using mechanical or hydraulic methods. The Subunit A residues and waste would be treated by ex-situ S/S, containerized, and temporarily stored on-site prior to being transported to an off-site licensed disposal facility.

Characterization of waste removed as part of Subunit A would be conducted during the excavation to evaluate treatment requirements. After treatment, the waste would be required to be packaged and transported to meet DOT requirements or to meet the WAC of the off-site disposal facility. Contaminated debris located within Building 411 may undergo treatment by decontamination or use of surface barriers during removal. Building debris would be downsized and containerized for subsequent transfer to a temporary staging location on-site prior to shipment to an off-site disposal facility.

The in-situ volume of these residues and other wastes contained in Subunit A is approximately 33,200 m^3 (43,415 yd^3) (see Table 2-3). The final disposal volume will be dependent on the DOT requirements or the final WAC of the off-site waste disposal facility.

The greatest radium-226 source in Subunit A is the K-65 residues (520,000 pCi/g). If this source, along with the other residues in Subunit A, was removed approximately 98.8% of the radium source would be eliminated.

Under this action, the following component described for Action A2 would be included with no changes:

- Site restoration.

The additional Action A3 components are as follows:

- Remedial design plan and activities,
- Site preparation/construction,
- RCS,

- Waste removal,
- Treatment,
- Waste handling,
- Temporary storage,
- Water treatment,
- Transportation,
- Off-site disposal,
- LUCs, and
- Five-year reviews.

5.1.3.1 Remedial Design Plan and Activities

Remedial design plans would be developed prior to implementing the selected remedy and would include details of site preparation activities, additional characterization activities, design of facilities (e.g., processing, treatment, and shipment areas), implementation and sequence of construction and removal activities, decontamination, segregation, and disposal of any generated waste streams.

Additional characterization activities may involve taking numerous corings of the materials located in Buildings 411, 413, and 414 to provide better data necessary for the proper design and operation of the waste handling and processing operations. Also, a site-specific health and safety plan for the various remediation phases or areas would be necessary to address the safety of remediation workers, on-site employees, and the general public.

5.1.3.2 Site Preparation/Construction

The site preparation/construction activities may include clearing and grubbing of designated equipment and material lay down areas in the vicinity of the IWCS. Local roads and ditches along the southern and eastern boundaries of the IWCS may need to be re-routed out of the construction zone. The site preparation activities would consist of installing or armoring of haul truck roadways, site fencing, site lighting, and process water piping; any water treatment operations; and sewer lines, power poles, and the extension of site power to the areas requiring service. A soil storage area for clean cap materials may be established to manage topsoil, drainage sand, and clay materials that would be removed from the cap. Temporary stormwater management controls (ponds and conveyances) would be established for management of stormwater run-off from the IWCS where the cover has been exposed.

Other facilities to be constructed may include a storage facility for processed wastes, water treatment facilities and a control room, and an RCS that services all temporary containment structures housing these facilities and the construction containment area for Subunit A.

5.1.3.3 RCS

Any removal action that includes excavation of the residues in Subunit A would likely result in the release of radon gas due to the high levels of radium-226 in the residues, building materials in contact with the residues, and construction debris in contact with the residues. Air containment technologies will be a necessary component of the removal, handling, and treatment activities associated with Action A3. Air containment systems would be designed to meet worker exposure limits as well as off-site radon limits.

The implementation of an RCS may include the construction of a temporary containment structure(s) over the Subunit A removal, waste processing, and storage work areas. Several types of sprung structures covering 3,700 m^2 (40,000 ft^2) (or approximately 0.4 ha [1-acre]) are commercially available. Sprung structures are highly versatile yet sturdy and reliable. Structures can be designed to include personnel and cargo doors. Some modifications would have to be made to ensure the capture of radon in a filtration system. Air locks for both personnel and equipment would be included. A temporary containment structure could be constructed to cover the entire Subunit A area, or a large portion of it. Additional temporary structures may be required for separate processing and storage facilities. The building or structure(s) would prevent the release of radon and dust from the excavation area to the environment. These structures could require the same horizontal and vertical controls as a more permanent facility, but the design of the temporary structures should support removal, decontamination, and/or disposal of the structures at the completion of any removal activities.

One method for removal of radon gas and dust containing contaminants from the temporary containment structure(s) may include installation of an RCS employing air conditioning, dehumidification, and activated carbon and high-efficiency particulate air filtration. Control systems would monitor pressure, air flow, and other operating conditions. The gas could be cooled and dehumidified to enhance the adsorption capacity of the activated carbon and would then pass through activated carbon filters. Trapped radon would be allowed to decay within the carbon beds. Once the contaminated air travels through the carbon beds, it would then pass through secondary high-efficiency particulate air filters to remove any remaining particulate from the radon decay chain. Cleaned air would be vented back into the containment structure or exhausted.

5.1.3.4 Waste Removal

The removal of wastes located in Subunit A involves the removal of the radioactive residues, Tower Soils, and contaminated rubble/waste in contact with these residues. Many of the mechanical removal techniques described in Section 3.4.3 could be used to remove cap materials and overburden waste materials placed on top of Buildings 411, 413, and 414. Cap materials could be removed to access Subunit A residues and segregated as uncontaminated material. Additional clay materials below the cap would be evaluated for potential radiological contamination using radiological scanning and soil sorting, and uncontaminated materials will be staged outside of the IWCS footprint.

The removal of non-residue wastes located above the residues within Building 411 could be conducted using mechanical removal methods. General contaminated soil would likely be removed first, sampled, and stockpiled within the temporary staging areas until further waste handling. The removal of the Tower Soils and sand layers separating lower-residues layers within Building 411 also may be conducted using mechanical methods. Tower Soils and sand layers may be sampled and stockpiled in temporary staging areas prior to treatment using S/S.

The removal of residues located within Buildings 411, 413, and 414 may be accomplished using hydraulic or mechanical methods. Additional waste materials (clay, synthetic rubber, etc.) that were placed over the L-50 residues located in Buildings 413 and 414 also could be removed using conventional or remote mechanical methods, downsized or crushed, sampled or surveyed, and staged within the temporary staging areas until further waste handling. The interior surfaces of Buildings 411, 413, and 414 may be pressure washed as part of the removal activities associated Action A3 to meet the visual criteria for removal of Subunit A residues and wastes. High-level activity residues and other wastes from Subunit A could be managed within a temporary containment structure established outside of the IWCS for waste processing prior to disposal.

These removal activities would produce waste streams that would need to be actively managed to meet worker exposure limits, disposal requirements, and off-site disposal WAC. Monitoring of radon emissions as well as other contaminant emissions within work zones and at the site boundary would be included, as necessary, as part of this action.

5.1.3.5 Treatment

The radioactive residues, contaminated soil and Tower Soils contained in Buildings 411, 413, and 414 will be treated using ex-situ S/S at an on-site S/S facility. Conventional S/S (using cement and/or fly ash) as well as encapsulation methods (polymers) will be evaluated further during the FS as an ex-situ S/S treatment for the IWCS OU. Additionally, the sand layers that separate the Tower Soils and the residues may require treatment, as well as potentially a portion of the contaminated soil that was placed above the waste in Building 411. Ex-situ S/S will involve the addition of cement or a cement-based mixture that limits the solubility or mobility of the contaminants. The goals of the S/S process are to limit the spread of radioactive material via leaching and to trap and contain radon within a densified soil mass. Additionally, the waste form represents the first and foremost barrier to the release of radionuclides.

The residues and waste removed from the IWCS would be transferred to a treatment facility, which would be constructed on-site. Following batch mixing of the stabilizing agent with the waste, the material would be containerized and the solidified mass would be transported to either a temporary staging area on-site or directly to an off-site disposal facility. Radon emanated during the treatment process will be collected and routed to the RCS.

Prior to implementation, treatability studies will be necessary to determine the optimum conditions for maximizing long-term effectiveness of the treatment on the residues and soil matrix materials that have been placed in Buildings 411, 413, and 414.

5.1.3.6 Waste Handling

As part of the removal and treatment process for the Subunit A residues and wastes, a mechanical system to receive, move, stage, and prepare containers for treated waste could be developed. Much of the equipment could be designed to operate automatically and remotely to minimize personnel involvement and exposures in radiological areas. The waste packaging system would be designed to produce filled containers that are safe and secure for transfer directly to an off-site disposal facility. Any generated waste materials from the IWCS would be characterized to meet the WAC for the selected off-site disposal facility. As described under the discussion of the RCS, a temporary containment structure may be required to house the waste processing, treatment, packaging, and storage areas for materials removed from Subunit A.

Waste processing for highly active residues may involve downblending with lower-level waste materials prior to application of any treatment technologies. For planning purposes, the radium-226 concentration limit of 80,000 pCi/g is used to calculate potential disposal volumes. This radium-226 concentration limit is based on a DOT-compliant limit used by the Fernald Site for disposal of the K-65 residues (USACE 2011c). The DOT-compliant limit of 80,000 pCi/g is the average radium-226 concentration within a given transport vehicle upon receipt, not for each individual container on the transport. This limit is independent of any specific disposal facility but is used to provide consistency among disposal alternatives. Based on a radium-226 concentration limit of 80,000 pCi/g, the waste disposal volume that may have to be accommodated by the disposal facility just for Subunit A would be approximately 60,580 m^3 (79,225 yd^3). This estimated disposal volume is based on a volume multiplier of 6.5 for the K-65 residues (USACE 2011c) and a waste loading of 50% for the other residues and wastes located in Subunit A per the volumes noted in Table 2-3, except for the miscellaneous materials and materials added to Buildings 413 and 414, which is assumed will not be solidified. The DOT-compliant limit could be met by downblending with contaminated soil, but the volume of soil required likely renders this option infeasible for disposal in at least one of the two potential 11e.(2) off-site facilities (Section 4.0). The intentional mixing or downblending of soil (and soil-like materials) to achieve disposal facility WAC limits is consistent with the NRC policy discussed in NRC Policy Issue SECY-04-0035 (March 1, 2004). Mixing waste materials to lower the radionuclide concentration does not alter the isotopes present in the waste or the regulatory classification of the waste. This approach differs from the unacceptable practice of “diluting” RCRA waste to change the hazardous characteristics (and, therefore, the regulatory classification) of the waste.

The contaminated rubble/debris within Subunit A would likely be containerized using hazardous material handling containers or other strong tight-type containers before disposal. A key consideration for disposal is the development of a highly durable waste package (including the waste form and the surrounding container barriers) that ensures the long-term stability of waste. Packaging requirements for the treated residues and contaminated soil waste materials would likely include a custom Industrial Package Type 2 container, such as was utilized by the Fernald Site for their treated K-65 residues, that may be developed specific to the needs of the NFSS. To ensure proper quality standards, materials and product specifications for the waste containers would be developed. Quality control and inspection criteria would be documented to ensure that the containers meet the design standards. In-situ monitoring would be implemented to evaluate the performance of the waste package.

DOT and NRC set radioactive packaging standards for materials that are transported using truck and rail. Shipping container specifications are typically defined to meet DOT shipping requirements. For informational purposes, the radium-226 concentration allowed for DOT-compliant shipping of the K-65 residues at the Fernald Site was 80,000 pCi/g (USACE 2011c). Additionally, off-site disposal facility WAC are usually written to be consistent with approved DOT containers; however, the choice of shipping container may be influenced by the off-site disposal facility's WAC (USACE 2011c). The remaining wastes streams (contaminated rubble/debris) would likely be packaged using bulk containers. Based upon the WAC of the off-site disposal facility, these bulk materials also could be placed directly into a cell of the disposal facility. Other waste forms and packaging requirements would be dictated by the characteristics of the waste to be disposed and the WAC of the off-site facility.

5.1.3.7 Temporary Storage

Waste handling activities proposed under Action A3 may require temporary storage of processed and/or treated wastes pending transport to the off-site disposal facility. The treated material may be temporarily placed in the waste handling facility storage area until proper release tests have been performed for off-site release. Temporary storage may be required for a period of time until acceptance of the waste at the selected off-site disposal facility. Based on the uncertainty associated with the duration of storage, the estimated size necessary to accommodate the material handling, processing, and storage areas is approximately 13,900 to 14,900 m^2 (150,000 to 160,000 ft^2) or approximately 1.38 to 1.45 ha (3.4 to 3.6 acres).

5.1.3.8 Water Treatment

Any processed wastewater generated by Action A3 would require treatment. A pond system similar to that used during the IWCS construction could be used to process wastewater from removal activities and could be recycled until the bulk of the residues has been removed from Buildings 411, 413, and 414 and other ancillary water treatment requirements associated with the removal and disposal activities have been met.

Stormwater may collect in the excavation during construction activities inside the IWCS and would require appropriate management practices such as filtration, carbon treatment, construction and operation of temporary stormwater collection ponds, sampling of stormwater during the construction phase, discharging treated water to a publicly owned treatment facility, hauling treated water off-site, and managing associated wastes generated during construction associated with water treatment.

5.1.3.9 Transportation

Transportation of radioactive material is strictly regulated by DOT (e.g., packaging, handling, marking, labeling, placarding, and paperwork). Waste materials could be hauled to a licensed off-site disposal facility by direct load to a railcar, trucking to a rail-loading facility, or direct trucking to the disposal facility. For direct loading to a railcar, a rail spur would need to be constructed at the NFSS. Improvements to the existing road system at the NFSS may be required to accommodate the increased truck activity. Radiological concentrations for each package and associated weight limits for truck and rail would need to be assessed to determine if the transport of material met the exposure criteria specified in DOT regulations for shipments of radiological materials (49 *CFR* Part 173.441). All shipments may assume the use of exclusive-use, open transport vehicles. Shielding may be necessary for the K-65 residues to meet DOT regulations when shipped by truck or rail. Specialty-designed rail or truck flatbeds may be required for the shipment of K-65 residues.

Each shipment would be manifested to ensure that the NFSS waste materials are properly shipped and received by the off-site disposal facility. Regulated and licensed transportation would travel along pre-designated routes, and an emergency response plan will be developed. A more detailed evaluation of the transportation modes, routes, and waste volumes will be conducted during the FS.

5.1.3.10 Off-Site Disposal

The potential off-site waste disposal facilities identified in the WDO/Fernald LL TM (USACE 2011c) included those licensed for receipt of 11e.(2), LLRW, and LLMW materials. Subunit A wastes removed from the IWCS under this action would be disposed of at an off-site facility licensed to accept 11e.(2) waste. The selection of the off-site facility will consider the types of wastes, location, transportation options, and cost. Currently, two off-site facilities, located in Utah and Texas, have been identified that operate an 11e.(2) disposal cell and are viable options for disposal of the Subunit A waste. Shipments of 11e.(2) waste will be managed and disposed at the facilities in a separate disposal embankment or cell specifically licensed and designed for the material (USACE 2011c).

The WAC at the two facilities differ. The lower radiological limit defined in the off-site facility’s WAC is acceptance of 11e.(2) byproduct material within any transport vehicle (truck or railcar) not to exceed 4,000 pCi/g for natural uranium or any radionuclide in the radium-226 series. The radium-226 licensing limit of the second off-site disposal facilities’ WAC is 100,000 pCi/g. This concentration is based upon the Fernald Site K-65 wastes received at the facility (USACE 2011c). Some of the IWCS wastes (K-65 and L-30) would require downblending to meet the WAC of the 11e.(2) disposal facilities. The limit could be met by downblending with contaminated soil, but the volume of soil required likely renders this option infeasible. Therefore, treatment of the waste using ex-situ S/S would not only immobilize the residues and waste but also could be used to meet the WAC of the disposal facility. Therefore, the detailed analysis conducted in the FS will need to evaluate transportation and disposal costs based on the increased volumes.

The generator or owner of the waste is required to certify, in writing, that the waste is 11e.(2) byproduct material, as defined by the Atomic Energy Act as amended. Additionally, the generator or owner must certify that the waste does not contain any other radioactive or hazardous material (USACE 2011c). The potential constituents in the residues or other wastes will be accounted for in the analysis of disposal options in the detailed analysis of the FS.

Building materials and debris associated with Subunit A wastes may require size reduction if specified in the disposal facility’s WAC. This can be achieved using dismantlement equipment (e.g., crushing with an excavator bucket). Materials such as pipes could be cut to conform to this requirement. Debris that does not meet this size criterion would be categorized as oversized debris.

5.1.3.11 LUCs

During implementation of the remedial activities associated with Action A3, the existing institutional controls would be maintained, and additional controls would be implemented, if needed, for those areas where remediation is being conducted.

The routine environmental monitoring and maintenance described under Action A2 would continue during remediation. Engineering controls, including maintenance of the site perimeter fencing, access gates, internal fences, ropes, signs, and site security measures would continue. Routine environmental monitoring also would continue to assess the performance of the remedial actions and provide early warning of potential contaminant releases.

To avoid duplication of effort, LUCs are generally implemented on a property- or site-wide basis. For this reason, under this action, the LUCs could be implemented in conjunction with the LUCs implemented for the remaining subunits or the BOP OU. At the completion of activities associated with the removal, treatment, and off-site disposal of the Subunit A residues and wastes, LUCs and monitoring that may be needed to manage the residual risk resulting from the remaining IWCS soil and structures could be implemented either under a remedial action associated with Subunits B and/or C or under the BOP OU should all of the IWCS waste be removed from all subunits.

5.1.3.12 Five-Year Reviews

After removal of all wastes from Subunit A, hazardous materials, pollutants, and/or contaminants may remain on-site above levels that allow for unlimited use and unrestricted exposure. Therefore, a CERCLA five-year review is required under this action. Five-year reviews would be discontinued when no hazardous substances, pollutants, or contaminants remain on-site above levels that allow for unlimited use and unrestricted exposure. It is assumed that five-year reviews would be conducted for 1,000 years, consistent with the performance period requirements of 40 *CFR* 192.02(a).

5.2 Descriptions of Subunit B Remedial Actions

5.2.1 Action B1: No Action

In accordance with the NCP (40 *CFR* 300.430[e][6]), the no action alternative shall be developed. This action is considered by EPA to equate with baseline conditions and defines baseline conditions (and baseline risk) to be those “associated with a site in the absence of any remedial action or control” (NCP 55 *Federal Register* 8711). No action is intended to account for maximum potential exposure, which means that exposure could be experienced in the absence of any form of active control (Federal or otherwise). Therefore, the baseline maximum potential exposure would be compatible with unlimited use and unrestricted exposure (e.g., residential land use).

Under Action B1, no remedial actions would be implemented for the structures of Buildings 411, 413, and 414 and the contaminated rubble/wastes and soil located outside of Buildings 411, 413, and 414 in the south end of the IWCS. The IWCS, residues, and waste materials would be left as-is, without the implementation of any other GRA, such as LUCs or any containment, removal, treatment, or other mitigating actions. No action also would not provide other access controls (e.g., physical barriers and deed restrictions) to reduce the potential for exposure. All existing LUCs and routine environmental monitoring and maintenance activities would cease. Because no actions would be taken under Action B1, it has no remedial components.

The residual risk for Action B1 would be the baseline conditions associated with no continued controls for the site. Without further actions to contain or control the residues and waste, the long-term protectiveness of the IWCS cannot be assured. However, the Federal Government is committed to operating, monitoring, and maintaining the IWCS and, although no action is not a realistic scenario, it is being evaluated to understand the risk that may exist if LUCs were not in place to be protective to the public.

5.2.2 Action B2: Enhanced Containment with Land-Use Controls

Under Action B2, enhancements to the IWCS would be implemented to reduce potential long-term exposures and releases of Subunit B wastes. As described under Action A2, the containment enhancements would likely include upgrades to the existing cap on the IWCS to minimize radionuclide migration, rainwater infiltration, inadvertent intrusion, biotic protection, and soil erosion. No waste materials would be removed from this part of the IWCS.

Action B2 would include the continued ownership of the IWCS by the Federal Government, access controls including site security (i.e., fencing), and surveillance (inspections). LUCs also would include institutional controls to restrict groundwater use, disturbances to the IWCS, and long-term environmental monitoring to assess the protectiveness to human health and the environment.

Although the Subunit B waste materials are located within the IWCS, with no treatment or enhancements to waste form, as is the case for no action, the residual risk would be significantly less for Action B2. The enhanced containment system would be designed to preclude/minimize the potential for receptors to come in contact with the wastes and to minimize the potential for releases from the unit to the environment. Enhanced containment would reduce the potential exposures to radon from the IWCS wastes by increasing the thickness of the cap layers to those required by a final cap design. The final cap design would reduce infiltration through the use of a sand drainage layer that maintains a low static head on the composite geomembrane/clay barrier layer and by using a high-density geomembrane placed on top of, and in contact with, the clay unit to further reduce infiltration of water through the cap. The enhancements made to the existing cap increase the performance (allowable infiltration of precipitation through the cap) by up to two orders of magnitude. In addition, by increasing the thickness of materials overlying the clay barrier layer, further frost protection is realized, thus increasing the longevity of the cap.

Components of Action B2 include the following:

- Remedial design plan and activities,
- Site preparation/construction,
- Containment enhancements,
- Waste handling,
- Water treatment,
- Site restoration,
- LUCs, and
- Five-year reviews.

5.2.2.1 Remedial Design Plan and Activities

Remedial design plans would be developed prior to implementing the selected remedy and would include details of site preparation activities, design of facilities, implementation and sequence of construction activities, decontamination, segregation, and disposal of any generated waste streams. Also, a site-specific health and safety plan would be necessary to address the safety of remediation workers, on-site employees, and the general public.

5.2.2.2 Site Preparation/Construction

Enhanced containment may require rerouting of existing roads and water conveyances (ditches) along the southeast corner of the IWCS so that the expanded footprint of the modified IWCS containment system would not be impacted by these resources. A soil staging area for clean cap materials could be established to manage topsoil, drainage sand, and clay materials that would be removed from the cap during cap reconstruction. Temporary stormwater management controls (ponds and conveyances) may be established for management of stormwater run-off from the IWCS where the cover has been exposed.

5.2.2.3 Containment Enhancements

The containment enhancements proposed as part of Action B2 would likely include upgrades to the existing cap on the IWCS to minimize radionuclide migration, rainwater infiltration through the cap, inadvertent intrusion, biotic protection, and soil erosion. Enhancements to the existing cap may include modifying the current engineered multi-layer cap as follows:

- Adding a geomembrane directly above the clay layer to further reduce infiltration through the waste.

- Increasing the clay layer thickness to provide an additional barrier against rainwater infiltration through the waste.
- Adding a rock layer to restrict inadvertent intrusion through the cap and to act as root penetration and burrowing animal restriction.
- Adding a drainage layer between the geomembrane and topsoil/subsoil layers to prevent water buildup on the top of the geomembrane.
- Adding geotextile between the drainage layer and rip-rap and topsoil/subsoil and rip-rap layers to act as a filter to prevent clogging of the designed, free-draining layers.
- Adding engineered outlets to the drainage layer to allow free drainage above the permeable layer and to reduce infiltration through the waste.
- Adding clay fill material to the existing side slopes to reduce the maximum slope from 3:1 (33%) to 5:1 (20%) to provide a more stable slope.
- Adding rip-rap to the surface of the IWCS at the toe of the slope to an elevation protective of the maximum probable flood level to prevent erosion of the cap.
- Adjusting nearby roads and drainage ditches to accommodate the larger footprint of the cap.

After site preparation in which temporary controls become operable, the capping materials would be removed in successive layers to the top of the clay layer and staged. The existing clay layer would be scarified to promote adhesion between the existing and new materials, and then new clay fill may be brought in and compacted to meet clay thickness and side slope design. Subsequent layers would be installed to enhance the clay barrier for drainage, erosion, and penetration and subsoil and topsoil layers which would then be re-vegetated.

Containment enhancements proposed could be impacted by any removal actions associated with the Subunit A materials. For example, if the removal of Subunit A materials for off-site disposal is implemented (Action A3), it would result in an unfilled excavation of at least 33,200 m^3 (43,415 yd^3) based on the volumes presented in Table 2-3. The void left by the removal of Subunit A wastes may need to be filled to a common grade with the rest of the IWCS. If necessary, additional fill materials could be brought in from on-site locations and/or from off-site sources. After the IWCS wastes have been reshaped into the final configuration, capping materials would be reinstalled based on the final design requirements as described in the other alternatives for enhanced containment.

5.2.2.4 Waste Handling

Enhanced containment would not include disposal requirements for removal of Subunit B waste. However, management of construction-related wastes generated as part of the enhanced containment action may require disposal in an appropriate off-site disposal facility.

5.2.2.5 Water Treatment

Stormwater that may collect during construction activities inside the IWCS would require appropriate management practices such as filtration, carbon treatment, construction and operation of temporary stormwater collection ponds, sampling of stormwater during the construction phase, discharging treated water to a publicly owned treatment facility, hauling treated water off-site, and managing associated wastes generated during construction associated with water treatment.

5.2.2.6 Site Restoration

Restoration of the IWCS cap is addressed under containment enhancements. Backfilling of temporary cap material staging areas and/or ancillary roads is included. Site restoration can progress area by area to prevent the occurrence of large disturbed areas in an attempt to minimize erosion and dust generation and in an effort to limit stormwater management.

5.2.2.7 LUCs

Under Action B2, access to radioactive residues and wastes within the IWCS would be controlled through appropriate institutional and engineering controls. These controls would be designed to be effective for up to 1,000 years, to match the design requirements under 40 *CFR* 192.02(a).

Action B2 would include the use of controls resulting from continued ownership of the IWCS by the Federal Government. The existing institutional controls at the NFSS would be maintained. The current controls resulting from Federal Government ownership include the following:

- Site access procedures that prevent unauthorized entry and ensure adequate training for workers who must enter hazardous areas to minimize their exposures to contaminated media.
- Restrictions on groundwater use except for the purpose of monitoring.
- Administrative procedures requiring prior governmental approval for intrusive activities such as excavation and drilling to prevent disturbances to the cap or other components of the remedy activities unless prior governmental approval is obtained.

In addition to the above existing governmental controls, the current property zoning for the NFSS excludes residential use.

Additional institutional controls would be implemented at the IWCS to meet the RAOs, if needed. The objectives of the LUCs could include the following:.

- Prevent construction activities involving drilling, boring, digging, or other use of heavy equipment that could disturb vegetation, disrupt grading or drainage patterns, cause erosion, or otherwise compromise the integrity of the cover or manage these activities such that any damage to the cover is avoided or repaired as necessary.
- Prevent withdrawal and/or use of groundwater.
- Provide for access necessary for continued maintenance/repair, monitoring, and site inspections.
- Ensure continued protectiveness in the event of a change in land use or property ownership.
- Provide information concerning the presence and location of residual COCs. This could be accomplished through deed notices, state registries, LUC tracking systems, or advisories.

Maintenance of the site perimeter fencing, access gates, internal fences, ropes, signs, and site security measures would continue. Periodic site inspections and review would be required to verify the integrity of the landfill cap. The site inspection and maintenance program for the IWCS would be upgraded as necessary to ensure protectiveness of the remedy.

Site monitoring would be conducted to document the effectiveness of this remedial action. Environmental monitoring may consist of air, groundwater, surface water, and sediment sampling. Air monitoring may include measurement of external gamma radiation, measurement of radon gas concentrations in air, monitoring of radon-222 flux, and air particulate monitoring. The environmental monitoring program could include the monitoring of surface water and sediment for radioactive, metal, and organic constituents and the monitoring of the upper water-bearing zone and lower water-bearing zone for radioactive constituents, metals, and water quality parameters. The monitoring results may be reviewed after each round of sampling to determine if changes in the monitoring program (e.g., analyte list, sampling frequency, and sampling locations) are warranted. The environmental monitoring data would be evaluated to ensure that the remedy continues to be protective.

An Institutional Controls Plan would be developed after the ROD is approved to document the approach for implementing and maintaining the institutional controls.

5.2.2.8 Five-Year Review

Under this action, five-year reviews would be conducted in accordance with CERCLA 121(c) for areas where hazardous substances, pollutants, or contaminants are left above levels that allow for unlimited use or unrestricted exposure. The five-year reviews would demonstrate that controls are maintained and that the remedy remains protective of human health and the environment. Five-year reviews would be discontinued when no hazardous substances, pollutants, or contaminants remain on-site above levels that allow for unlimited use and unrestricted exposure. It is assumed that five-year reviews would be conducted for 1,000 years, consistent with the performance period requirements of 40 *CFR* 192.02(a).

5.2.3 Action B3: Removal and Off-Site Disposal

Under Action B3, the contaminated building debris, underground piping, equipment debris, and contaminated soil placed outside of Buildings 411, 413, and 414 in the south end of the IWCS would be removed using mechanical methods. The remaining buildings (e.g., Buildings 411, 413, and 414) and foundations within the southern containment area of the IWCS (e.g., Building 410) would be demolished. Building surfaces of Buildings 411, 413, and 414 may undergo treatment by decontamination or use of surface barriers prior to demolition. Building debris would be downsized and containerized for subsequent transfer to a temporary staging area on-site prior to being transported to an off-site licensed disposal facility. Characterization of waste removed as part of Subunit B would be conducted during any excavation and removal to determine whether the waste meets the WAC of the receiving off-site facility. All Subunit B waste would be required to be packaged and transported to meet DOT requirements.

Based on the volumes tabulated in Table 2-3, the total in-situ volume of material that would be removed is approximately 71,740 m^3 (98,830 yd^3). Based on the radium-226 concentrations presented in Table 2-3, treatment by ex-situ S/S will not be conducted on the Subunit B wastes and, therefore, the disposal volume is assumed to be the same.

The greatest radium-226 source in Subunit B is associated with the estimated concentration calculated for the contaminated building rubble of Building 411 (6,181 pCi/g). If this source, along with the other debris and waste in Subunit B, was removed, approximately 1.18% of the radium source would be eliminated.

Under this action, the following component described for Action B2 would be included with no changes:

- Site restoration.

Action B2 components requiring revised discussions and additional components that would be necessary for Action B3 are as follows:

- Remedial design plan and activities,
- Site preparation/construction,
- RCS,
- Waste removal,
- Treatment,
- Waste handling,
- Temporary storage,
- Water treatment,
- Transportation,
- Off-site disposal,
- LUCs, and
- Five-year reviews.

5.2.3.1 Remedial Design Plan and Activities

Remedial design plans would be developed prior to implementing the selected remedy and would include details of site preparation activities, additional characterization activities, design of facilities (e.g., processing, treatment, and shipment areas), implementation and sequence of construction and removal activities, decontamination, segregation, and disposal of any generated waste streams.

Additional characterization activities may involve taking numerous corings of the materials located in the south end of the IWCS to provide better data necessary for the proper design and operation of the waste handling and processing operations. Also, a site-specific health and safety plan for the various remediation phases or areas would be necessary to address the safety of remediation workers, on-site employees, and the general public.

5.2.3.2 Site Preparation/Construction

The site preparation/construction activities may include clearing and grubbing of designated equipment and material lay down areas in the vicinity of the IWCS. Local roads and ditches along the southern and eastern boundaries of the IWCS may need to be re-routed out of the construction zone. The site preparation activities would consist of installing or armoring haul truck roadways, site fencing, site lighting, and process water piping; any water treatment operations; and sewer lines, power poles, and the extension of site power to the areas requiring service. A soil storage area for clean cap materials may be established to manage topsoil, drainage sand, and clay materials that would be removed from the cap. Temporary stormwater management controls (ponds and conveyances) would be established for management of stormwater run-off from the IWCS where the cover has been exposed.

Other facilities that would be constructed as described under Action A3 for the removal of wastes from Subunit A would include a processing and packaging facility, a storage facility for processed wastes, water treatment facilities and a control room, and an RCS. These facilities would be available for use for removal, packaging, and shipment of specific wastes associated with Subunit B.

5.2.3.3 RCS

The RCS described under Action A3 that would be constructed as part of the removal of Subunit A wastes also would be available for Subunit B waste removal activities if necessary. The need for any RCS would be determined based on the results of the characterization sampling to be conducted for Subunit B. For any Subunit B areas where an elevated potential for worker exposure or release of radon gas may be of concern, temporary containment structures would be extended, moved, or installed over the areas within the south end so that the RCS may be implemented during excavation or during shifting and sorting of the Subunit B waste materials within the IWCS. Some reductions in the use of the RCS during removal of the Subunit B wastes are anticipated due to the anticipated reductions in radiological activity of the wastes included in Subunit B. Work zone and site boundary monitoring and waste characterization activities will support decisions on the ongoing use of the RCS.

5.2.3.4 Waste Removal

Mechanical removal techniques described in Section 3.4.3 may be used to remove cap materials and overburden waste materials placed on top of the south end of the IWCS. Cap materials would be removed to access Subunit B wastes and then would be segregated from the waste material. Additional clay materials below the cap may be evaluated for potential radiological contamination and radiological scanning and soil sorting, and uncontaminated materials will be staged outside of the IWCS footprint.

The removal of contaminated soil surrounding Buildings 411, 413, and 414 would be conducted using mechanical removal methods. General contaminated soil would likely be removed first, sampled, and then stockpiled within the temporary storage areas until further waste handling. Building debris placed within

Building 410 and any other foundations, building debris, underground pipes, or contaminated equipment that were placed in the south end of the IWCS could be removed using mechanical methods, downsized or crushed, sampled or surveyed, and staged within the temporary storage areas until further waste handling.

If the residues and wastes are removed from Buildings 411, 413, and 414 under Action A3, the interior surfaces of Buildings 411, 413, and 414 also would be decontaminated as described under Action A3. Additional decontamination of Buildings 411, 413, and 414 may be necessary as part of the removal of wastes from the south end of the IWCS. The decontamination methods would be conducted as described under Action A3. Removal of Buildings 411, 413, and 414 would require mechanical demolition by the use of hydraulic breakers and concrete cutting. Waste processing for building demolition and construction debris also could involve manual or mechanical technologies to break up the material for disposal.

Waste materials from Subunit B may be managed in piles within the IWCS or, if necessary based on sampling results, could be staged within the RCS containment area. A temporary construction berm also may be constructed to isolate potential run-off from these storage areas to the rest of the IWCS.

These removal activities could produce waste streams that may need to be actively managed to meet worker exposure limits, disposal requirements, and off-site disposal WAC. Monitoring of radon emissions within work zones and at the site boundary would be included, as necessary, as part of this action.

5.2.3.5 Treatment

The primary method for decontamination of building structures (Buildings 411, 413, and 414) could be high-pressure water. Flushing building surfaces with water using high-pressure water jet or an abrasive water jet results in contaminated particulates being dissolved or dislodged. The resulting water would be collected and routed for water treatment. The interior surfaces of Buildings 411, 413, and 414 may be pressure washed as part of removal activities associated Action A3 to meet the visual criteria for removal of Subunit A residues and wastes.

Radiation surveys would be conducted after treatment to determine if building surfaces meet WAC for the selected off-site disposal facility or if additional decontamination is necessary. Grout or other surface barrier materials may be applied to building materials (e.g., the interior walls of Building 411) prior to demolition to prevent the release of radon contained within the debris based upon health and safety evaluations during remediation of Subunit B.

Although the contaminated rubble/debris included in Subunit B has not been previously characterized, their radiological concentrations are expected to be significantly lower than concentrations of the residues based on the placement of the materials outside of Buildings 411, 413, and 414. Subunit B wastes are not proposed for S/S treatment; although, waste characterization conducted during removal of the Subunit B material may result in some wastes recommended for treatment to meet the DOT requirements or the WAC for the off-site disposal facility.

5.2.3.6 Waste Handling

The contaminated rubble/debris and contaminated soil within Subunit B would likely be containerized using hazardous material handling containers or other strong tight-type containers before disposal. Packaging requirements for the contaminated soil, contaminated rubble/debris, and other Subunit B waste materials would likely use bulk containers. Other waste forms and packaging requirements will be dictated by the characteristics of the waste to be disposed and the WAC of the off-site facility.

5.2.3.7 Temporary Storage

Waste handling activities proposed under Action B3 may require temporary storage of processed wastes pending transport to the off-site disposal facility. Subunit B packaged wastes may require temporary placement until proper release tests have been performed for off-site release. Additionally, temporary storage may be required for a period of time until acceptance of the waste at the selected off-site disposal facility. Based on this uncertainty as to the duration of storage, the estimated size necessary to accommodate the material handling, processing, and storage areas is approximately 13,900 to 14,900 m^2 (150,000 to 160,000 ft^2) or approximately 1.38 to 1.45 ha (3.4 to 3.6 acres).

5.2.3.8 Water Treatment

Water used for the decontamination of the structures of Buildings 411, 413, and 414 in Subunit B would require treatment. A pond system similar to that used during the IWCS construction could be used to process wastewater from the decontamination activities. Any processed wastewater would be recycled until the building structures have been demolished and removed or any other ancillary water treatment requirements associated with the removal and disposal activities have been met.

Stormwater may collect in the excavation during construction activities inside the IWCS and would require appropriate management practices such as filtration, carbon treatment, construction and operation of temporary stormwater collection ponds, sampling of stormwater during the construction phase, discharging treated water to a publicly owned treatment facility, hauling treated water off-site, and managing associated wastes generated during construction associated with water treatment.

5.2.3.9 Transportation

Transportation of radioactive material is strictly regulated by DOT (e.g., packaging, handling, marking, labeling, placarding, and paperwork). Waste materials could be hauled to a licensed off-site disposal facility by direct load to a railcar, trucking to a rail-loading facility, or direct trucking to the disposal facility. For direct loading to a railcar, a rail spur would need to be constructed at the NFSS. Improvements to the existing road system at the NFSS may be required to accommodate the increased truck activity. Radiological concentrations for each package and associated weight limits for truck and rail would need to be assessed to determine if the transport of material met the exposure criteria specified in DOT regulations for shipments of radiological materials (49 *CFR* Part 173.441).

Each shipment would be manifested to ensure that the NFSS waste materials are properly shipped and received by the off-site disposal facility. Regulated and licensed transportation would travel along pre-designated routes, and an emergency response plan will be developed. A more detailed evaluation of the transportation modes, routes, and waste volumes will be conducted during the FS.

5.2.3.10 Off-Site Disposal

The off-site disposal of Subunit B wastes generated under Action B3 would require disposal in an 11e.(2)-licensed or an LLRW-licensed facility. Because some of the contaminated rubble and debris identified as being placed in the south end of the IWCS is associated with the former storage and handling of the K-65 residues, this debris is deemed as 11e.(2) waste. Additionally, contaminated debris contained in Buildings 410 and 415 (Figure 1-3) within the south end of the IWCS also are deemed 11e.(2) waste because these building structures were once used for storage of the residues now contained in Subunit A. The potential constituents in the residues or other wastes will be accounted for in the analysis of disposal options in the detailed analysis of the FS.

The selection of the off-site facility will consider the types of wastes, location, transportation options, and cost. Currently, two off-site 11e.(2) disposal facilities described under Action A3 also are viable options for disposal of the Subunit B waste. The WAC at the two facilities differ. The lower radiological limit defined in the off-site facility's WAC is acceptance of 11e.(2) byproduct material within any transport vehicle (truck or railcar) not to exceed 4,000 pCi/g for natural uranium or any radionuclide in the radium-226 series. The radium-226 licensing limit of the second off-site disposal facilities' WAC is 100,000 pCi/g. This concentration is based upon the Fernald Site K-65 wastes received at the facility (USACE 2011c). Shipments of 11e.(2) waste will be managed and disposed at the facilities in a separate disposal embankment or cell specifically licensed and designed for the material (USACE 2011c).

The generator or owner of the waste is required to certify, in writing, that the waste is 11e.(2) byproduct material, as defined by the Atomic Energy Act as amended. Additionally, the generator or owner must certify that the waste does not contain any other radioactive or hazardous material (USACE 2011c).

Both 11e.(2) facilities described above also are licensed to accept LLRW and LLMW. Due to more stringent engineering controls, the limit for radium-226 in the LLRW and LLMW cells is 10,000 pCi/g. Based on these activity levels, there would be no need to treat the Subunit B materials to reduce the radium-226 activity levels to meet their WAC. Therefore, the disposal volume is approximately 71,740 m^3 (93,830 yd^3). Other facilities located in Idaho, Michigan, and Nevada also were determined to be viable options for off-site disposal of LLRW and LLMW. The WAC limits for radium-226 concentrations of the waste at these facilities range between 50 and 500 pCi/g (USACE 2011c). These later facilities are not being considered for the Subunit B wastes.

Building materials and debris associated with Subunit B wastes may require size reduction if specified in the disposal facility's WAC. This can be achieved using dismantlement equipment (e.g., crushing with an excavator bucket). Materials such as pipes could be cut to conform to this requirement. Debris that does not meet this size criterion would be categorized as oversized debris.

5.2.3.11 LUCs

During implementation of the remedial activities associated with Action B3, the existing land-use controls would be maintained, and additional controls would be implemented, if needed, for those areas where remediation is being conducted. See Section 5.2.2.7 for further information concerning the existing LUCs and the additional LUCs that could be implemented at the site. Engineering controls, including maintenance of the site perimeter fencing, access gates, internal fences, ropes, signs, and site security measures, would continue during remediation. Routine environmental monitoring would be conducted to assess the performance of the remedial actions and to provide early warning of potential contaminant releases.

To avoid duplication of effort, LUCs are generally implemented on a property- or site-wide basis. For this reason, under this action, the LUCs could be implemented in conjunction with the LUCs implemented for the remaining subunits or the BOP OU. At the completion of activities associated with the removal, treatment, and off-site disposal of the Subunit B wastes, LUCs and monitoring that may be needed to manage the residual risk resulting from the remaining IWCS soil and structures could be implemented either under a remedial action associated with Subunit A and/or C or under the BOP OU should all of the IWCS waste be removed from all subunits.

5.2.3.12 Five-Year Reviews

After removal of all wastes from Subunit B, hazardous materials, pollutants, and/or contaminants may remain on-site above levels that allow for unlimited use and unrestricted exposure. Five-year reviews would be discontinued when no hazardous substances, pollutants, or contaminants remain on-site above levels that allow for unlimited use and unrestricted exposure. It is assumed that five-year reviews would be conducted for 1,000 years, consistent with the performance period requirements of 40 *CFR* 192.02(a).

5.3 Descriptions of Subunit C Remedial Actions

5.3.1 Action C1: No Action

In accordance with the NCP (40 *CFR* 300.430[e][6]), the no action alternative shall be developed. This action is considered by EPA to equate with baseline conditions and defines baseline conditions (and baseline risk) to be those “associated with a site in the absence of any remedial action or control” (NCP 55 *Federal Register* 8711). No action is intended to account for maximum potential exposure, which means that exposure could be experienced in the absence of any form of active control (Federal or otherwise). Therefore, the baseline maximum potential exposure would be compatible with unlimited use and unrestricted exposure (e.g., residential land use).

Under Action C1, no remedial actions would be implemented for the contaminated soil and wastes located in the north end of the IWCS. IWCS and waste materials would be left as-is, without the implementation of any other GRA, such as LUCs or any containment, removal, treatment, or other mitigating actions. No action also would not provide other access controls (e.g., physical barriers and deed restrictions) to reduce the potential for exposure. All existing LUCs and routine environmental monitoring and maintenance activities would cease. Because no actions would be taken under Action C1, this action has no remedial components.

The residual risk for Action C1 would be the baseline conditions associated with no continued controls for the site. Without further actions to contain or control the residues and waste, the long-term protectiveness of the IWCS cannot be assured. However, the Federal Government is committed to operating, monitoring, and maintaining the IWCS and, although no action is not a realistic scenario, it is being evaluated to understand the risk that may exist if LUCs were not in place to protect the public.

5.3.2 Action C2: Enhanced Containment with Land-Use Controls

Under Action C2, enhancements to the IWCS would be implemented to reduce potential long-term exposures and releases of Subunit C wastes. The containment enhancements would include upgrades to the existing cap on the IWCS to minimize radionuclide migration, rainwater infiltration through the cap, inadvertent intrusion, biotic protection, and soil erosion. Under Action C2, no waste materials would be removed from this part of the IWCS.

Action C2 would include the continued ownership of the IWCS by the Federal Government, access controls including site security (i.e., fencing), and surveillance (inspections). LUCs also would include institutional controls to restrict groundwater use, disturbances to the IWCS, and long-term environmental monitoring to assess the protectiveness to human health and the environment.

Although the same waste materials are located within the IWCS, with no treatment or enhancements to waste form, as is the case for no action, the residual risk would be significantly less for Action C2. The enhanced containment system would be designed to preclude/minimize the potential for receptors to come in contact with the wastes and to minimize the potential for releases from the unit to the environment. Enhanced containment would reduce the potential exposures to radon from the IWCS wastes by increasing the thickness of the cap layers to those required by a final cap design. The final cap design would reduce infiltration through the use of a sand drainage layer that maintains a low static head on the composite geomembrane/clay barrier layer and by using a high-density geomembrane placed on top of, and in contact with, the clay unit to further reduce infiltration of water through the cap. The enhancements made to the existing cap increase the performance (allowable infiltration of precipitation through the cap) by up to two orders of magnitude. In addition, by increasing the thickness of materials overlying the clay barrier layer, further frost protection is realized, thus increasing the longevity of the cap.

Components of Action C2 include the following:

- Remedial design plan and activities,
- Site preparation/construction,
- Containment enhancements,
- Waste handling,
- Water treatment,
- Site restoration,
- LUCs, and
- Five-year reviews.

5.3.2.1 Remedial Design Plan and Activities

Remedial design plans would be developed prior to implementing the selected remedy and would include details of site preparation activities, design of facilities, implementation and sequence of construction activities, decontamination, segregation, and disposal of any generated waste streams. Also, a site-specific health and safety plan would be necessary to address the safety of remediation workers, on-site employees, and the general public.

5.3.2.2 Site Preparation/Construction

Enhanced containment may require rerouting of existing roads and water conveyances (ditches) along the southeast corner of the IWCS so that the expanded footprint of the modified IWCS containment system would not be impacted by these resources. A soil staging area for clean cap materials may be established to manage topsoil, drainage sand, and clay materials that would be removed from the cap during cap reconstruction. Temporary stormwater management controls (ponds and conveyances) would be established for management of stormwater run-off from the IWCS where the cover has been exposed.

5.3.2.3 Containment Enhancements

The containment enhancements proposed as part of Action C2 would likely include upgrades to the existing cap on the IWCS to minimize radionuclide migration, rainwater infiltration through the cap, inadvertent intrusion, biotic protection, and soil erosion. Enhancements to the existing cap may include modifying the current engineered multi-layer cap as follows:

- Adding a geomembrane directly above the clay layer to further reduce infiltration through the waste.
- Increasing the clay layer thickness to provide an additional barrier against rainwater infiltration through the waste.
- Adding a rock layer to restrict inadvertent intrusion through the cap and to act as root penetration and burrowing animal restriction.
- Adding a drainage layer between the geomembrane and topsoil/subsoil layers to prevent water buildup on the top of the geomembrane.
- Adding geotextile between the drainage layer and rip-rap and topsoil/subsoil and rip-rap layers to act as a filter to prevent clogging of the designed, free-draining layers.
- Adding engineered outlets to the drainage layer to allow free drainage above the permeable layer and to reduce infiltration through the waste.
- Adding clay fill material to the existing side slopes to reduce the maximum slope from 3:1 (33%) to 5:1 (20%) to provide a more stable slope.
- Adding rip-rap to the surface of the IWCS at the toe of the slope to an elevation protective of the maximum probable flood level to prevent erosion of the cap.
- Adjusting nearby roads and drainage ditches to accommodate the larger footprint of the cap.

After site preparation in which temporary controls become operable, the capping materials would be removed in successive layers and subsections down to the top of the clay layer and staged. The existing clay layer would be scarified to promote adhesion between the existing and new materials, and then new clay fill would be brought in and compacted along the sides and top of the IWCS to meet clay thickness and side slope design. Subsequent layers would be installed to enhance the clay barrier for drainage, erosion, and penetration and subsoil and topsoil layers, which would then be re-vegetated.

Containment enhancements proposed would be impacted by any removal actions associated with the Subunits A and B materials. If the removal of Subunits A and/or B materials for off-site disposal is implemented (Actions A3 or B3), it would result in an unfilled excavation of approximately 104,940 m^3 (137,245 yd^3) based on the volumes presented in Table 2-3. The void left by the removal of Subunits A and/or B wastes would need to be filled to a common grade with the rest of the IWCS or backfilled to ground surface with suitable material and graded to promote stormwater drainage away from the remaining capped areas. If necessary, additional fill materials may be brought in from on-site locations and/or from off-site sources. After the IWCS wastes have been reshaped into the final configuration, capping materials would be reinstalled based on the final design requirements.

5.3.2.4 Waste Handling

Enhanced containment would not include disposal requirements for removal of Subunit C waste. However, management of construction-related wastes generated as part of the enhanced containment action may require disposal in an appropriate off-site disposal facility.

5.3.2.5 Water Treatment

Stormwater may collect during construction activities inside the IWCS and would require appropriate management practices such as filtration, carbon treatment, construction and operation of temporary stormwater collection ponds, sampling of stormwater during the construction phase, discharging treated water to a publicly owned treatment facility, hauling treated water off-site, and management of associated wastes generated during construction associated with water treatment.

5.3.2.6 Site Restoration

Restoration of the IWCS cap is addressed under containment enhancements. Backfilling of temporary cap material staging areas and/or ancillary roads is included. Site restoration can progress area by area to prevent the occurrence of large disturbed areas in an attempt to minimize erosion and dust generation and in an effort to limit stormwater management.

5.3.2.7 LUCs

Under Action C2, access to radioactive residues and wastes within the IWCS would be controlled through appropriate institutional and engineering controls. These controls would be designed to be effective for up to 1,000 years to match the design requirements under 40 *CFR* 192.02(a).

Action C2 would include the use of controls resulting from continued ownership of the IWCS by the Federal Government. The existing institutional controls at the NFSS would be maintained. Current controls resulting from Federal Government ownership include the following:

- Site access procedures that prevent unauthorized entry and ensure adequate training for workers who must enter hazardous areas to minimize their exposures to contaminated media.
- Restrictions on groundwater use except for the purpose of monitoring.
- Administrative procedures requiring prior government approval for intrusive activities such as excavation and drilling to prevent disturbances to the cap or other components of the remedy.

In addition to the existing government controls described above, the current property zoning for the NFSS excludes residential use.

Additional institutional controls would be implemented at the IWCS to meet the RAOs, if needed. The objectives of the LUCs could include the following:

- Prevent construction activities involving drilling, boring, digging, or other use of heavy equipment that could disturb vegetation, disrupt grading or drainage patterns, cause erosion, or otherwise compromise the integrity of the cover or manage these activities such that any damage to the cover is avoided or repaired as necessary.
- Prevent withdrawal and/or use of groundwater.
- Provide for access necessary for continued maintenance/repair, monitoring, and site inspections.
- Ensure continued protectiveness in the event of a change in land use or property ownership.
- Provide information concerning the presence and location of residual COCs. This could be accomplished through deed notices, state registries, LUC tracking systems, or advisories.

Maintenance of the site perimeter fencing, access gates, internal fences, ropes, signs, and site security measures would continue. Periodic site inspections and review would be required to verify integrity of the landfill cap. The site inspection and maintenance program for the IWCS would be upgraded as necessary to ensure protectiveness of the remedy.

Site environmental monitoring will be conducted to document the effectiveness of this remedial action. Environmental monitoring may consist of air, groundwater, surface water, and sediment sampling. Ground moisture monitoring may include the installation of several remote-sensing devices placed within the topsoil, drainage, and clay layers that would be tied into a monitored control system that also would serve the irrigation requirements for the vegetative layer. Air monitoring could include measurement of external gamma radiation, measurement of radon gas concentrations in air, monitoring of radon-222 flux, and air particulate monitoring. The environmental monitoring program may include the monitoring of surface water and sediment for radioactive, metal, and organic constituents and the monitoring of the UWBZ and LWBZ for radioactive constituents, metals, and water quality parameters. The monitoring results would be reviewed after each round of sampling to determine if changes in the monitoring program (e.g., analyte list, sampling frequency, and sampling locations) are warranted. The environmental monitoring data would be evaluated to ensure that the remedy continues to be protective.

An Institutional Controls Plan would be developed after the ROD is approved to document the approach for implementing and maintaining the institutional controls.

5.3.2.8 Five-Year Reviews

Under this action, five-year reviews would be conducted in accordance with CERCLA 121(c) for areas where hazardous substances, pollutants, or contaminants are left above levels that allow for unlimited use or unrestricted exposure. The five-year reviews would demonstrate that controls are maintained and that the remedy remains protective of human health and the environment. Five-year reviews would be discontinued when no hazardous substances, pollutants, or contaminants remain on-site above levels that allow for unlimited use and unrestricted exposure. It is assumed that five-year reviews would be conducted for 1,000 years, consistent with the performance period requirements of 40 *CFR* 192.02(a).

5.3.3 Action C3: Removal and Off-Site Disposal

Under Action C3, the R-10 residues, contaminated soil, and other wastes placed in the north end of the IWCS would be removed using mechanical methods, segregated, processed, and temporarily stored on-site prior to transport to an off-site licensed disposal facility. Wastes removed from the IWCS would need to be characterized during any excavation and removal to meet the WAC of the off-site disposal facility. If any wastes are determined to be LLMW during removal and characterization of Subunit C wastes, any necessary treatment is assumed to occur at the off-site licensed disposal facility. For planning purposes, the volume of LLMW is assumed to be 10% of the total volume. Subunit C wastes may be required to be containerized or packaged to meet DOT requirements.

Based on the volumes tabulated in Table 2-3, the total in-situ volume of material that would be removed is approximately 180,190 m^3 (235,660 yd^3). Because there is no treatment assumed for these wastes, the disposal volume would not increase.

The greatest radium-226 source in Subunit C is associated with the R-10 soil pile in the north end of the IWCS (95 pCi/g). If this source, along with the other contaminated soil in Subunit C, was removed, approximately 0.02% of the radium source would be eliminated.

Under this action, the following component described for Action C2 would be included with no changes:

- Site restoration.

Action C2 components requiring revised discussions and additional components that would be necessary for Action C3 are as follows:

- Remedial design plan and activities,
- Site preparation/construction,
- Waste removal,
- Waste handling,
- Temporary storage,
- Water treatment,
- Transportation,
- Off-site disposal,
- LUCs, and
- Five-year reviews.

5.3.3.1 Remedial Design Plan and Activities

Remedial design plans would be developed prior to implementing the selected remedy and would include details of site preparation activities, additional characterization activities, design of facilities (e.g., processing, treatment, and shipment areas), implementation and sequence of construction and removal activities, decontamination, segregation, and disposal of any generated waste streams.

Additional characterization activities may involve taking additional corings of the materials located in the north end of the IWCS to provide better data necessary for the proper design and operation of the waste handling and processing operations. Also, a site-specific health and safety plan for the various remediation phases or areas would be necessary to address the safety of remediation workers, on-site employees, and the general public.

5.3.3.2 Site Preparation/Construction

The site preparation/construction activities may include clearing and grubbing of designated equipment and material lay down areas in the vicinity of the IWCS. Local roads and ditches along the southern and eastern boundaries of the IWCS may need to be re-routed out of the construction zone. The site preparation activities would consist of installing or armoring haul truck roadways, site fencing, site lighting, and process water piping; any water treatment operations; and sewer lines, power poles, and the extension of site power to the areas requiring service. A soil storage area for clean cap materials may be established to manage topsoil, drainage sand, and clay materials that would be removed from the cap. Temporary stormwater management controls (ponds and conveyances) would be established for management of stormwater run-off from the IWCS where the cover has been exposed.

Other facilities that would be constructed as described under Action A3 for the removal of wastes from Subunit A would include a processing and packaging facility, a storage facility for processed wastes, water treatment facilities, and a control room. These facilities would be available for use as deemed necessary for removal, packaging, and shipment of specific wastes associated with Subunit C.

5.3.3.3 Waste Removal

Mechanical removal techniques described in Section 3.4.3.1 could be used to remove cap materials and overburden waste materials placed on top of the north end of the IWCS. Cap materials would be removed to access Subunit C wastes and would be segregated from the waste material. Additional clay materials below the cap would be evaluated for potential radiological contamination using radiological scanning and soil sorting, and uncontaminated materials will be staged outside of the IWCS footprint.

The removal of contaminated soil in the north end of the IWCS would be conducted using mechanical removal methods. General contaminated soil would likely be removed first, sampled, and then stockpiled within the temporary storage areas until further waste handling. Miscellaneous debris (e.g., Hittman tanks) also would be removed using mechanical removal and may be segregated in piles in the temporary storage area. The R-10 soil pile would be segregated as 11e.(2) wastes. A temporary construction berm could be constructed to isolate potential run-off from these storage areas to the rest of the IWCS.

These removal activities could produce waste streams that may need to be actively managed to meet worker exposure limits, disposal requirements, and off-site disposal WAC. Monitoring of radon emissions within work zones and at the site boundary would be included, as necessary, as part of this action.

5.3.3.4 Waste Handling

Packaging requirements for the contaminated soil and the R-10 residues and soil would likely use intermodal and gondola containers. Other waste forms and packaging requirements will be dictated by the characteristics of the waste to be disposed and the WAC of the off-site facility. Any LLMW requiring treatment for disposal will be packaged and shipped in accordance with applicable regulations for off-site treatment and disposal at a properly licensed facility.

5.3.3.5 Temporary Storage

Waste handling activities proposed under Action C3 may require temporary storage of processed wastes pending transport to the off-site disposal facility. The size of the storage facility may be required to handle Subunits A, B, and C waste streams. Based on the uncertainty of the duration of storage, the estimated size necessary to accommodate the material handling, processing, and storage areas is approximately 13,900 to 14,900 m^2 (150,000 to 160,000 ft^2) or approximately 1.38 to 1.45 ha (3.4 to 3.6 acres).

5.3.3.6 Water Treatment

Any processed wastewater generated by Action C3 would require treatment. Based on the extent of removal activities associated with the IWCS, a pond system similar to that used during the IWCS construction could be used to process wastewater from the decontamination activities. Any processed wastewater would be recycled until any ancillary water treatment requirements associated with the removal and disposal activities have been met.

Stormwater may collect in the excavation during construction activities inside the IWCS and would require appropriate management practices such as filtration, carbon treatment, construction and operation of temporary stormwater collection ponds, sampling of stormwater during the construction phase, discharging treated water to a publicly owned treatment facility, hauling treated water off-site, and managing associated wastes generated during construction associated with water treatment.

5.3.3.7 Transportation

Transportation of radioactive material is strictly regulated by DOT (e.g., packaging, handling, marking, labeling, placarding, and paperwork). Waste materials could be hauled to a licensed off-site disposal facility by direct load to a railcar, trucking to a rail-loading facility, or direct trucking to the disposal facility. For direct loading to a railcar, a rail spur would need to be constructed at the NFSS. Improvements to the existing road system at the NFSS may be required to accommodate the increased truck activity. Radiological concentrations for each package and associated weight limits for truck and rail would need to be assessed to determine if the transport of material met the exposure criteria specified in DOT regulations for shipments of radiological materials (49 *CFR* Part 173.441).

Each shipment would be manifested to ensure that NFSS waste materials are properly shipped and received by the off-site disposal facility. Regulated and licensed transportation would travel along pre-designated routes, and an emergency response plan will be developed. A more detailed evaluation of the transportation modes, routes, and waste volumes will be conducted during the FS.

5.3.3.8 Off-Site Disposal

The off-site disposal of R-10 residues and soil and a portion of the contaminated soil generated under Action C3 is assumed to require disposal in an 11e.(2)-licensed facility. A majority of the contaminated soil defined within Subunit C have been defined as LLRW (USACE 2011c).

Some waste that is removed as part of Subunit C may contain hazardous waste given the presence of potentially hazardous materials at the NFSS. It is expected that a small fraction of wastes would need to be disposed of as LLMW. Sampling would be conducted, and wastes that are LLMW would have to comply with RCRA (40 *CFR* 261-268). Because RCRA (40 *CFR* 268) requires hazardous waste to meet land disposal restrictions prior to disposal in a land-based unit, treatment may be required to immobilize the hazardous constituent(s) and to meet the concentration standards. Given the small quantity of mixed waste expected in the IWCS, this waste would be sent to a licensed off-site LLMW facility for treatment rather than developing an on-site treatment facility to handle these wastes. The potential constituents in the residues or other wastes will be accounted for in the analysis of disposal options in the detailed analysis of the FS.

The selection of the off-site facility will consider the types of wastes, location, transportation options, and cost. Currently, two off-site 11e.(2) disposal facilities described under Action A3 also are viable options for disposal of the Subunit C waste. The WAC criteria for 11e.(2) wastes such as the R-10 residues and soil could be met without further processing of the wastes. Shipments of 11e.(2) waste will be managed and disposed at the facilities in a separate disposal embankment or cell specifically licensed and designed for the material (USACE 2011c).

Both 11e.(2) facilities described above also are licensed to accept LLRW and LLMW. The radium-226 limit for the LLRW and LLMW cells would be met without further processing of the wastes. Other facilities located in Idaho, Michigan, and Nevada also were determined to be viable options for off-site disposal of LLRW and LLMW. The WAC limits for radium-226 concentrations of the waste at these facilities range between 50 and 500 pCi/g (USACE 2011c). Some processing of the materials (downblending) may be required to meet the WAC of these facilities.

5.3.3.9 LUCs

During implementation of the remedial activities associated with Action C3, the existing LUCs would be maintained, and additional controls would be implemented, if needed, for those areas where remediation is being conducted. See Section 5.3.2.7 for further information concerning the existing LUCs and the additional LUCs that could be implemented at the site. Engineering controls, including maintenance of the site perimeter fencing, access gates, internal fences, ropes, signs, and site security measures, would continue during remediation. Routine environmental monitoring could be conducted to assess the performance of the remedial actions and to provide early warning of potential contaminate releases.

To avoid duplication of effort, LUCs are generally implemented on a property- or site-wide basis. For this reason, under this action, the LUCs could be implemented in conjunction with the LUCs implemented for the remaining subunits or the BOP OU. At the completion of activities associated with the removal, treatment, and off-site disposal of the Subunit C waste, LUCs and monitoring that may be needed to manage the residual risk resulting from the remaining IWCS soil and structures could be implemented under the BOP OU based on the assumption that, if all of Subunit C is removed and shipped off-site for disposal, then Subunits A and C also have been removed and shipped off-site for disposal.

5.3.3.10 Five-Year Reviews

After removal of all wastes within the north end of the IWCS, hazardous materials, pollutants, and/or contaminants may remain on-site above levels that allow for unlimited use and unrestricted exposure. Therefore, a CERCLA five-year review is required under this action. Five-year reviews would be discontinued when no hazardous substances, pollutants, or contaminants remain on-site above levels that allow for unlimited use and unrestricted exposure. It is assumed that five-year reviews would be conducted for 1,000 years, consistent with the performance period requirements of 40 *CFR* 192.02(a).

5.4 Interim Waste Containment Structure Operable Unit Alternatives

The primary goal of this TM is to provide a set of remedial alternatives for the detailed analysis that will be conducted in the IWCS OU FS. Through the identification and evaluation of remedial technologies and process options, alternatives were developed for each subunit (A, B, or C) of the IWCS OU. The actions for each subunit were combined in an assembly process detailed in Appendix C and summarized in Figure 5-1.

The assembly process results in the following five alternatives for the IWCS OU (Table 5-1). These alternatives include the no action alternative, a containment alternative, and a range of removal actions for the source media within the IWCS. All of the removal-based alternatives (3A, 3B, and 4) include treatment of the Subunit A waste. LUCs are included for all action-based alternatives where IWCS wastes would remain on-site.

Table 5-1. Combined Alternatives for the IWCS OU

Alternative Type	Alternative ID	Alternative [a]
No Action	1	No Action
Enhanced Containment	2	Enhanced Containment
Partial Removal with On- and Off-Site Disposal	3A	Removal, Treatment, and Off-Site Disposal of Subunit A Enhanced Containment of Subunits B and C
	3B	Removal, Treatment, and Off-Site Disposal of Subunits A and B Enhanced Containment of Subunit C
Complete Removal	4	Removal, Treatment, and Off-Site Disposal of Subunits A, B, and C

[a] All removal alternatives (3A, 3B, and 4) assume treatment of Subunit A waste. Land-use controls are assumed for any alternative where IWCS waste would remain on-site.

ID = Identifier.
IWCS = Interim Waste Containment Structure.
OU = Operable unit.

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6.0 RECOMMENDATIONS

One result of the process of identifying alternatives is the identification of data needs required to complete the detailed analysis in the FS. Recommendations for additional studies to fill those data needs are presented below.

6.1 Interim Waste Containment Structure Inventory

A review of historic records and documents is required during the FS to create an inventory and cross-section, to the extent possible, of all recorded contents and IWCS structures that will be potentially removed for disposal or otherwise handled. This inventory would be used to better define the conceptual design and cost considerations associated with the removal alternatives developed in the FS for the various subunits.

The inventory of waste would need to include the construction debris (e.g., pond liner, concrete, equipment, etc.) that was consolidated with the waste inside Building 411 as well as other waste materials placed within the IWCS. These wastes would be further defined in terms of volumes and locations placed within the IWCS by reviewing and reconciling historic construction reports. The inventory would gather specific information to support remedial design, including such information as

- The physical description (e.g., 1.6 km [1 mile] of 10-cm [4-in.] steel pipe cut in 6-m [20-ft] sections covered in fillcrete),
- Waste form (e.g., drummed, encased in concrete, concrete structures, bulldozer, tank debris, etc.),
- The location (e.g., pipe stacked along Building 411, north wall, east end, etc.),
- The source and associated contamination (e.g., pipe used to transfer sluiced K-65 from Building 434 to Building 411),
- Volume assumptions (e.g., number of yards [meters] of fillcrete poured over the pipe after the pipe ends were capped to fill voids and preclude subsidence), and
- The assumed waste type (e.g., 11e.[2] byproduct material, etc.).

6.2 Treatability Studies

Two treatment technologies have been retained for further evaluation. First, ex-situ S/S would be applied to the residues contained in Subunit A (Buildings 411, 413, and 414). Following the removal of the residues and wastes, the surfaces of Buildings 411, 413, and 414 and the contaminated rubble/waste contained therein would be decontaminated using high-pressure water or other decontamination methods or using surface barriers. Treatability studies for these technologies are not necessary for the FS evaluation.

Conventional S/S (using cement and/or fly ash) as well as encapsulation methods (polymers) will be evaluated further during the FS as an ex-situ S/S treatment for the IWCS OU. Cement-based S/S is a proven technology for the K-65 residues; however, if removal and treatment are selected for Subunit A, treatability studies will be necessary in the design/implementation phase of the project. Treatability data for application of S/S to K-65 residues are available from the Fernald Environmental Management Project treatment evaluations. However, site-specific variables would need to be considered when utilizing the Fernald Site data. For example, Fernald Silos 1 and 2 contained K-65 residues and BentoGrout clay, the latter of which is not present in the K-65 residues, and other residues, in the IWCS. Additionally, the other radioactive residues in the IWCS, which do not have the same physical characteristics matrix as the K-65 residues, were not present in Fernald Silos 1 and 2; therefore, the Fernald K-65 treatment data are not applicable to treatment of the IWCS residues. However, due to the availability of the Fernald Site treatability data, along with the consideration that samples of K-65 residues and other residues may be difficult to obtain, S/S treatability studies are not required prior to proceeding with the FS. For the FS, estimation of the physical parameters of the waste stream (i.e., moisture content, residue/on-site soil mixture, and porosity) can be conducted knowing the method of retrieval from the IWCS (e.g., mechanical versus hydraulic or pneumatic removal). Knowing the method of removal will identify the physical form of the waste stream prior to treatment. This information will be key in facilitating the detailed analysis of alternatives and cost estimations in the FS.

No treatability studies are necessary for surface decontamination of the buildings and rubble/debris because, during remediation, radiation surveys will be conducted. The surveys will be conducted after treatment to determine if building surfaces meet the WAC for the selected off-site disposal facility or if additional decontamination is necessary. Similar to Fernald Silos 1 and 2, some building materials (e.g., the interior walls of Building 411) may need to be grouted prior to demolition. Grouting will be included as part of the cost estimate for the FS. Regarding the rubble/debris, it is expected that flushing with high-pressure water will be sufficient to remove the contaminated portion of the waste.

6.3 Contaminant Fate and Transport Studies

Alternatives that involve leaving wastes in place may need to be evaluated for contaminant fate and transport as part of the FS. Existing studies include the evaluation of contaminant fate and transport primarily for the residues. The removal of a portion of the waste (Subunit A only or Subunits A and B) would require a new evaluation of the reconfiguration of waste within the IWCS that may be left in place under enhanced containment. Contaminant fate and transport studies (such as groundwater modeling or radon modeling) would provide information regarding cap design requirements and other potential mitigations toward the potential long-term impact of leaving wastes within the IWCS for permanent containment.

6.4 Transportation Assessment

Potential transportation options for any remedial alternatives that would involve the excavation and transport of wastes for off-site disposal need to be evaluated as part of the FS. The feasibility and costs of off-site transportation of wastes would require additional information regarding the various modes of transportation (e.g., rail, truck, or bimodal methods), regulations, container types, routes, and costs.

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FIGURES

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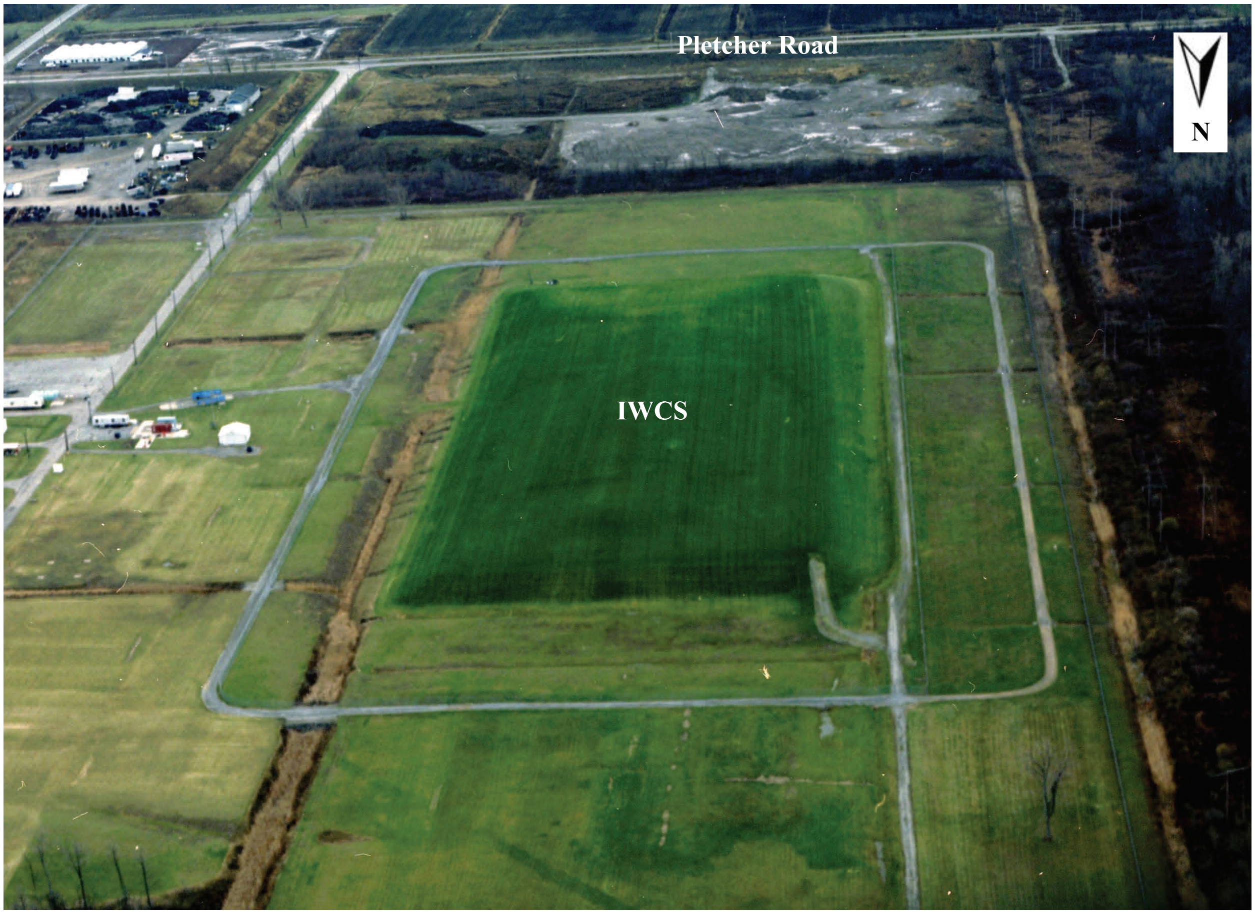
W:\Niagara Falls\GIS\Projects\Figure 1-1 Regional Areas Surrounding the Niagara Falls Storage Site.mxd

Figure 1-1. Regional Areas Surrounding the NFSS



2002 Aerial Photograph

Figure 1-2. IWCS Aerial View

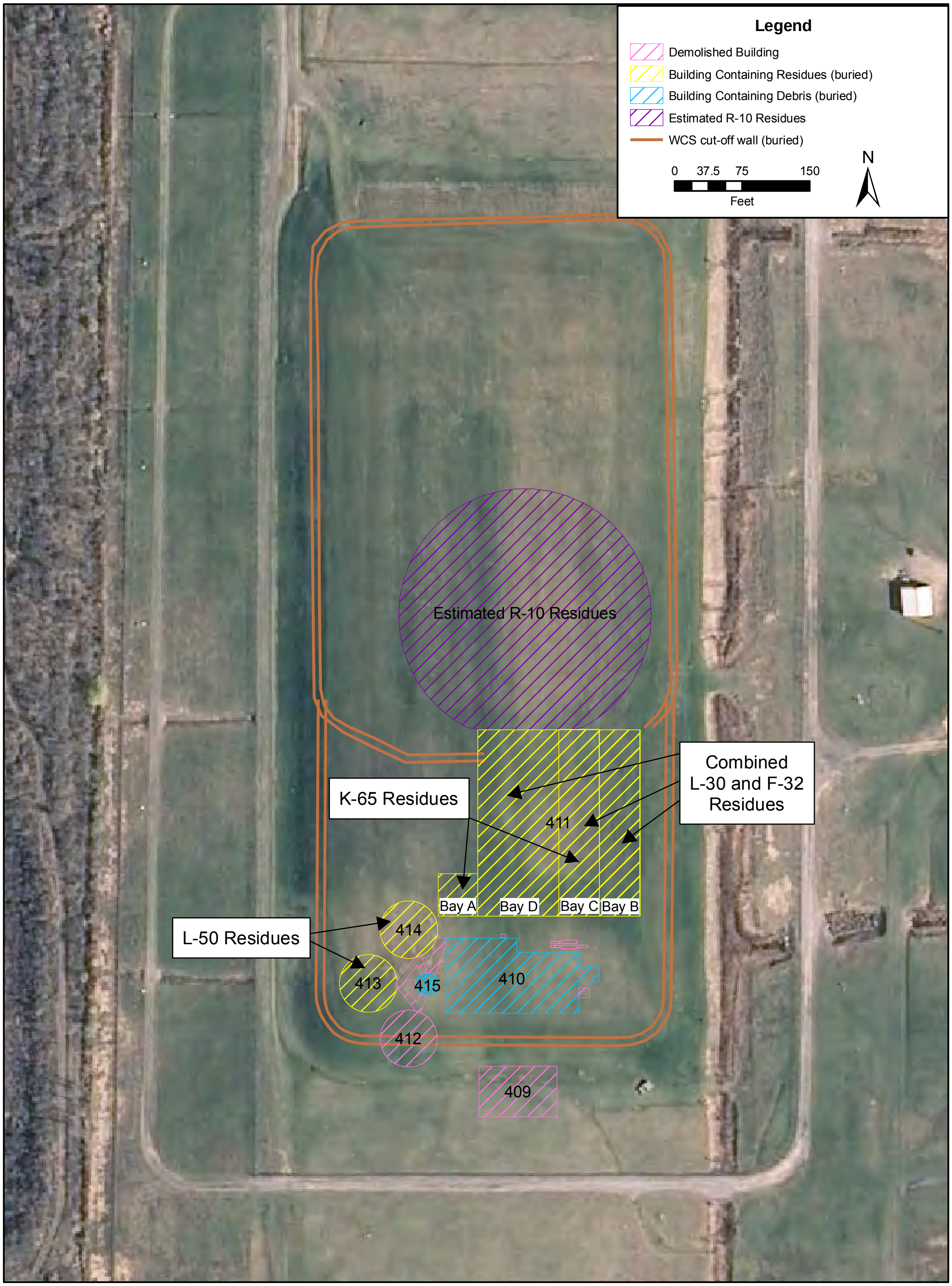


Figure 1-3. IWCS Layout with Former Building Locations

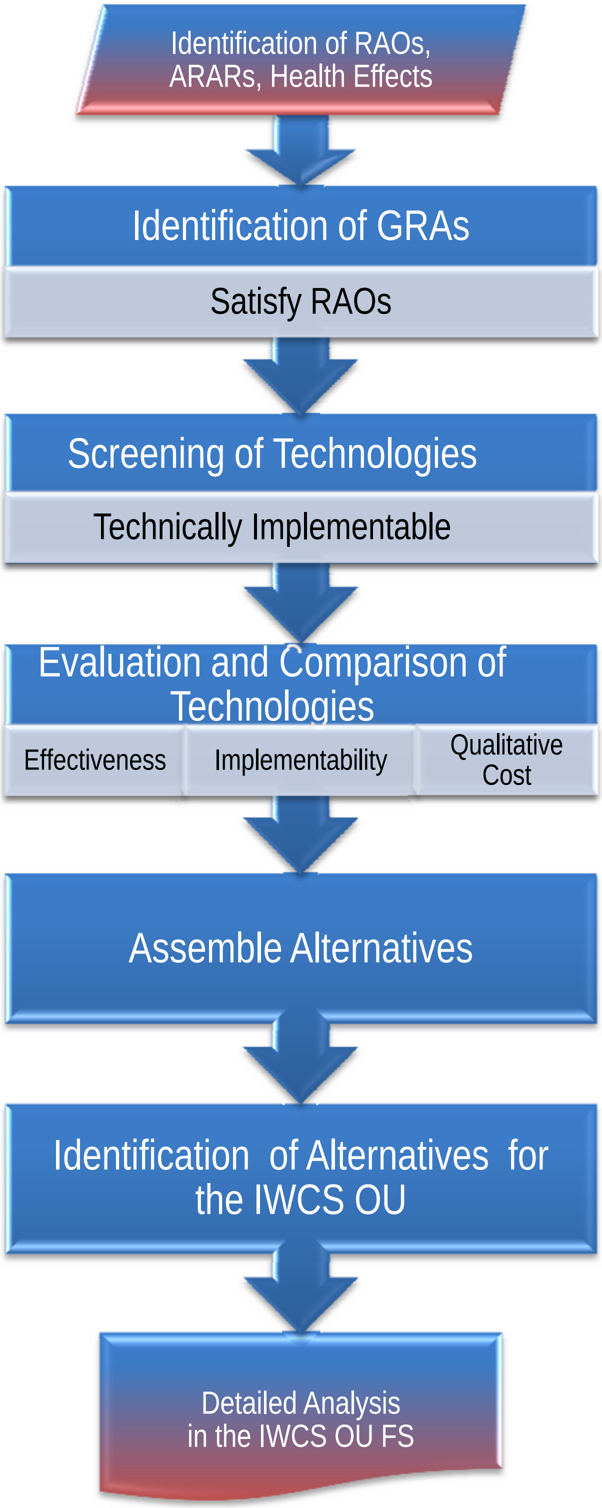


Figure 1-4. Initial Steps of the FS Remedy Selection Process

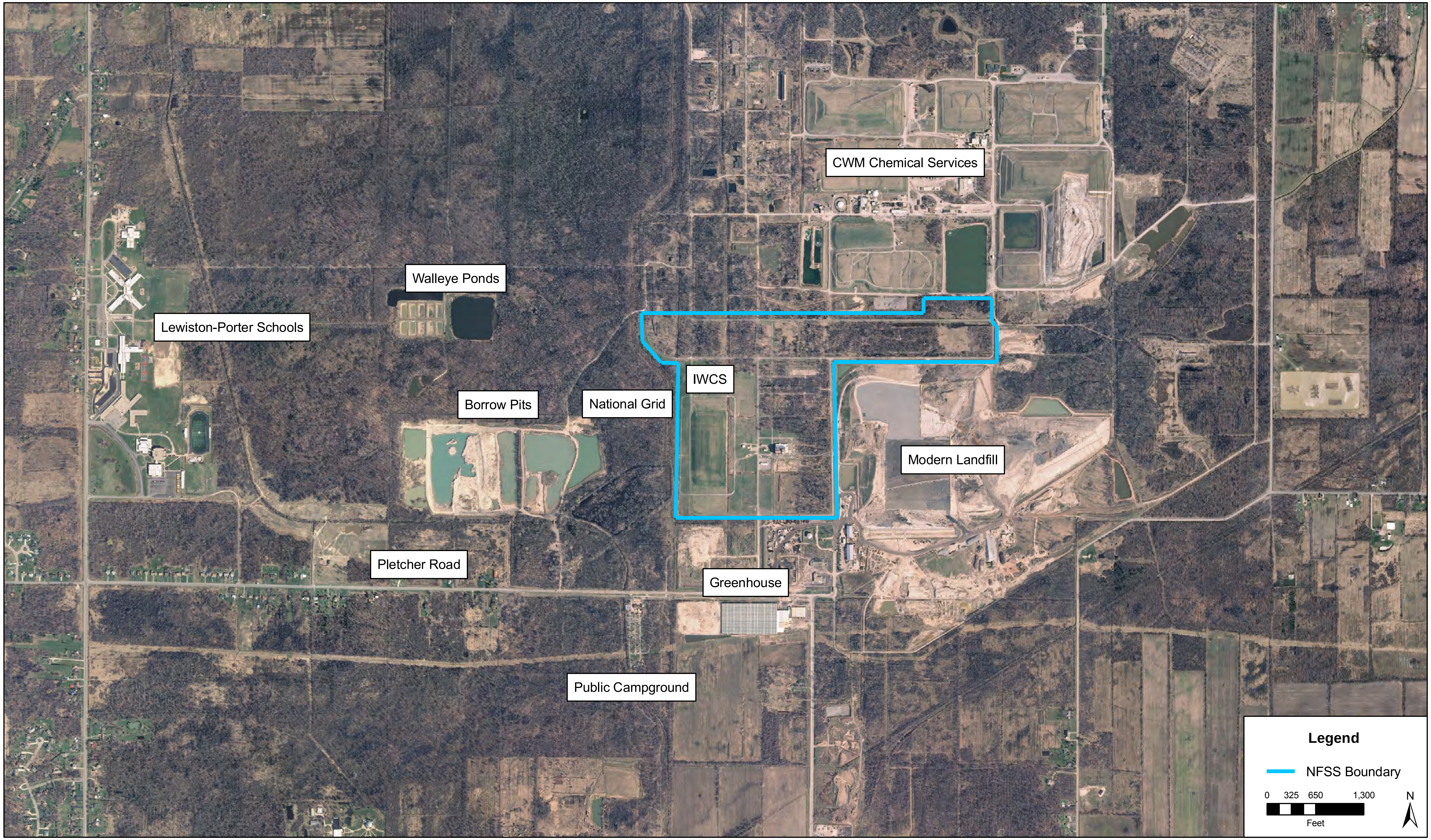


Figure 2-1. Land Use in the Vicinity of the NFSS

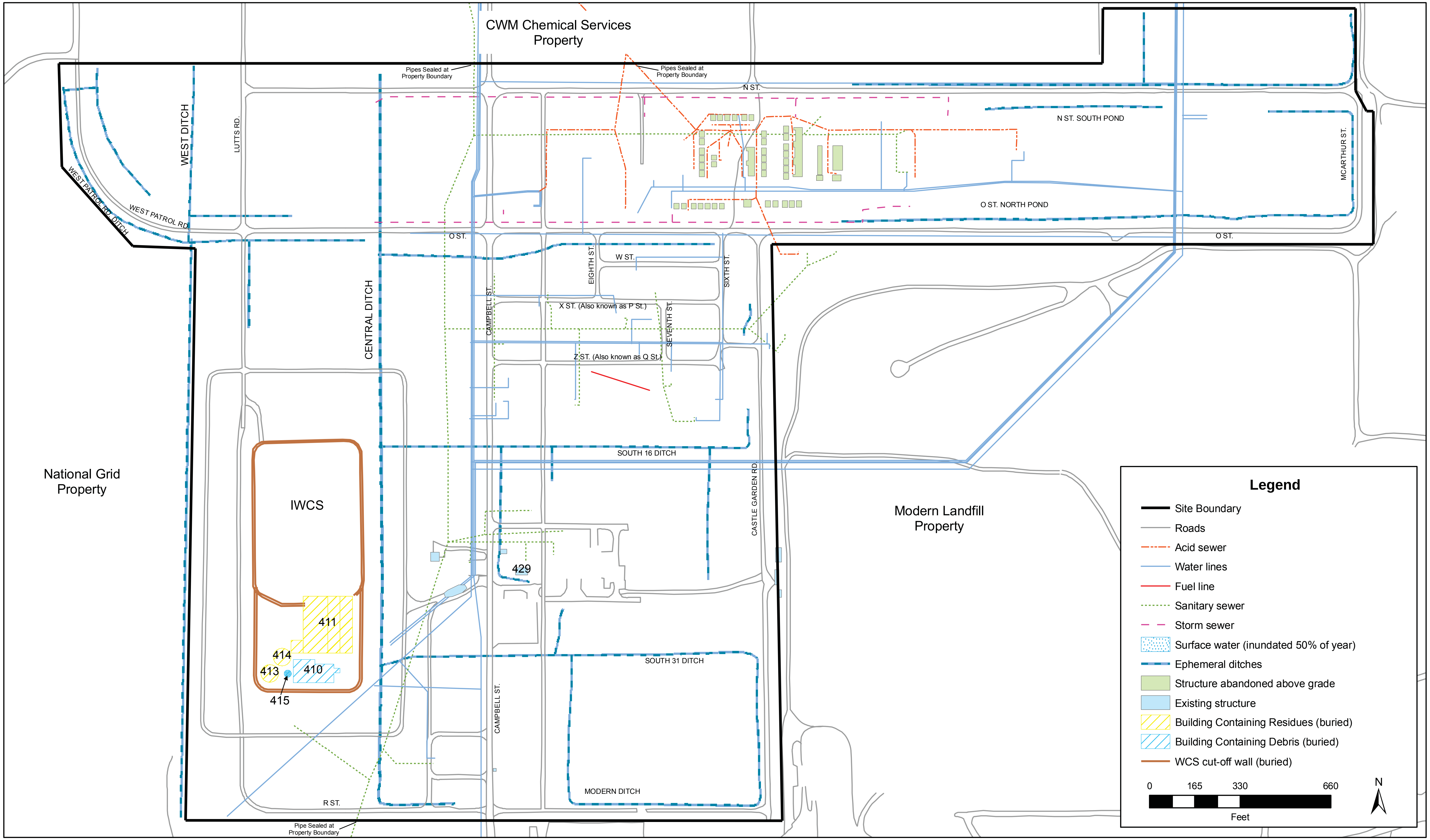


Figure 2-2. NFSS Features

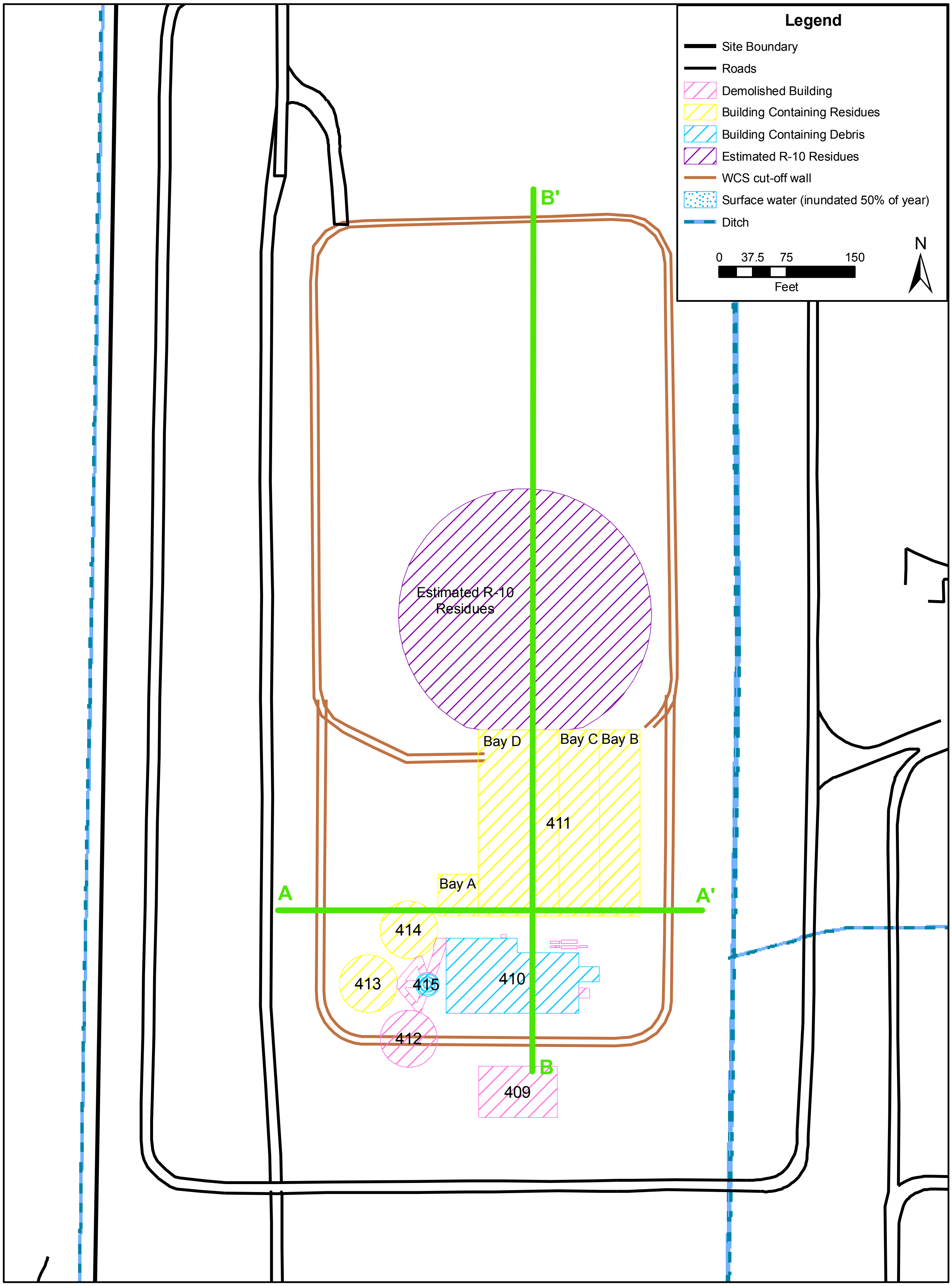


Figure 2-3. IWCS Plan View Cross-Section Locations

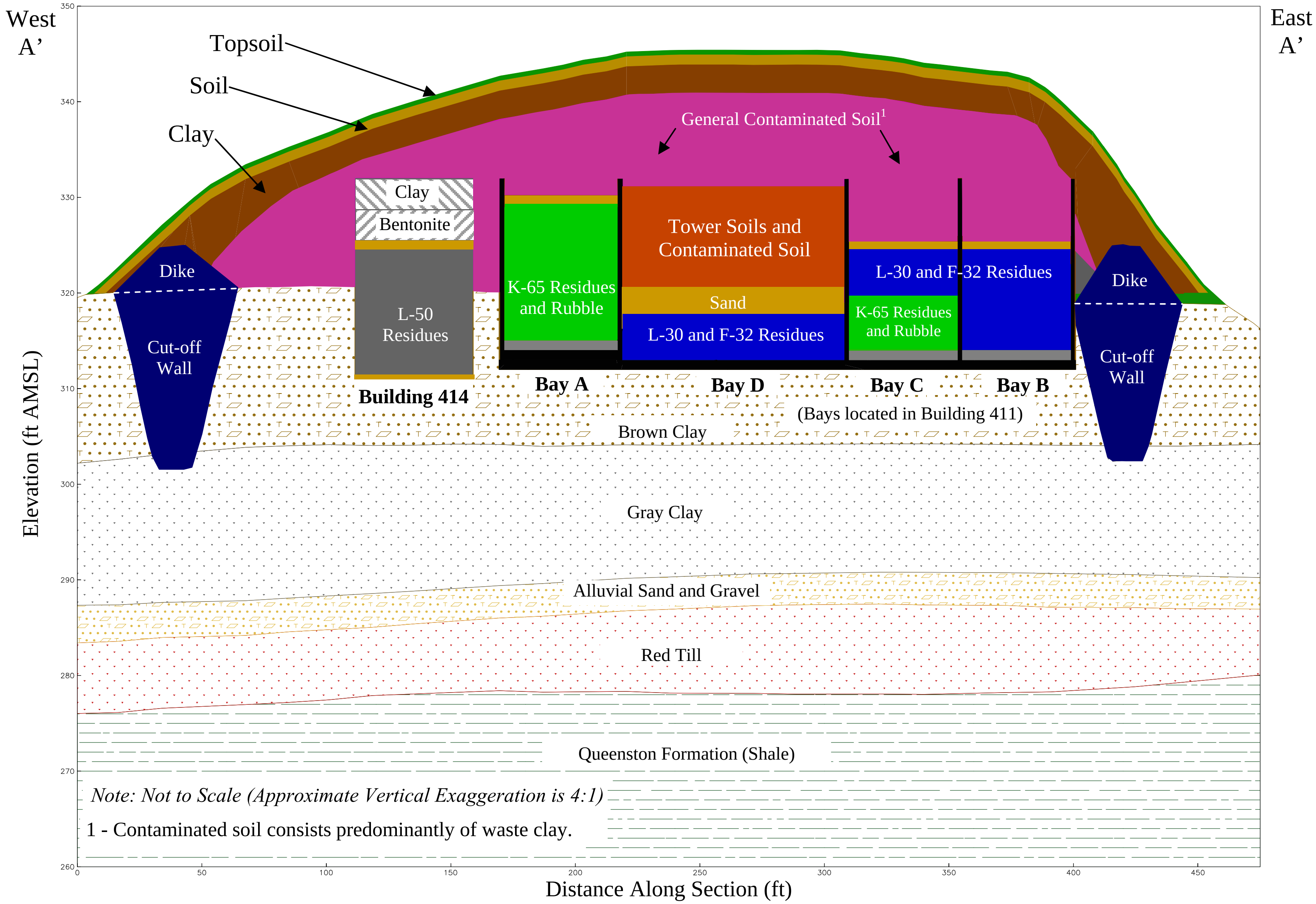
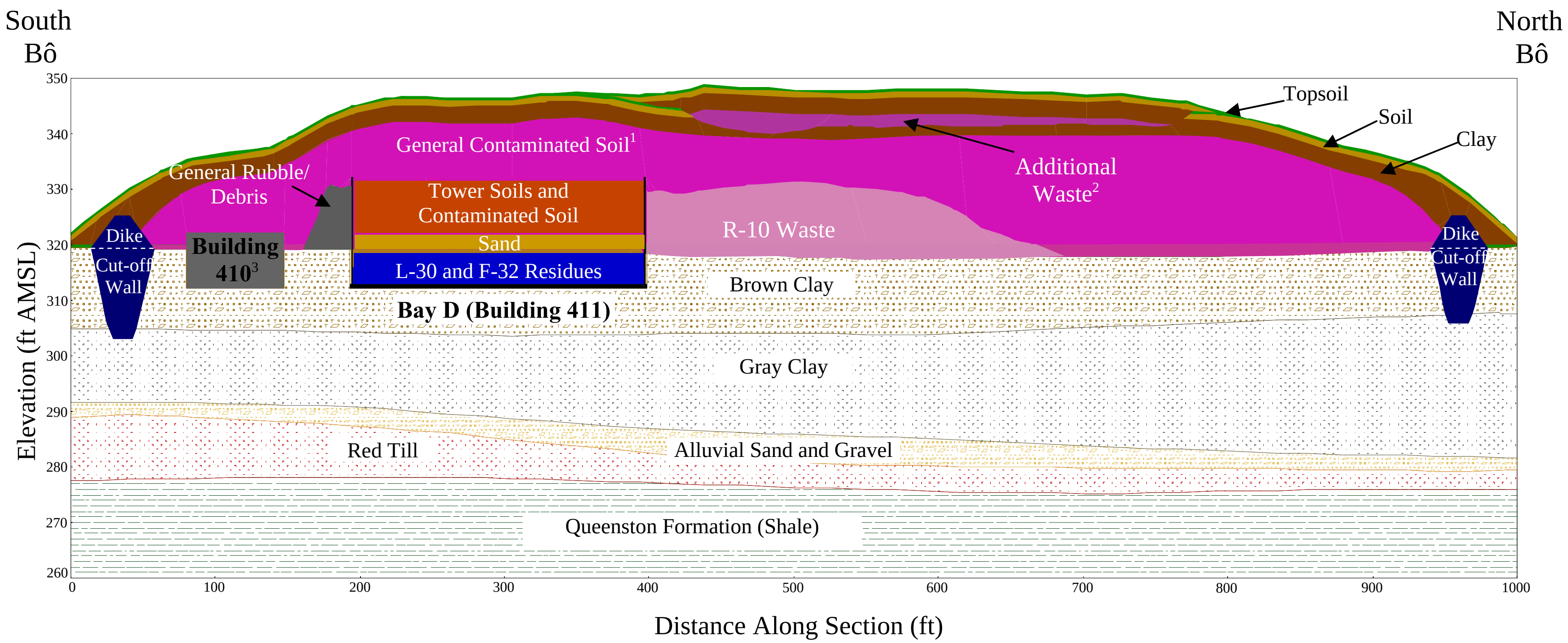


Figure 2-4. IWCS and Waste Placement East-West Cross-Section



Note: Not to Scale (Approximate Vertical Exaggeration is 4:1)

1 - Contaminated soil consists predominantly of waste clay.

2 - Thickness is estimated. No documentation is available on depth of layer. 3,500 cubic yards of contaminated soil and materials were placed in a 325-ft by 192-ft waste containment cell that was excavated in 1991.

3 - Building 410 contains assorted rubble and debris and 230 cubic yards of the Middlesex Sands.

Figure 2-5. IWCS and Waste Placement North-South Cross-Section

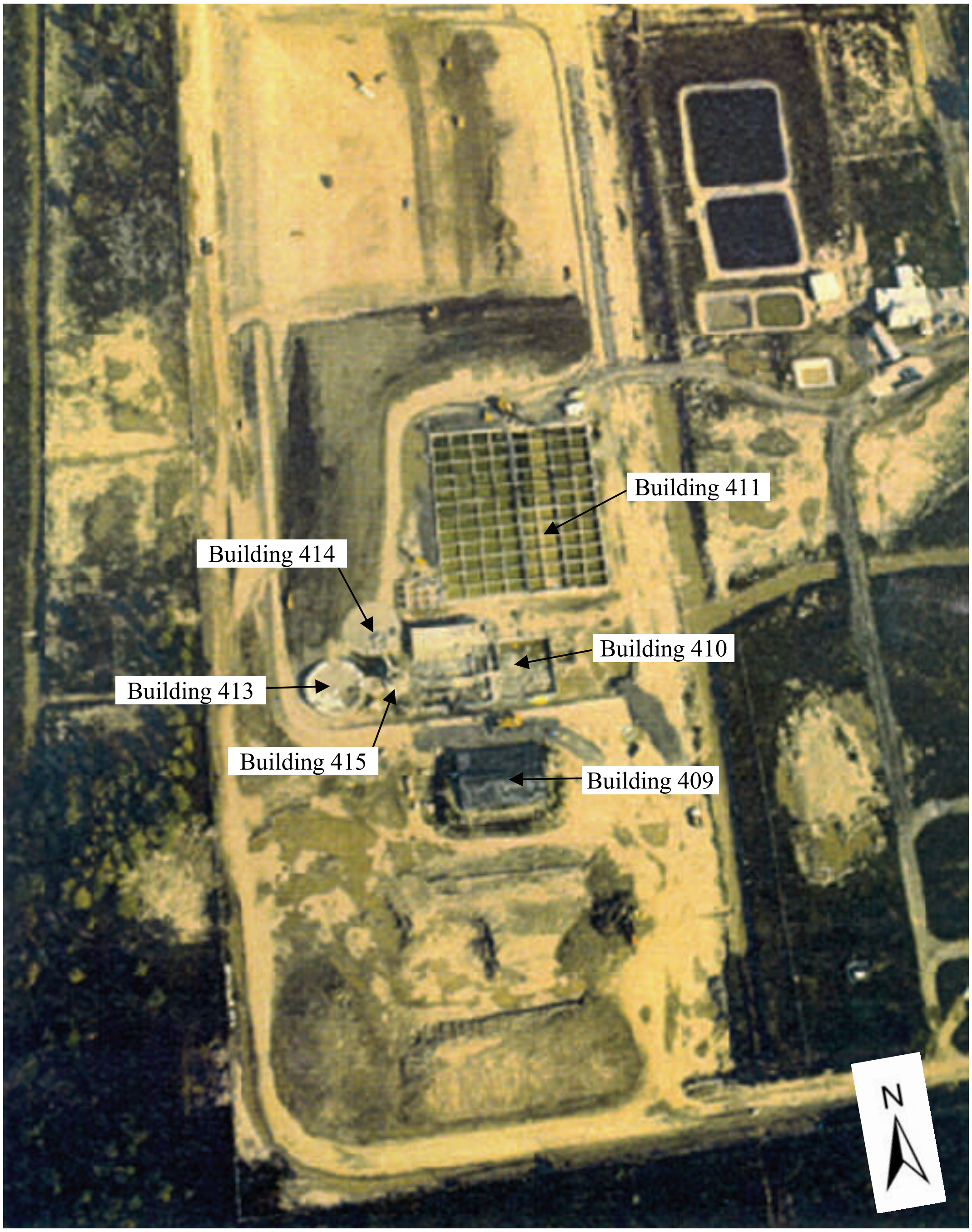


Figure 2-6. Aerial View of the Construction of the IWCS (1985)

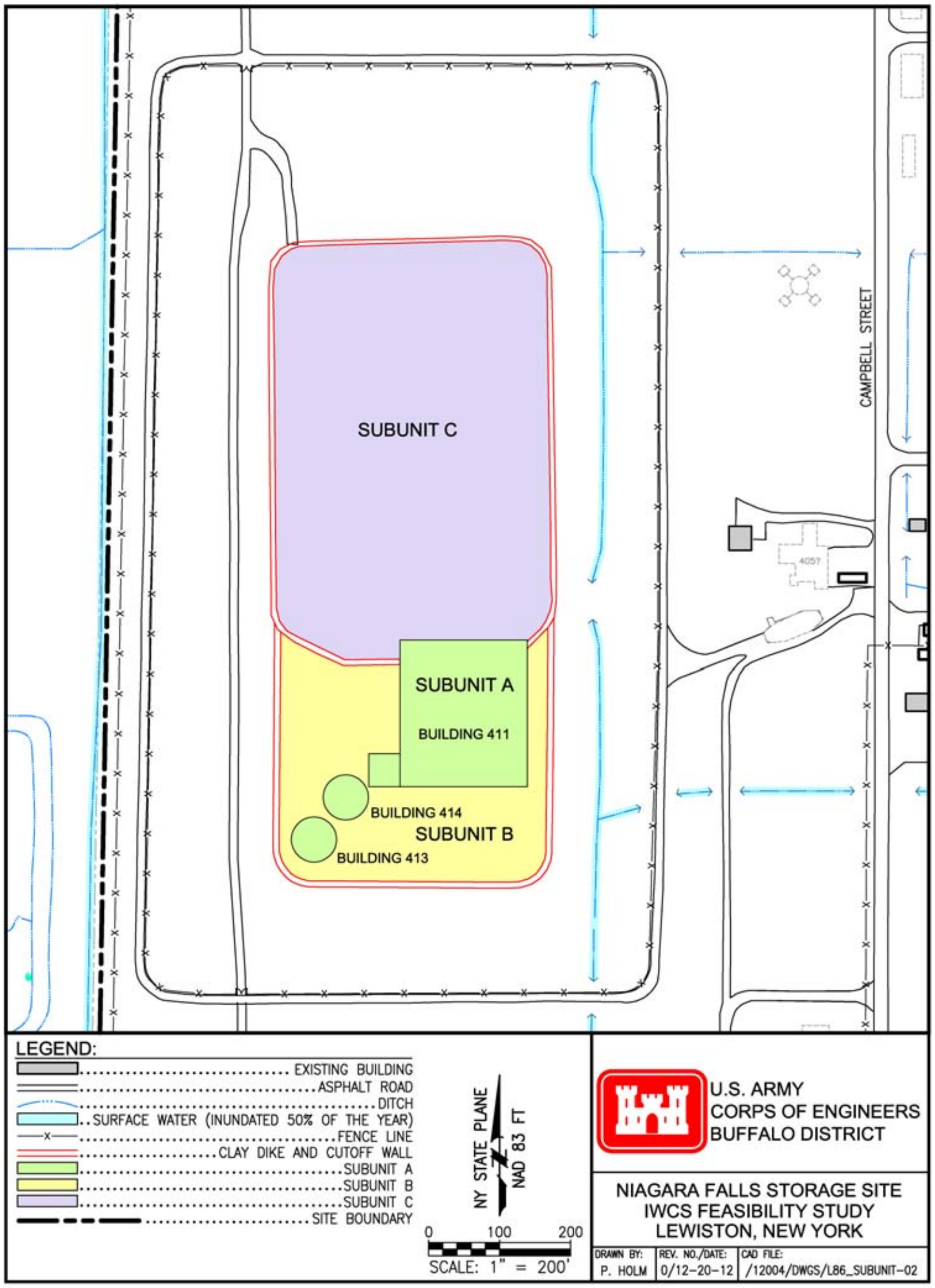
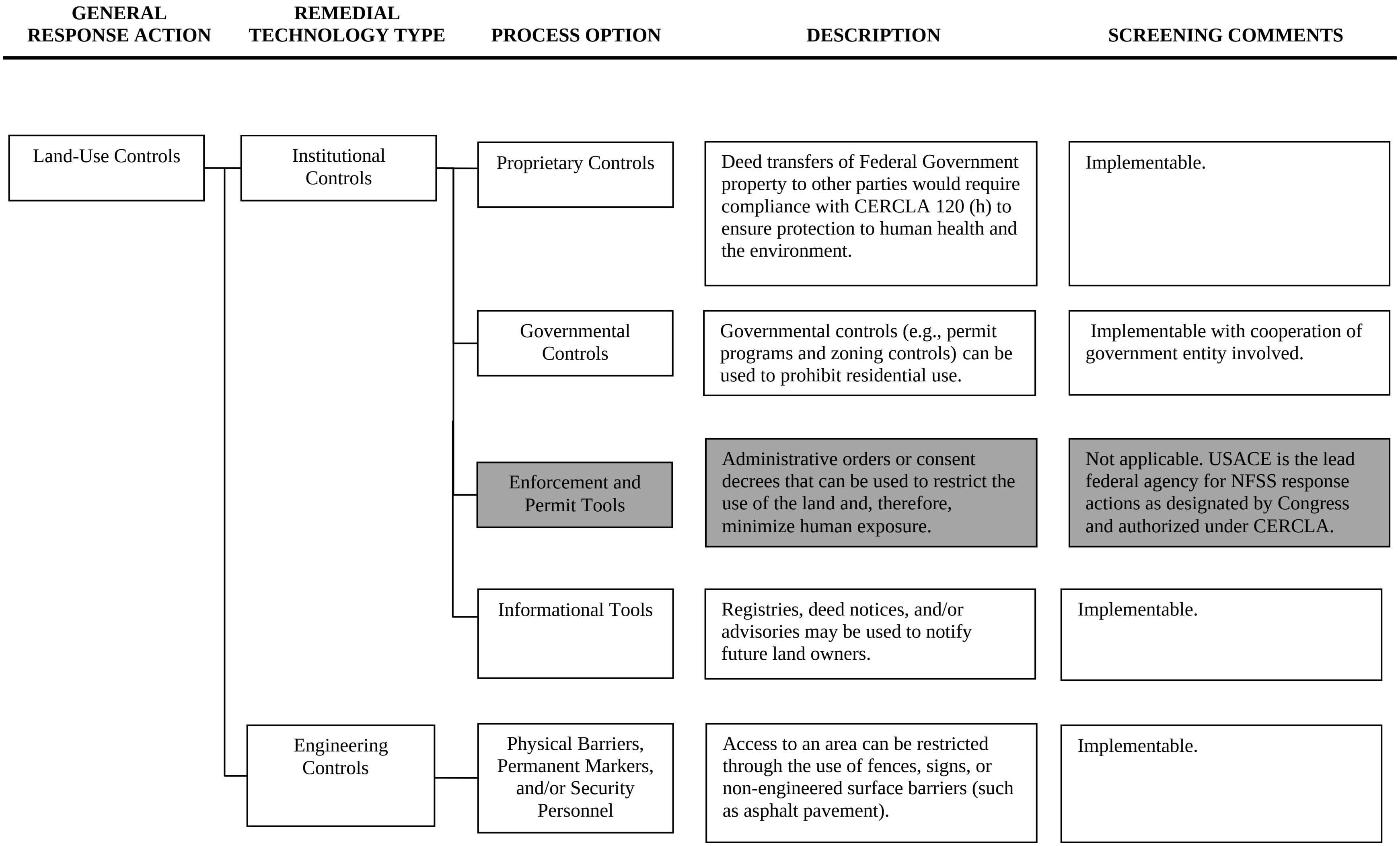


Figure 2-7. Subunit Designations for the IWCS OU

Figure 3-1. Initial Screening of Remedial Technologies and Process Options



GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
Land-Use Controls	Institutional Controls	Proprietary Controls	Deed transfers of Federal Government property to other parties would require compliance with CERCLA 120 (h) to ensure protection to human health and the environment.	Implementable.
		Governmental Controls	Governmental controls (e.g., permit programs and zoning controls) can be used to prohibit residential use.	Implementable with cooperation of government entity involved.
		Enforcement and Permit Tools	Administrative orders or consent decrees that can be used to restrict the use of the land and, therefore, minimize human exposure.	Not applicable. USACE is the lead federal agency for NFSS response actions as designated by Congress and authorized under CERCLA.
		Informational Tools	Registries, deed notices, and/or advisories may be used to notify future land owners.	Implementable.
	Engineering Controls	Physical Barriers, Permanent Markers, and/or Security Personnel	Access to an area can be restricted through the use of fences, signs, or non-engineered surface barriers (such as asphalt pavement).	Implementable.

Figure 3-1. Initial Screening of Remedial Technologies and Process Options (continued)

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
Land-Use Controls (continued)	Environmental Monitoring	Air Monitoring	Installation of air monitoring devices to identify potential external gamma radiation, radon gas concentrations, and radon-222 flux from IWCS.	Implementable.
		Surface Water/Sediment Monitoring	Sampling of surface water/sediment within on-site drainages to evaluate potential migration of COCs.	Implementable.
		Groundwater Monitoring	Installation of wells or use of existing wells to evaluate potential migration of COCs.	Implementable.
	Surveillance and Maintenance	Surveillance Activities	Inspections conducted routinely to determine whether the land-use control remains in place and it meets the objectives. Activities would include responding to unexpected conditions and emergencies.	Implementable.
		Maintenance Activities	Maintenance and repair activities are performed on physical components (e.g., caps, fences, signs, etc.) to keep them functioning as designed.	Implementable.
Containment	Engineered Caps	Single-Layer Cap	Layer of material (concrete, soil) used to contain areas of surface contamination.	Not technically implementable as it provides no further protection than the existing IWCS.
		Multi-Layered Engineered Cap	Composite barrier that includes the existing slurry walls and clay dikes.	Implementable.

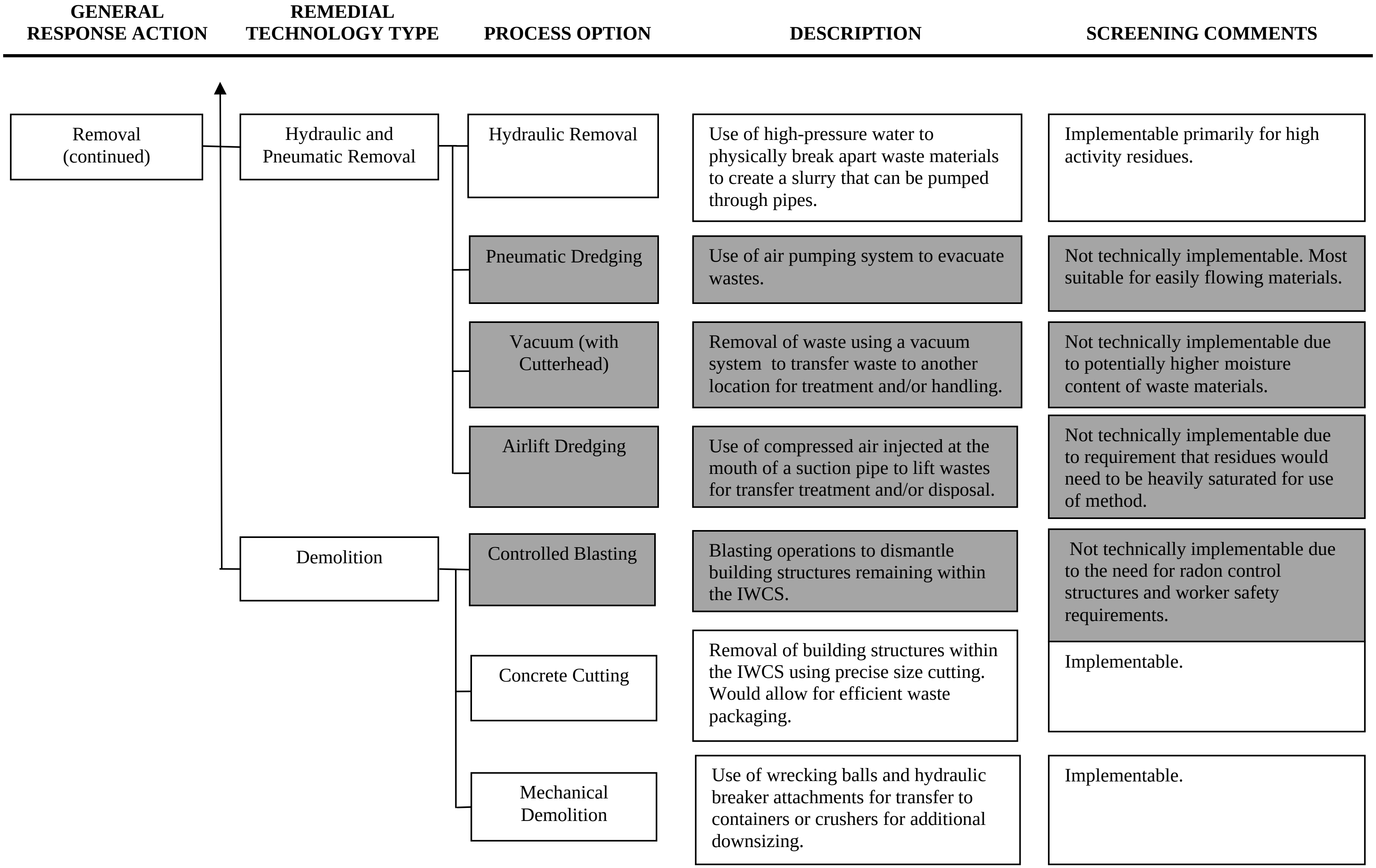
Figure 3-1. Initial Screening of Remedial Technologies and Process Options (continued)

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
Containment (continued)	Vertical Barriers	Trench Walls	Creation of trench walls surrounding the IWCS to inhibit or prevent groundwater movement or transport.	Potentially implementable but provides no benefit over the existing IWCS dike/cut-off walls.
		Grout Curtains	Narrow, vertical grout walls installed by pressure-injecting grout directly into the soil at closely space intervals to form a continuous wall to inhibit or prevent migration of groundwater.	Potentially implementable but provides no benefit over the existing IWCS dike/cut-off walls.
		Sheet Pilings	Creation of vertical barrier using overlapping sheets of impermeable material such as metal or vinyl to prevent migration of groundwater.	Potentially implementable but provides no benefit over the existing IWCS dike/cut-off walls.
		Vitrified Barrier Walls	Form a glass-like barrier using soil surrounding the area of containment to prevent migration.	Potentially implementable but provides no benefit over the existing IWCS dike/cut-off walls.
		Cryogenic Barriers	Formation of a barrier of ice created by freezing soil around the area of containment to prevent migration.	Potentially implementable but provides no benefit over the existing IWCS dike/cut-off walls.
		Permeable Reactive Barriers	Variation of the trench walls that surround the containment area and are filled with a barrier material designed to interact with and treat groundwater.	Potentially implementable but provides no benefit over the existing IWCS dike/cut-off walls.
	Horizontal Barriers	EarthSaw Block Displacement	Use of a vertical trench, along with a horizontal cutting tool, to fill the horizontal space with grout, which serves as a confining layer beneath the IWCS	Not technically implementable. Has not been implemented on the scale required for the IWCS.

Figure 3-1. Initial Screening of Remedial Technologies and Process Options (continued)

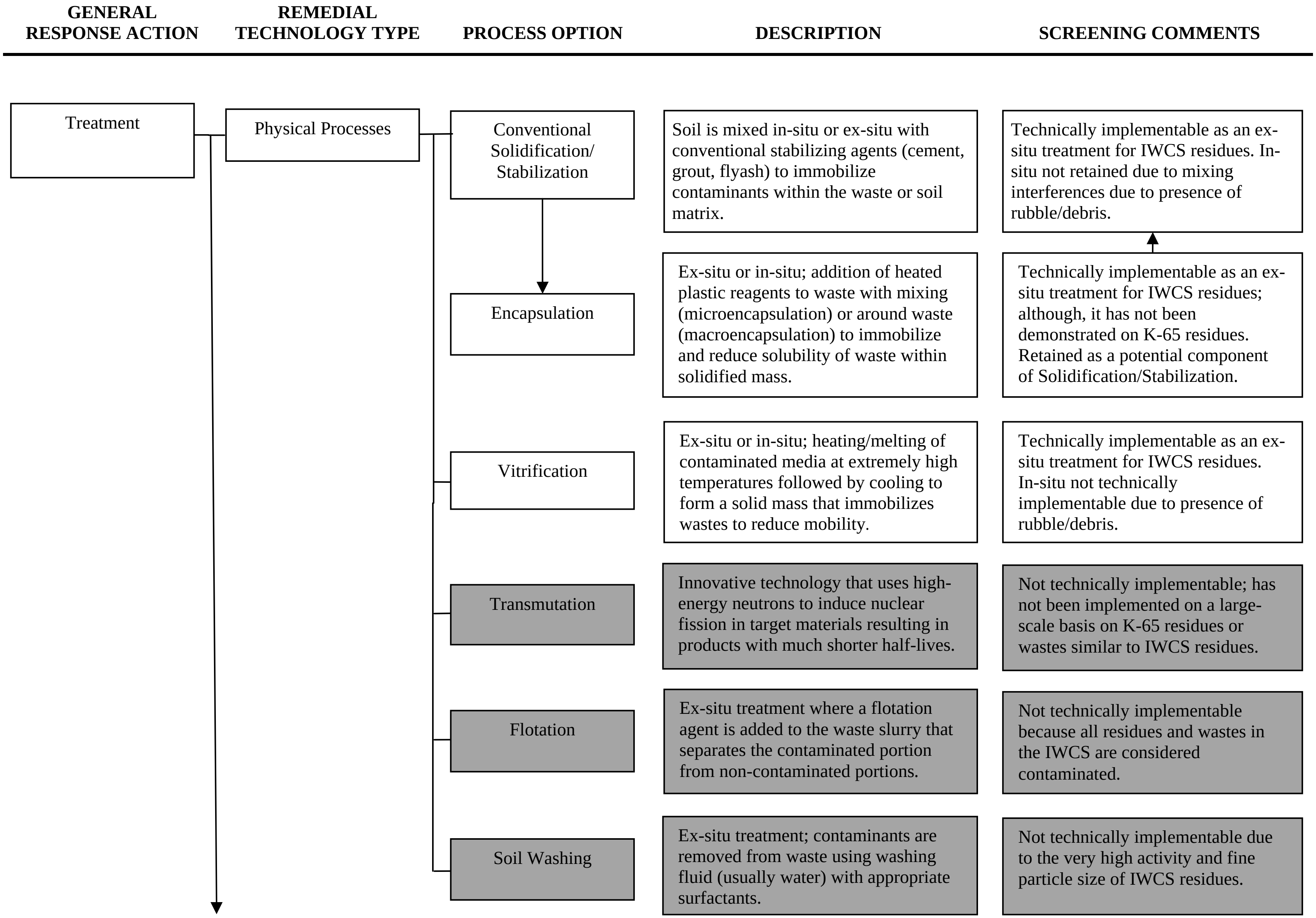
GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
Containment (continued)	Horizontal Barriers (continued)	Horizontal Excavation Method	Use of a horizontal trench dug beneath the IWCS that is filled with grout and a sensor system for long-term monitoring.	Not technically implementable. Has not been implemented on the scale required for the IWCS.
		Grouting/Permeable Reactive Barrier by Horizontal Directional Drilling	Horizontal trench created by drilling boreholes and injecting or reactive material to form a homogenous mass to prevent migration.	Not implementable on a large scale such as the IWCS facility.
Removal	Mechanical Removal	Conventional Earthmoving Equipment	Mechanically operated units such as excavators, front-end loaders, and/or hand tools.	Implementable.
		Overhead Removal	Use of crane and clamshell overhead systems. Can be used to remove debris and other bulk materials.	Implementable.
		Conveyor System	Used to excavate and transfer contaminated media to loading point.	Not technically implementable due to the relatively small size of the IWCS site but may be used for waste handling.
		Dragline System	Removal of waste using a system of boom and cables that drag waste.	Implementable.
		Remotely Operated Equipment	All removal/excavation equipment can be modified with robotics to allow remote equipment option for worker protection.	Implementable.
		Auger Mining	Employed to bore into the residues and discharge product out and onto a waiting conveyor belt.	Implementable.

Figure 3-1. Initial Screening of Remedial Technologies and Process Options (continued)



GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
Removal (continued)	Hydraulic and Pneumatic Removal	Hydraulic Removal	Use of high-pressure water to physically break apart waste materials to create a slurry that can be pumped through pipes.	Implementable primarily for high activity residues.
		Pneumatic Dredging	Use of air pumping system to evacuate wastes.	Not technically implementable. Most suitable for easily flowing materials.
		Vacuum (with Cutterhead)	Removal of waste using a vacuum system to transfer waste to another location for treatment and/or handling.	Not technically implementable due to potentially higher moisture content of waste materials.
		Airlift Dredging	Use of compressed air injected at the mouth of a suction pipe to lift wastes for transfer treatment and/or disposal.	Not technically implementable due to requirement that residues would need to be heavily saturated for use of method.
	Demolition	Controlled Blasting	Blasting operations to dismantle building structures remaining within the IWCS.	Not technically implementable due to the need for radon control structures and worker safety requirements.
		Concrete Cutting	Removal of building structures within the IWCS using precise size cutting. Would allow for efficient waste packaging.	Implementable.
		Mechanical Demolition	Use of wrecking balls and hydraulic breaker attachments for transfer to containers or crushers for additional downsizing.	Implementable.

Figure 3-1. Initial Screening of Remedial Technologies and Process Options (continued)

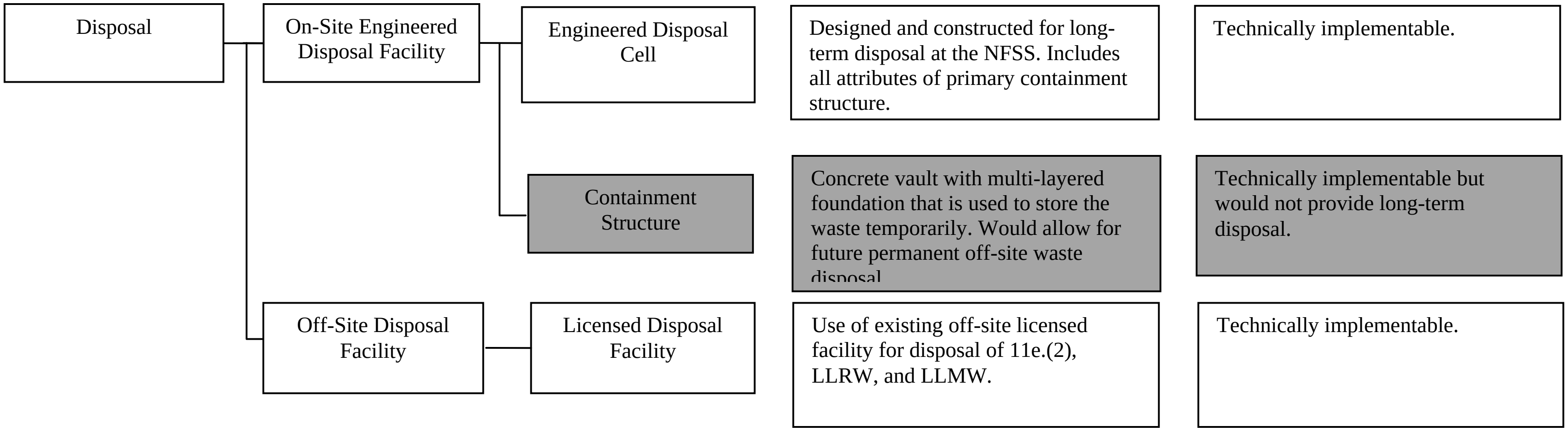


GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
Treatment	Physical Processes	Conventional Solidification/ Stabilization	Soil is mixed in-situ or ex-situ with conventional stabilizing agents (cement, grout, flyash) to immobilize contaminants within the waste or soil matrix.	Technically implementable as an ex-situ treatment for IWCS residues. In-situ not retained due to mixing interferences due to presence of rubble/debris.
		Encapsulation	Ex-situ or in-situ; addition of heated plastic reagents to waste with mixing (microencapsulation) or around waste (macroencapsulation) to immobilize and reduce solubility of waste within solidified mass.	Technically implementable as an ex-situ treatment for IWCS residues; although, it has not been demonstrated on K-65 residues. Retained as a potential component of Solidification/Stabilization.
		Vitrification	Ex-situ or in-situ; heating/melting of contaminated media at extremely high temperatures followed by cooling to form a solid mass that immobilizes wastes to reduce mobility.	Technically implementable as an ex-situ treatment for IWCS residues. In-situ not technically implementable due to presence of rubble/debris.
		Transmutation	Innovative technology that uses high-energy neutrons to induce nuclear fission in target materials resulting in products with much shorter half-lives.	Not technically implementable; has not been implemented on a large-scale basis on K-65 residues or wastes similar to IWCS residues.
		Flotation	Ex-situ treatment where a flotation agent is added to the waste slurry that separates the contaminated portion from non-contaminated portions.	Not technically implementable because all residues and wastes in the IWCS are considered contaminated.
		Soil Washing	Ex-situ treatment; contaminants are removed from waste using washing fluid (usually water) with appropriate surfactants.	Not technically implementable due to the very high activity and fine particle size of IWCS residues.

Figure 3-1. Initial Screening of Remedial Technologies and Process Options (continued)

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
Treatment (continued)	Physical Processes	Decontamination (Surface Decontamination)	Various methods for removing or reducing radiological contaminants that have become adhered to the structural surfaces of buildings or equipment.	Technically implementable for contaminated building surfaces to reduce exposures during waste handling.
		Decontamination (Surface Removal)	Various methods for removal of radiologically contaminated building surfaces.	Technically implementable for contaminated building surfaces to reduce exposures during waste handling.
		Surface Barriers (Sealants)	Spray or paint surfaces with chemicals to reduce exposures.	Technically implementable. Proposed as a method to reduce exposures during waste handling.
		Surface Barriers (Impermeable Sheeting)	Applied sheeting to reduce exposures.	Not technically implementable; debris would not be left in place.
	Chemical Processes	Chemical Separation/ Electrodialysis	In-situ process that uses electrodes to recover metal compounds.	Not technically implementable due to incompatibility with IWCS residue characteristics.
		Chemical Extraction/Metals Recovery	Ex-situ treatment; contaminated waste is mixed with a solvent to chemically extract radium and metals from residues and soil for recovery and reuse.	Has been technically implemented for other radiological source materials.
	Thermal Processes	Thermal Drying (Drying/Calcination)	Ex-situ application of heat to volatilize, decompose, or melt contaminants.	Not technically implementable; does not treat radioactive soil.
	Biological Processes	Phytoremediation	Process by which plants uptake soluble contaminates from waste (Phytoaccumulation) with or without the use of amendments and sequester them for later harvesting and disposal.	Not technically implementable; no large-scale application for wastes contaminated with high radionuclide levels found in IWCS residues.

Figure 3-1. Initial Screening of Remedial Technologies and Process Options (continued)



GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	DESCRIPTION	SCREENING COMMENTS
Disposal	On-Site Engineered Disposal Facility	Engineered Disposal Cell	Designed and constructed for long-term disposal at the NFSS. Includes all attributes of primary containment structure.	Technically implementable.
		Containment Structure	Concrete vault with multi-layered foundation that is used to store the waste temporarily. Would allow for future permanent off-site waste disposal	Technically implementable but would not provide long-term disposal.
	Off-Site Disposal Facility	Licensed Disposal Facility	Use of existing off-site licensed facility for disposal of 11e.(2), LLRW, and LLMW.	Technically implementable.

☐ Technically Implementable

▨ Eliminated from further consideration

Figure 4-1. Evaluation of Technologies and Process Options

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	EVALUATION CRITERIA [a]			RETAINED?
			EFFECTIVENESS	IMPLEMENTABILITY	COST	
Land-Use Controls	Institutional Controls	Proprietary Controls	Moderate [b]	High [b]	Moderate	Y
		Governmental Controls	Moderate [b]	High [b]	Moderate	Y
		Informational Tools	Moderate [b]	High [b]	Moderate	Y
	Engineering Controls	Physical Barriers, Permanent Markers, and/or Security Personnel	Moderate [b]	High [b]	Moderate	Y
	Environmental Monitoring	Air Monitoring	Moderate [b]	High [b]	Moderate	Y
		Surface Water/ Sediment Monitoring	Moderate [b]	High [b]	Moderate	Y
		Groundwater Monitoring	Moderate [b]	High [b]	Moderate	Y
	Surveillance and Maintenance	Surveillance Activities	Moderate [b]	High [b]	Moderate	Y
		Maintenance Activities	Moderate [b]	High [b]	Moderate	Y

[a] Ratings apply to all Subunits (A, B, and C) unless specifically identified.
[b] When used in combination with other GRAs.
[c] Includes potential use of Ex-situ Encapsulation

Figure 4-1. Evaluation of Technologies and Process Options (continued)

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	EVALUATION CRITERIA[a] EFFECTIVENESS	IMPLEMENTABILITY	COST	RETAINED?
Containment	Engineered Caps	Multi-Layered Engineered Cap	Moderate	High	Moderate	Y
Removal	Mechanical Removal	Conventional Earthmoving Equipment (Excavator)	Moderate (Subunit A) High (Subunits B/C)	Moderate	Moderate	Y
		Overhead Removal (Clamshell)	Moderate (Subunit A) High (Subunits B/C)	Moderate	Moderate	Y
		Dragline System	Low (Subunit A) Moderate (Subunits B/C)	Moderate	Moderate	Y
		Remotely Operated Equipment	Moderate (Subunit A) High (Subunits B/C)	Moderate	High	Y
		Auger Mining	Moderate (Subunit A) Low (Subunits B/C)	Moderate	Moderate	Y
	Hydraulic Removal	Hydraulic Mining (Subunit A only)	Moderate	Low	High	Y
	Demolition	Concrete Cutting	Moderate	Moderate	Moderate	Y
		Mechanical Demolition (Hydraulic Breaker)	High	High	Low	Y

[a] Ratings apply to all Subunits (A, B, and C) unless specifically identified.

[b] When used in combination with other GRAs.

[c] Includes potential use of Ex-situ Encapsulation

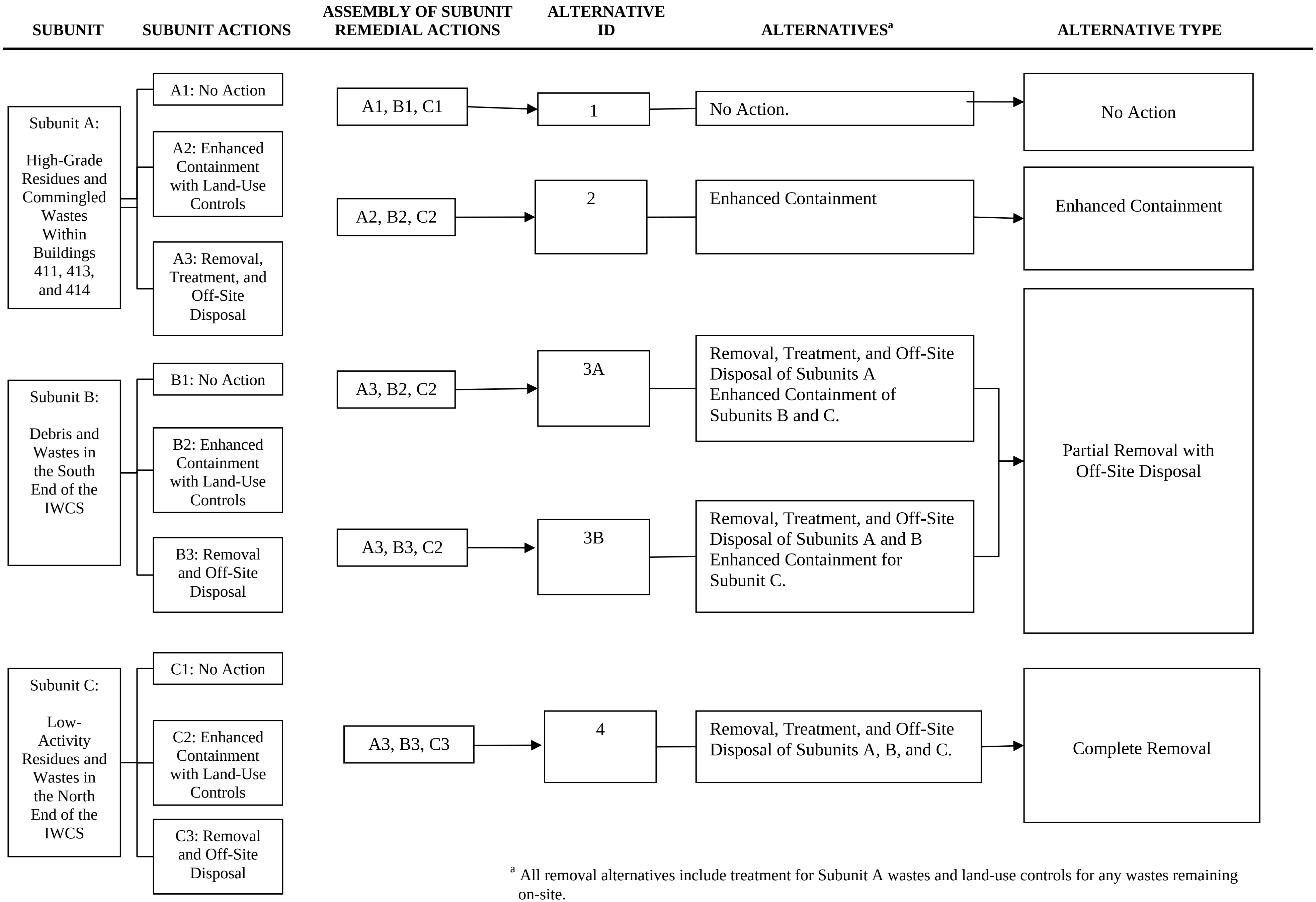
Figure 4-1. Evaluation of Technologies and Process Options (continued)

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY TYPE	PROCESS OPTION	EVALUATION CRITERIA[a]			RETAINED?
			EFFECTIVENESS	IMPLEMENTABILITY	COST	
Treatment	Physical Process	Ex-Situ Conventional Solidification/ Stabilization[c]	Moderate	High	Moderate	Y Subunit A
		▨ Ex-Situ Vitrification	▨ Moderate	▨ Low	▨ High	▨ N
		Decontamination (Surface Decontamination)	High	High	Low	Y Subunit B
		Decontamination (Surface Removal)	High	Moderate	Low	Y Subunit B
		Surface Barriers (Sealants)	Moderate	High	Low	Y Subunit B
	▨ Chemical Processes	▨ Chemical Extraction/Metals Recovery	▨ Moderate	▨ Low	▨ High	▨ N
Disposal	▨ On-Site Engineered Disposal Facility	▨ Engineered Disposal Facility	▨ Moderate	▨ Low	▨ Moderate	▨ N
	Off-Site Facility	Licensed Disposal Facility	High	High	High	Y

☐	Technologies retained.
▨	Technologies rated as low for effectiveness and low for implementability are not retained. Some treatment technologies rated as low or moderate for implementability and effectiveness also were not retained, as discussed in Section 4.

[a] Ratings apply to all Subunits (A, B, and C) unless specifically identified.
[b] When used in combination with other GRAs.
[c] Includes potential use of Ex-situ Encapsulation

Figure 5-1. Assembly of Alternatives



[a] All removal alternatives include treatment for Subunit A wastes and land-use controls for any wastes remaining on-site.

APPENDICES

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APPENDIX A

Technical Memorandum Fact Sheet and Responses to Public Comments

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Niagara Falls Storage Site
Feasibility Study Technical Memorandum Development

U.S. Army Corps of Engineers **Building Strong ®**
Buffalo District

Formerly Utilized Sites Remedial Action Program (FUSRAP)

December 2010

Development of Interim Waste Containment Structure Remedial Alternatives Technologies Development and Screening Technical Memorandum

Purpose

This fact sheet announces that the U.S. Army Corps of Engineers will be developing a technical memorandum to identify and evaluate various remedial alternatives for the Interim Waste Containment Structure (IWCS) Operable Unit at the Niagara Falls Storage Site (NFSS) as part of the IWCS Feasibility Study. Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process, a Feasibility Study evaluates technologies and alternatives that may be used to remediate the site. This technical memorandum will identify the remedial alternatives that will undergo a detailed analysis in the Feasibility Study report. The Corps seeks input from the public on the contents of this fact sheet so that the Corps can address public concerns during the initial stages of the development of this technical memorandum. The Corps intends to complete this technical memorandum and provide it to the public by the winter of 2012.

Project Background

The NFSS is a 191-acre Federal property containing the 10-acre IWCS. Radioactive residues and wastes brought to the site by the Manhattan Engineer District and the Atomic Energy Commission during the 1940s and 1950s were consolidated into the IWCS by the U.S. Department of Energy in the 1980s. In 1997, the Corps became the Federal agency responsible for implementing the Formerly Utilized Sites Remedial Action Program (FUSRAP) subject to CERCLA. As previously announced, the Corps has begun transitioning into the Feasibility Study phase. The Corps will prepare a number of technical memoranda that will be made available to the public prior to the development and release of the Feasibility Study. In this manner, the public will be given the opportunity for review and comment as we progress through the development of the Feasibility Study.

IWCS Remedial Alternatives Technologies Development and Screening Technical Memorandum Objective

This technical memorandum will identify remedial alternatives for the IWCS Operable Unit that will be subjected to further analysis and evaluation against the CERCLA criteria in the Feasibility Study report. Remedial alternatives will be developed to remediate and control contaminated media in the IWCS Operable Unit in order to provide protection to human health and the environment. The development of remedial alternatives for the IWCS Operable Unit involves two steps. The first step identifies and screens various technologies that may be used for development of remedial alternatives. Secondly, technologies that pass the screening process are used to configure remedial alternatives that may be selected for further analysis and evaluation in the Feasibility Study report. These two steps are further described below.

Identification and Screening of Technologies - Various technologies (e.g., treatment, removal, handling, resource recovery, etc.,) will be identified and screened to ensure that only technologies applicable to the contaminants and conditions present at the site will be considered. The screening process will determine if a technology is able to reduce mobility, toxicity, and/or volume of contaminants, is implementable and cost effective.

Configuration and Evaluation of Alternatives - The Corps will develop alternatives to remediate and control contaminated media in the IWCS Operable Unit in order to provide protection to human health and the environment. The Corps will develop and screen the following range of potential alternatives:

- Complete removal of the IWCS contents, including the K-65 residues, other lower-activity residues, and contaminated soils and debris;
- A range of partial removal alternatives (e.g. remove all residues, remove K-65 residues only) involving disposal off-site;
- A removal option involving the construction of an on-site disposal cell;
- Disposal options including transportation to remote, out-of-state locations;
- A range of alternatives involving containment with little or no treatment;
- Limited Action alternatives (e.g., enhanced IWCS containment and environmental monitoring);
- A No Further Action alternative (continued current site maintenance and monitoring); and
- A No Action alternative (no site maintenance or monitoring).*****

* The Corps does not consider the “No Action” alternative to be a viable long-term remedy due to its lack of protectiveness for human health and the environment. However, the “No Action” alternative will be evaluated as mandated by 40 CFR 300.430, for comparative purposes to other proposed remedial alternatives.

For each IWCS alternative, the Corps will define maintenance and monitoring requirements, remediation time requirements, transportation options, etc. These alternatives, which incorporate multiple remedial technologies, will then be evaluated with respect to their long-term and short-term effectiveness, their ability to achieve Applicable or Relevant and Appropriate Requirements, their ability to reduce the toxicity, mobility or volume of contaminated media, and their cost-effectiveness.

Public Input Regarding the Technical Memorandum

The Corps encourages input from the public regarding the objectives of this specific technical memorandum including suggestions of remedial alternatives. Input should be provided to the Corps by January 17, 2011, to allow the Corps to consider the input while developing the technical memorandum. Responses to public comments will be made available on the project website. Input can be sent via e-mail to fusrap@usace.army.mil (please note "IWCS Remedial Alternatives Technologies Development and Screening Technical Memorandum" in the subject of the e-mail) or mail your comments to the FUSRAP Team at the address noted below.

Administrative Record File

The Administrative Record File for the NFSS FUSRAP Site contains the Remedial Investigation Report, Baseline Risk Assessment, Groundwater Flow and Contaminant Transport Modeling and other CERCLA-related documentation for the NFSS. Reports and documents in the Administrative Record may be viewed at the following locations:

US Army Corps of Engineers
1776 Niagara Street
Buffalo, New York 14207 (by appointment only)

Town of Lewiston Public Library
305 South 8th Street
Lewiston, NY 14092
Phone: 716-754-4720

Youngstown Free Library
240 Lockport Street
Youngstown, NY 14174
Phone: (716) 745-3555

Responses to Public Comments on the IWCS Remedial Alternatives Technologies Development and Screening Technical Memorandum Fact Sheet

Comment No.	Comment	Response
1	I am a resident of Lewiston, NY (Lower River Road). I have evaluated the documents and encourage you to consider complete removal of the IWCS contents, including all K-65 residues, lower activity residues and contaminated soil.	The feasibility study that is planned for the NFSS IWCS will evaluate various removal alternatives associated with the contents within the IWCS, including the complete removal of the contents of the IWCS. The scope of this technical memorandum is to identify a range of technologies and alternatives based on criteria specific to the CERCLA decision process. This information will be used in the feasibility study to support a final remedial decision at the NFSS. The technical memorandum and the feasibility study will be made available for public review.
2	I am a resident of Lewiston, NY (The Circle). I have evaluated the documents and encourage you to consider complete removal of the IWCS contents, including all K-65 residues, lower activity residues and contaminated soil.	The feasibility study that is planned for the NFSS IWCS will evaluate various removal alternatives associated with the contents within the IWCS, including the complete removal of the contents of the IWCS. The scope of this technical memorandum is to identify a range of technologies and alternatives based on criteria specific to the CERCLA decision process. This information will be used in the feasibility study to support a final remedial decision at the NFSS. The technical memorandum and the feasibility study will be made available for public review.

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APPENDIX B

Estimates of Waste Volumes and Associated Radiological Concentrations Within the Niagara Falls Storage Site Interim Waste Containment Structure

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This appendix inventories the waste streams that are present in the Niagara Falls Storage Site (NFSS) Interim Waste Containment Structure (IWCS) and provides an estimated volume that is used as the basis for evaluating technologies and remedial actions in the technical memorandum (TM). The inventory is based on available information regarding the IWCS and previous waste management that has been conducted at the site. Information provided in this appendix is a preliminary estimate of waste volumes and waste placement. The inventory will be further defined and evaluated in the IWCS Operable Unit Feasibility Study.

Table B-1 shows volumes of the residues, contaminated soil, and rubble present in the IWCS. Table B-1 also shows the assumed waste classification for the purposes of the off-site disposal and disposal cost estimates as presented in the *Waste Disposal Options and Fernald Lessons Learned Technical Memorandum* (USACE 2011c). Table B-2 provides the radionuclide concentrations for the various residues and soil buried within the IWCS. The information in Tables B-1 and B-2 is based on the *Remedial Investigation Report for the Niagara Falls Storage Site* (USACE 2007a) and the associated references in the footnotes of these tables.

- K-65 Residues and Other IWCS Residues/Wastes: These constitute the K-65 residues and other IWCS residues reported in Table B-2. The residues are assumed to be 11e.(2) for the purposes of disposal.
- Tower Soils: As discussed in Section 2.2.2 of the TM, this soil is assumed to be 11e.(2) waste because it was contaminated by the K-65 residues in the Building 434 silo used for waste storage.
- Contaminated Rubble/Waste: As discussed in Section 2.2.2 of the TM, these materials are assumed to be 11e.(2) wastes. This determination assumes that the rubble is physically segregated from the other IWCS wastes so that it is not contaminated by non-11e.(2) materials. If these wastes have been impacted by non-11e.(2) wastes, then it may have to be disposed of as low-level radioactive waste (LLRW) and/or low-level mixed waste (LLMW).
- R-10 Residues and Soil: As discussed in Section 2.2.2 of the TM, these materials are assumed to be 11e.(2) wastes. Below-grade soil contaminated by leaching through the R-10 pile is to be managed under the Balance of Plant Operable Unit. However, for the purposes of the volume estimate, the below-grade soil is included (Table B-1) because it is assumed that removal of the R-10 spoil pile would continue until the contamination is removed rather than being terminated at an administrative boundary.
- Contaminated Soil: As discussed in Section 2.2.2 of the TM, this consists of soil from various sources and corresponding waste classifications.
    - For most of these materials, the waste is expected to be designated as LLRW with a minor component of LLMW. The LLMW is assumed to be 10 percent (%) of the total waste volume; it is assumed to be generated by contact with hazardous contamination in the removed soil or through contamination prior to the remedial action that generated the soil. The use of a 10% level for LLMW is a conservative assumption and is made for volume estimation purposes only.
    - Sand/Clay Separating Layers Within the IWCS in the Foundation of Building 411: This soil is assumed to be 11e.(2) waste for the purposes of disposal because it has been in contact with the IWCS residues over a significant time period.
    - Contaminated Dike Material: The soil volume included here constitutes the 0.6 meter (m) (2 feet [ft]) closest to the contaminated materials in the NFSS IWCS. For the purposes of the volume estimate, this is assumed to be a mixture of LLRW (90% of the total volume) and LLMW (10%).
    - Contaminated Cap Material: The soil volume included here constitutes only the 0.6 m (2 ft) that lie on top of the NFSS IWCS waste. The rest of the cap is assumed to be uncontaminated. For the purposes of the volume estimate, this is assumed to be a mixture of LLRW (90% of the total volume) and LLMW (10%).
    - Soil Beneath the IWCS: For the purposes of the volume estimates, a total thickness of 3 m (10 ft) of soil is assumed to be contaminated beneath the IWCS. This estimated soil depth is intended to overestimate the actual depth of contamination. In addition, this soil is assumed to constitute

11e.(2) waste, LLRW, and LLMW. The soil beneath the footprint of former Buildings 411, 413, and 414 is assumed to be 11e.(2) waste for the purpose of disposal because the buildings pre-dated waste operations at the NFSS and the source of contamination would be the K-65 materials in the NFSS IWCS. The remaining volume is assigned to a mixture of LLRW (90% of the remaining volume) and LLMW (10%).

Table B-1. Volumes and Densities of Materials in the NFSS IWCS

	Source	Concentration of U_3O_8 in Ore	Total Waste Volume		11e.(2) Waste Volume		LLRW Volume		LLMW Volume		Density Damp[g]	
			yd^3	m^3	yd^3	m^3	yd^3	m^3	yd^3	m^3	lb/yd^3	kg/m^3
K-65 Residues												
K-65	Afrimet	35 - 60%	4,030[d,l]	3,080	4,030	3,080	0	0	0	0	3,000	1,800
Other IWCS Residues/Wastes												
L-30	Afrimet	approx 10%	7,960[m]	6,090	7,960	6,090					3,000	1,800
L-50	Afrimet	approx 7%	2,150[n]	1,640	2,150	1,640						
F-32	Afrimet	unknown	440[p]	340	440	340						
Subtotal Other IWCS Residues/Wastes			10,550	8,070	10,550	8,070	0	0	0	0		
Tower Soils												
Higher-Activity Tower Soils in Building 411			4,115[q]	3,150	4,115	3,150	0	0	0	0	3,000	1,800
Contaminated Rubble/Waste												
Building 410 and Grouted Piping			4,210	3,220	4,210	3,220					3,200	1,898[k]
Building 415			100	80	100	80						
Building 434			1,400	1,070	1,400	1,070						
Thaw House Foundation			200	150	200	150						
K-65 Slurry Transfer Piping			170	130	170	130						
1991– Hittman Tanks and Miscellaneous Debris[c]			300	230	300	230						
Middlesex Sands			230	180	230	180						
Existing Structures Prior to the IWCS			15,000	11,470	15,000	11,470						
Miscellaneous Materials and Materials Added to Buildings 413 and 414			25,000	19,120	25,000	19,120						
Subtotal Rubble			46,610	35,650	46,610	35,650	0	0	0	0		
R-10 Residues and Soil												
R-10 Residues and Soil (includes the 1972 remedial action[a])			59,500[f,o]	45,500	59,500	45,500	0	0	0	0	3,000	1,800
Contaminated Soil												
1982 Remedial Action[a,e]			15,700	12,000			14,130	10,800	1,570	1,200	3,000	1,800
1983 Remedial Action												
On-Site Cleanup			39,850	30,470			35,870	27,420	3,980	3,050		
Off-Site Cleanup			14,150	10,820			12,740	9,740	1,410	1,080		
1984 Remedial Action[a]												
On-Site Cleanup[e]			4,640	3,550			4,180	3,200	460	350		
Off-Site Cleanup			23,260	17,780			20,930	16,000	2,330	1,780		
1985 Remedial Action[a,b]												
On-Site Cleanup			8,300	6,350			7,470	5,720	830	630		
Vicinity Properties			1,000	760			900	680	100	80		
Hot Spot			3,000	2,290			2,700	2,060	300	230		

Table B-1. Volumes and Densities of Materials in the NFSS IWCS (continued)

	Source	Concentration of U_3O_8 in Ore	Total Waste Volume		11e.(2) Waste Volume		LLRW Volume		LLMW Volume		Density Damp[g]	
			yd^3	m^3	yd^3	m^3	yd^3	m^3	yd^3	m^3	lb/yd^3	kg/m^3
1991 Remedial Action[c]												
Miscellaneous Soil			3,200	2,450			2,880	2,210	320	240		
Sand/Clay Separating Layers in Building 411			3,900	2,980	3,900	2,980						
Contaminated Dike Material (2 ft on the inside face of the walls)			3,600[h]	2,750			3,240	2,480	360	270		
Contaminated Cap Material (2 ft that lie next to the waste)			40,000[i]	30,580			36,000	27,520	4,000	3,060		
Soil Beneath the IWCS (assume 10 ft for costing)			87,500[j]	66,900	16,846	12,880	63,590	48,620	7,064	5,400		
Subtotal Soil			248,100	189,680	20,746	15,860	204,630	156,450	22,724	17,370		
Total Waste Volume			372,905	285,130	145,551	111,310	204,630	156,450	22,724	17,370		

[a] U.S. Department of Energy 1986. *Closure/Post-Closure Plan for the Interim Waste Containment Facility at the Niagara Falls Storage Site* (DOE 1986a). Prepared by Bechtel National, Inc.. DOE/OR/20722-85. May.

[b] Includes 3,600 yd^3 excavated from the Central Drainage Ditch and placed on bank in 1984 but not transported to the waste containment area until 1985.

[c] U.S. Department of Energy 1991. *Geotechnical Post-Construction Report for the NFSS Waste Pile Consolidation July-October 1991* (DOE 1991). Prepared by Bechtel National, Inc.

[d] U. S. Department of Energy 1981. *Comprehensive Characterization and Hazard Assessment of the DOE-Niagara Falls Storage Site* (DOE 1981b). Prepared by Battelle Columbus Laboratories. June.

[e] Potentially contaminated with cesium. This soil was from areas reported to have stored wastes from Knolls Atomic Power Laboratory.

[f] Based on core samples in 1980. From the U. S. Department of Energy 1986a. *Environmental Impact Statement, Long Term Management of the Existing Radioactive Wastes and Residues at the Niagara Falls Storage Site.* Final. April.

[g] DOE 1986a, Table 3.5. Soil densities are assumed to be approximately equal to the dry and wet densities of clay.

[h] The total volume of clay in the perimeter dikes and cut-off walls is approximately 54,000 yd^3. The dikes and cut-off walls are approximately 30 ft thick on average. Assuming 2 ft of clay on the inside face of the cut-off walls and dike are contaminated results in about 6.7% (2 out of 30) of the total volume being contaminated.

[i] Assumes 2 ft of the clay cap that lies next to the waste is contaminated.

[j] For the purposes of cost estimating, assumes that 10 ft of the brown clay that lies beneath the waste within the IWCS is contaminated. The actual extent of contamination is expected to be much less. The area within the dikes is approximately 331,000 ft^2, which results in approximately 122,500 yd^3. Then subtracting the 35,000 yd^3 of contaminated below-grade soil accounted for in the R-10 spoils pile (see footnote d) results in 87,500 yd^3.

[k] Assumes contaminated rubble consists of concrete with some rebar.

[l] Different volumes are presented by different documents: Listed as 4,074 yd^3 in the May 1981 document (DOE 1981a) and 4,030 yd^3 in the June 1981 document (DOE 1981b). The Environmental Impact Statement (DOE 1986a) lists 4,000 yd^3. Internal documentation by Bechtel personnel compiled after construction of the IWCS indicates that the volume could be as little as 3,200 yd^3 based on visual observation inside Building 434 during the slurrying process.

[m] Different volumes are presented by different documents: Listed as 7,964 yd^3 in the May 1981 document (DOE 1981a) and 7,873 yd^3 in the June 1981 document (DOE 1981b). The EIS (DOE 1986a) lists 8,000 yd^3 when converted from cubic meters and rounded to the nearest 500 yd^3.

[n] Different volumes are presented by different documents: Listed as 2,148 yd^3 in the May 1981 document (DOE 1981a) and 2,124 yd^3 in the June 1981 document (DOE 1981b). The EIS (DOE 1986a) lists 2,000 yd^3.

[o] The EIS indicates that the R-10 spoils pile consists of 9,500 yd^3 of residues and 15,000 yd^3 of contaminated soil from 1972 remedial actions placed on top of the R-10 pile. The resulting R-10 spoils pile subsequently leached into the underlying soil, contaminating an additional 35,000 yd^3 of below-grade soil for a total of 59,500 yd^3 (DOE's June 1981 document [DOE 1981b] indicates that there are 9,265 yd^3 of residues and the R-10 area consists of 69,760 yd^3 of contaminated material).

[p] Different volumes are presented by different documents: Listed as 444 yd^3 as the maximum volume in the May 1981 document (DOE 1981a) and 439 yd^3 in the June 1981 document (DOE 1981b). The EIS (DOE 1986a) lists 500 yd^3 when converted from cubic meters and rounded to the nearest 500 yd^3.

[q] The approximate volume of Tower Soils was estimated assuming that the soil fills half of Bay D (interior dimensions rounded to 87 ft x 98 ft) with a soil height of 13 ft.

ft = Foot.
ft^2 = Square feet.
IWCS = Interim Waste Containment Structure.
kg = Kilogram.
lb = Pound.
LLMW = Low-level mixed waste.
LLRW = Low-level radioactive waste.
m^3 = Cubic meters.
NFSS = Niagara Falls Storage Site.
% = Percent.
U_3O_8 = Uranium oxide.
yd^3 = Cubic yards.

Table B-2. Estimated Source Term (pCi/g) for Residues and Contaminated Soil at the NFSS

Radionuclide	Half-Life (year)	Activities in pCi/g						
		K-65	L-30	F-32	L-50	R-10[a]	Tower Soils[g]	Contaminated Soil
Uranium Series								
U-238	$4.47x10^9$	**650**	**970**	**1,750**	**515**	**1.7**	13	**4.8**
Th-234	24.1 days	650	**1,000**	1,750	515	1.7	13	4.8
Pa-234m	1.17 min	650	1,000	1,750	515	1.7	13	4.8
Pa-234	6.7 hr	1	1.3	2.3	0.7	0.002	0.02	0.006
U-234	$2.44 x10^5$	650	970	1,750	515	1.7	13	4.8
Th-230	77,000	**54,000**	12,000	300	3,300	50	1,080	16
Ra-226	1,600	**520,000**[b]	**12,000**	**300**	**3,300**	**95**	10,400	**16**
Rn-222	3.82 days	520,000	12,000	300	3,300	95	10,400	16
Po-218	3.05 min	520,000	12,000	300	3,300	95	10,400	16
Pb-214	26.8 min	520,000	**15,000**	300	3,300	95	10,400	16
Bi-214	19.9 min	520,000	**14,000**	300	3,300	95	10,400	16
Po-214	$1.64x 10^{-6}$	519,896	13,997	300	3,299	95	10,398	16
Tl-210	1.3 min	104	2.8	0.1	1	0.02	2.1	0.003
Pb-210	22.3	**155,000**	**18,000**	450	4,950	143	3,100	24
Bi-210	5.01 days	**155,000**	18,000	450	4,950	143	3,100	24
Po-210	138 days	**155,000**	18,000	450	4,950	143	3,100	24
Thorium Series								
Th-232	$1.41 x 10^{10}$	1,210	24[c]	1	7	0.2	24.2	0.03
Ra-228	5.75	1,210	24	1	7	0.2	24.2	0.03
Ac-228	6.13 hr	1,210	24	1	7	0.2	24.2	0.03
Th-228	1.91	1,210	24	1	7	0.2	24.2	0.03
Ra-224	3.66 days	1,210	24	1	7	0.2	24.2	0.03
Rn-220	55.6 sec	1,210	24	1	7	0.2	24.2	0.03
Po-216	0.15 sec	1,210	24	1	7	0.2	24.2	0.03
Pb-212	10.64 hr	1,210	24	1	7	0.2	24.2	0.03
Bi-212	60.55 min	1,210	24	1	7	0.2	24.2	0.03
Po-212	$3.05x10^{-9}$	775	15	0.4	4	0.1	15.5	0.02
Tl-208	3.07 min	435	9	0.2	2	0.07	8.7	0.01

Table B-2. Estimated Source Term (pCi/g) for Residues and Contaminated Soil at the Niagara Falls Storage Site (continued)

Radionuclide	Half-Life (year)	Activities in pCi/g						
		K-65	L-30	F-32	L-50	R-10[a]	Tower Soils,[g]	Contaminated Soil
Actinide Series								
U-235	7.04 x 10^{8}	33	**70**[d]	126	37	0.1	0.7	0.3
Th-231	25.5 hr	33	70	126	37	0.1	0.7	0.3
Pa-231	32,760	**5,000**[e]	82[f]	147	43	0.1	100	0.4
Ac-227	21.77	10,000	82	147	43	0.1	200	0.4
Th-227	18.72 days	**10,000**	**80**	144	42	0.1	200	0.4
Fr-223	21.8 min	138	1	2	1	0.0	2.8	0.0
Ra-223	11.43 days	**10,000**	**850**	1,534	451	1.5	200	4.2
Rn-219	3.96 sec	**10,000**	**800**	1,443	425	1.4	200	4.0
Po-215	1.78x10^{-3} s	10,000	850	1,534	451	1.5	200	4.2
Pb-211	36.1 min	10,000	850	1,534	451	1.5	200	4.2
Bi-211	2.14 min	10,000	850	1,534	451	1.5	200	4.2
Tl-207	4.77 min	9,973	848	1,529	450	1.5	199	4.2
Po-211	0.516 sec	27	2	4	1.2	0.004	0.5	0.01

□	Numbers in **bold** are measured values.
░	Activities based on assumptions of secular equilibrium or natural abundance.
▓	Activities based on ratios from the L-30 analyses in Battelle 1981b.
▥	Activities based on ratios from the Fernald Environment Management Project Silo 1 data.

[a] Based on the *Environmental Impact Statement, Long-Term Management of the Existing Radioactive Wastes and Residues at the Niagara Falls Storage Site* (DOE 1986a), the R-10 spoils pile represents 11,500 cubic meters (m^3) (15,000 cubic yards [yd^3]) of contaminated soil from the 1972 cleanup; 26,500 m^3 (35,000 yd^3) from below ground; and 7,000 m^3 (9,500 yd^3) of the original residues. The reported concentrations are results of sampling the spoils pile and the subsurface.

[b] Value is an average activity as reported in the *Failure Analysis Report* (DOE 1994). The value for the Ra-226 activity in the K-65 residues corresponds to the rounded average value (dry weight; alpha count) of three K-65 slurry samples with activities of 450,000 ; 640,000; and 460,000 pCi/g (TMC 1986).

[c] The value for the Th-232 activity in the Linde Residues is based on the ratio of Ra-226/Th-232 found in the sample with the highest concentration of Ra-226 from the Linde Site remedial investigation data.

[d] The actinide actual values (**bold**) are from the June 1981 Battelle document as are the L-30 values for Th-234, Pb-214, Bi-214, and Pb-210.

[e] The Pa-231 value is probably based on the Th-227 analysis and, if the Fernald Environment Management Project measured data are correct, is about half the value.

[f] Pa-231 is assumed to be in equilibrium with the measured value for Th-227 for the Linde residues.

[g] Tower Soils represents the K-65 contaminated material that was added to the north end of Bay D. It is assumed to have 2 percent (%) of the K-65 contaminant levels. This soil is included in the source term for consolidation of Building 411 materials.

hr = Hour.
pCi/g = Picocuries per gram.
NFSS = Niagara Falls Storage Site.
Min = Minute.
Sec = Second.

APPENDIX C

Assembly of Alternatives for the Interim Waste Containment Structure Operable Unit

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The primary goal of the technical memorandum is to provide a set of remedial alternatives for the detailed analysis in the feasibility study (FS). Through the identification and evaluation of remedial technologies and process options, which are presented in Sections 4.0 and 5.0, respectively, of the technical memorandum, the following subunit remedial actions were identified. Additionally, the no action alternative is evaluated as part of the FS process as a baseline for comparison to the other alternatives being considered (40 *Code of Federal Regulations* 300.430[e][6]).

The subunit remedial actions were combined to provide a view of what the potential remedial action alternatives may be for the entire Interim Waste Containment Structure (IWCS) Operable Unit (OU). This appendix presents the assembly process in which each of the subunit alternatives is combined and screened to define the most feasible alternatives for further analysis in the IWCS OU FS. The potential actions for each subunit (A, B, and C) identified in Section 6.0 of the technical memorandum are as follows:

Subunit A: High-Grade Residues and Commingled Wastes Within Buildings 411, 413, and 414

A1: No Action
A2: Enhanced Containment with Land-Use Controls (LUCs)
A3: Removal, Treatment, and Off-Site Disposal

Subunit B: Debris and Wastes in the South End of the IWCS

B1: No Action
B2: Enhanced Containment with LUCs
B3: Removal and Off-Site Disposal

Subunit C: Low-activity Residues and Wastes in the North End of the IWCS

C1: No Action
C2: Enhanced Containment with LUCs
C3: Removal and Off-Site Disposal

To develop alternatives for the IWCS OU, each of the subunit actions (e.g., A3, B3, and C2) that can be combined are shown in Table C-1. An IWCS OU remedy must include an action for Subunit A, an action for Subunit B, and an action for Subunit C. For example, Removal, Treatment, and Off-Site Disposal for Subunit A (Action A3) could be combined with Enhanced Containment and LUCs for Subunit B (Action B2) along with Enhanced Containment and LUCs for Subunit C (Action C2). The no action alternative for all three subunits is not presented in Table C-1 because it was retained only to serve as a baseline comparison for the detailed analysis in the IWCS OU FS.

Table C-1. IWCS OU Alternatives Based on Subunit Actions

Alternatives[a]	**Subunits**		
	A	**B**	**C**
Enhanced Containment	A2	B2	C2
Removal, Treatment, and Off-Site Disposal	A3		
Removal and Off-Site Disposal		B3	C3

[a] The no action alternative for all three subunits (A1, B1, and C1) is retained only to serve as a baseline comparison for the detailed analysis in the IWCS OU Feasibility Study.

IWCS = Interim Waste Containment Structure.
LUC = Land-use control.
OU = Operable unit.

Table C-2 presents all possible combined options for the IWCS OU alternatives based on an action for each subunit shown in Table C-1. A combination of subunits remedial actions A3+B2+C2 would be described as Removal, Treatment, and Off-Site Disposal of Subunit A with Enhanced Containment and LUCs of Subunits B and C Waste. A simple screening of each potential alternative was conducted to determine the protectiveness of a combined remedy for the IWCS OU. As shown in Table C-2, some combined alternatives were not retained. A combined alternative was not retained if it would not provide a greater degree of protectiveness for a subunit having lower radioactivity as evidenced by the radium-226 concentration (see Table 2-2 of the technical memorandum). The specific component of the potential alternatives shown in italics in Table C-2 is the component that would consider a more protective remedy for waste with lower radioactivity and, therefore, results in the alternative not being retained. This screening also serves to assess the administrative implementability of the remedy for the IWCS OU and reduces the number of alternatives that will undergo the detailed analysis in the FS.

Table C-2. IWCS OU Alternatives Screening

Combination	Alternative Description	Retained[a]
A1, B1, C1	No Action	√
A2, B2, C2	Enhanced Containment with LUCs	√
A2, B2, C3	Enhanced Containment with LUCs of Subunit A Enhanced Containment with LUCs of Subunit B *Removal and Off-Site Disposal of Subunit C*	Not retained
A2, B3, C2	Enhanced Containment with LUCs of Subunit A *Removal and Off-Site Disposal of Subunit B* Enhanced Containment with LUCs of Subunit C	Not retained
A2, B3, C3	Enhanced Containment with LUCs of Subunit A *Removal and Off-Site Disposal of Subunit B* *Removal and Off-Site Disposal of Subunit C*	Not retained
A3, B2, C2	Removal, Treatment, and Off-Site Disposal of Subunit A Enhanced Containment and LUCs of Subunit B Enhanced Containment and LUCs of Subunit C	√
A3, B2, C3	Removal, Treatment, and Off-Site Disposal of Subunit A Enhanced Containment and LUCs of Subunit B *Removal and Off-Site Disposal of Subunit C*	Not retained
A3, B3, C2	Removal, Treatment, and Off-Site Disposal of Subunit A Removal and Off-Site Disposal of Subunit B Enhanced Containment and LUCs of Subunit C	√
A3, B3, C3	Removal, Treatment, and Off-Site Disposal of Subunit A Removal and Off-Site Disposal of Subunit B Removal and Off-Site Disposal of Subunit C	√

[a] Alternatives were not retained if wastes with higher radioactivity would not have a greater or equally protective action.

IWCS = Interim Waste Containment Structure.
LUC = Land-use control.
OU = Operable unit.

The assembly process results in the following five potential alternatives for the IWCS OU as presented in Table C-3. These alternatives include the no action alternative, a limited action alternative, and a range of removal actions for the source media within the IWCS. All of the removal-based alternatives (3A, 3B, and 4) include treatment of the Subunit A residues and waste. LUCs are included for all action-based alternatives where IWCS wastes would remain on-site.

Table C-3. Proposed Alternatives for the IWCS OU

Alternative Type	Alternative ID	Alternative[a]
No Action	1	No Action
Enhanced Containment	2	Enhanced Containment
Partial Removal with On- and Off-Site Disposal	3A	Off-Site Disposal of Subunit A and Enhanced Containment of Subunits B and C
	3B	Off-Site Disposal of Subunits A and B and Enhanced Containment of Subunit C
Complete Removal	4	Off-Site Disposal of Subunits A, B, and C

[a] All removal-based alternatives (3A, 3B, and 4) assume treatment of Subunit A waste. LUCs are assumed for any alternative where IWCS waste would remain on-site.

ID = Identifier.
IWCS = Interim Waste Containment Structure.
LUC = Land-use control.
OU = Operable unit.

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