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Waste Management Area C Phase 2 Corrective Measures Study Remediation Technologies Screening White Paper

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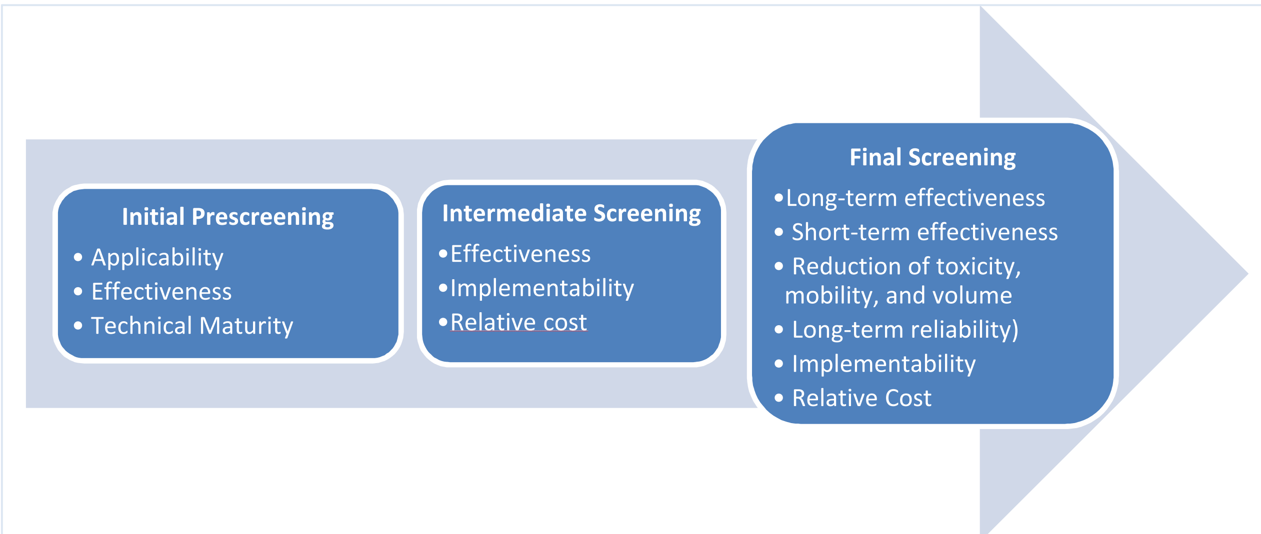
EXECUTIVE SUMMARY

This paper describes and assesses the effectiveness of the technology screening process that was performed during the development of RPP-RPT-59379, *Waste Management Area C Phase 2 Corrective Measures Study Report* (WMA C CMS). The WMA C CMS technology screening identified a range of potentially applicable remediation technologies for both shallow and deep vadose zone soil contamination. These were evaluated in a three-step screening process summarized in the figure below and detailed in this document.



Criteria Evaluated in Three Stage Screening Process

Technologies identified and screened during this process were grouped into the general response action categories below.

- Containment
- Treatment
- Removal
- Disposal

The results of this screening concluded that no practicable or effective technologies were readily available to address mobile contaminants at depth at WMA C. The eight technologies shown in the figure to the left were retained through the screening process and used to develop process options for WMA C CMS alternatives development.

Retained Technologies

- Concrete Isolation Barrier
- Modified-asphalt Surface Barrier
- Conventional Excavation
- Remotely Operated Excavation Equipment
- Standard Sloping and Benching Systems
- Sheet Pile Walls
- Onsite Disposal of Excavated Material
- Ex Situ Solidification and Stabilization

Technologies Retained through the Three-Stage Screening Process

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APPENDICES

FIGURES

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TERMS

ARAR	applicable or relevant and appropriate requirement.
BRA	baseline risk assessment.
CAO	corrective action objective.
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*.
CFR	Code of Federal Regulations.
CMS	corrective measures study.
COC	contaminant of potential concern.
DOE	U.S. Department of Energy.
EIS	environmental impact statement.
ERDF	Environmental Restoration Disposal Facility.
ft	feet or foot.
gal	gallon.
GRA	general response action.
L	liter.
m	meter.
RCRA	*Resource Conservation and Recovery Act* of 1976.
RFI	RCRA facility investigation.
SST	single-shell tank.
UPR	unplanned release.
WAC	Washington Administrative Code.
WCS	Waste Control Specialist, LLC, Andrews, Texas.

WMA	waste management area.
WRPS	Washington River Protection Solutions.

1.0 INTRODUCTION

Waste Management Area (WMA) C is located in the 200 East Area on the Central Plateau of the U.S. Department of Energy's (DOE) Hanford Site (Figure 1-1). WMA C will be the first of seven WMAs at Hanford that will undergo closure. WMA C will be landfill closed as discussed in RPP-RPT-58858, *Tier 1 Closure Plan - Single-Shell Tank System*. Conceptually, landfill closure of WMA C will include filling tanks with grout and as much of the ancillary equipment as practicable, and installing a final Modified *Resource Conservation and Recovery Act of 1976* (RCRA) Subtitle C barrier (final closure cap), followed by post-closure care. The final closure cap would be installed after most closure activities are completed at Tank Farms C, A, AN, AP, AW, AX, AY, and AZ, as discussed in Appendix E, Section E.1.2.5.4.1 of DOE/EIS-0391, *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*. Placement of the final closure cap will not occur for many decades.

The DOE conducted a corrective measures study, RPP-RPT-59379, *Waste Management Area C Phase 2 Corrective Measures Study Report* (WMA C CMS) to address contaminated soils at WMA C. As part of the WMA C CMS process, a comprehensive screening of candidate remediation technologies was performed. This document provides a more detailed description of this technologies screening process than that which appears in the WMA C CMS.

WMA C contaminants of potential concern (COPC) are identified in RPP-RPT-58329, *Baseline Risk Assessment for Waste Management Area C* (WMA C BRA). Past leaks at WMA C have resulted in soil contamination distributed in both the shallow (upper 4.6 m [15 ft]) and deep (greater than 4.6 m [15 ft]) vadose zone soils. Shallow soil contamination in localized areas represents a human health and ecological risk from direct-contact exposure, while deep soil contamination associated with mobile contaminants represents a potential impact to groundwater quality.

This paper is comprised of the following components:

- Introduction (Section 1.0)
- Methods and Approach (Section 2.0)
- Prescreening (Section 3.0)
- Intermediate Screening (Section 4.0)
- Final Screening (Section 5.0)
- Summary (Section 6.0)
- References (Section 7.0)

A complete list of all prescreened technologies along with a brief description of each, is provided in Appendix A.

1.1 PURPOSE AND APPROACH

The purpose of this document is to summarize the technology screening process that was implemented during the development of the WMA C CMS. Over 100 remediation technologies were identified for application in WMA C vadose zone (the region that extends from the ground surface to the water table) soils and screened throughout this process.

This document details the technologies that were identified for screening and describe the three-step screening process implemented. To evaluate the thoroughness of the approach used, the remediation technologies evaluated during the WMA C CMS screening process will be compared to the technologies considered during the Deep Vadose Zone and Central Plateau Vadose Zone technologies screening.

1.2 WMA C VADOSE ZONE CONDITIONS, BACKGROUND, AND CONCPETUAL SITE MODEL

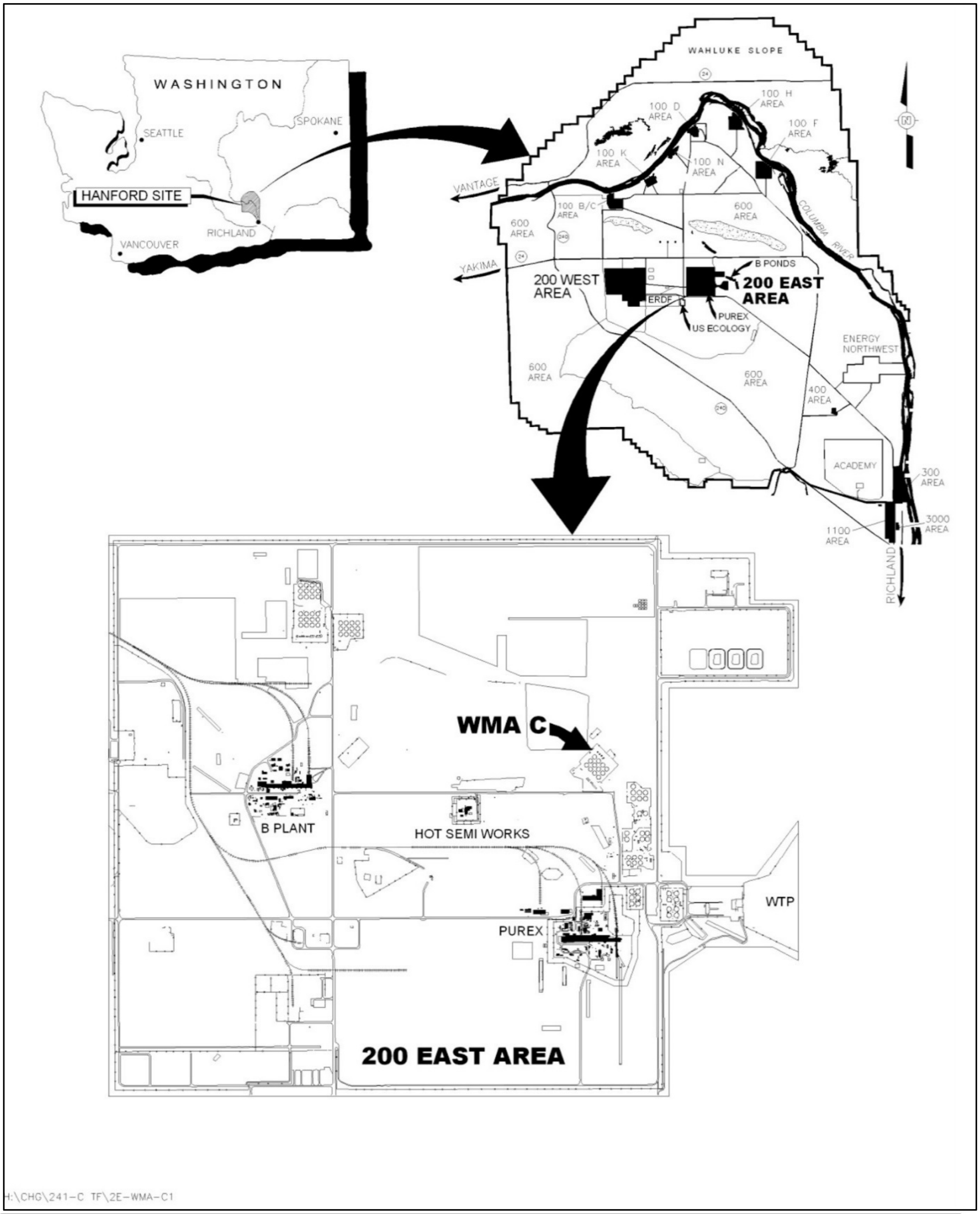
This section provides a summary of the vadose zone physical setting and a general conceptual model of soil contamination at WMA C, as relevant to the discussion of remediation technologies. This section is not intended to provide an exhaustive discussion of these elements, but rather the information and references necessary to support identification and evaluation of technologies. Information provided here was taken from several Hanford Site documents applicable to WMA C, as referenced throughout this section.

General background information about the Central Plateau geology is briefly summarized in Section 1.2.1. The nature of WMA C vadose zone geology, including infiltration and recharge rates for meteoric water and factors controlling moisture movement in the vadose zone and the groundwater impact pathway is summarized in Section 1.2.2. A brief discussion about the general conceptual model for the site is provided in Section 1.2.3. Current and likely future land use is discussed in Section 1.2.4.

Detailed operational history, geography, climate, ecological, socioeconomic, and other site conditions have been addressed extensively in several documents including:

- RPP-16608, *Site-Specific Single-Shell Tank Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan Addendum for Waste Management Areas C, A-AX, and U*
- RPP-PLAN-39114, *Phase 2 RCRA Facility Investigation/Corrective Measures Study Work Plan for Waste Management Area C*
- RPP-RPT-58339, *Phase 2 RCRA Facility Investigation Report for Waste Management Area*
- RPP-RPT-59379, *Waste Management Area C Phase 2 Corrective Measures Study Report (CMS)*

1 **Figure 1-1. Location Map of Waste Management Area C at the Hanford Site**



PUREX = Plutonium Uranium Extraction (Plant)
WTP = Hanford Tank Waste Treatment and Immobilization Plant
WMA = Waste Management Area

2

1.2.1 Central Plateau Geology

The Central Plateau is located within the Pasco Basin and encompasses the 200 East Area, 200 West Area, and the area between. Descriptions of the primary stratigraphic formations discussed in the following subsections are taken primarily from PNNL-15955, *Geology Data Package for the Single Shell Tank Waste Management Areas at the Hanford Site* and RPP-RPT-46088, *Flow and Transport in the Natural System at Waste Management Area C*. The major stratigraphic units and features comprising the Central Plateau vadose zone include (from depth to surface):

- Columbia River Basalt Group
- Ringold Formation
- Cold Creek unit and Pre-Missoula gravels
- Hanford formation and surface eolian sand and silt
- Clastic dikes

Columbia River Basalt Group. The uppermost basalt flow beneath the Central Plateau is the Elephant Mountain Member. The top of basalt surface dips to the southwest beneath the 200 West Area and to the south-southwest beneath the 200 East Area.

Ringold Formation. The Ringold Formation is largely absent in the northern and northeastern parts of the 200 East Area. In the Central Plateau, the lower half of the Ringold Formation, the member of Wooded Island, is the main unconfined aquifer under the Hanford Site and contains five separate stratigraphic intervals dominated by the fluvial gravel facies. In the 200 Areas, only fluvial gravel units A and E occur. The suprabasalt unit A is a confined aquifer that is separated from the unconfined aquifer in unit E by the Ringold Formation lower mud unit, which is an aquitard.

Ringold unit A occurs throughout much of the Central Plateau and is generally a conglomerate with clasts of basalt and other lithologies in a silty sand matrix intercalated with beds of sand and silt. The unit is thickest to the north and south of the 200 West Area. Beneath the 200 East Area, the unit dips south into the Cold Creek syncline.

The Ringold Formation lower mud unit has been eroded from beneath most of the 200 East Area. The lower mud is thinnest beneath the 200 East Area and increases to the south. This unit consists primarily of lacustrine silt and clay, with at least one well-developed paleosol noted in the 200 West Area.

Unit E is the thickest of the Ringold Formation units present in the Central Plateau and consists of bimodal, well-rounded gravel in a sand and silt matrix. Unit E increases in thicknesses to the west of the 200 West Area and to the south of the 200 East Area. Paleo channels that developed across the northeastern part of the 200 East Area removed unit E from most of that area and left a complicated surface in their path.

The Ringold Formation member of Taylor Flat consists of fluvial sands and overbank deposits. The Member of Taylor Flat has been eroded from beneath all of the 200 East Area. Erosional remnants are found beneath parts of the 200 West Area (BHI-00184, *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South Central Washington*).

Cold Creek unit and Pre-Missoula gravels. The laterally discontinuous Cold Creek unit overlies the tilted and truncated Ringold Formation in the vicinity of the 200 West Area. To the east, the pre-Missoula gravels replace the calcrete and silt dominated subunits of the Cold Creek unit. The nature of the contact between the pre-Missoula gravels and the overlying Hanford formation is not clear. In addition, it is unclear whether the pre-Missoula gravels overlie or interfinger with the Cold Creek unit (RPP-RPT-46088). Two facies of the Hanford formation/Cold Creek unit beneath the 200 East Area tank farms include a fine-grained eolian/overbank silt (silt facies Cold Creek unit), and a sandy gravel to gravelly sand facies Cold Creek unit (HNF-5507, *Subsurface Conditions Description of the B-BX-BY Waste Management Area*).

Hanford formation and surface eolian sand and silt. The Hanford formation is the main stratigraphic unit at the surface of the tank farms. The Hanford formation consists of pebble to boulder gravel, fine- to coarse-grained sand, and silt. These deposits are divided into three facies: 1) gravel-dominated, 2) sand-dominated, and 3) sand- and silt-dominated. The gravel-dominated facies association generally consists of coarse-grained basaltic sand and granule to boulder gravel. The gravel facies dominates the Hanford formation in the northern part of the 200 East and West Areas. The sand-dominated facies association consists of fine- to coarse-grained sand and granule gravel displaying plane lamination and bedding. These sands may contain small pebbles and rip-up clasts in addition to pebble-gravel interbeds and silty interbeds less than 1 m thick. The interbedded sand- and silt-dominated facies association consists of thinly bedded, plane laminated and ripple cross-laminated silt and fine- to coarse-grained sand that commonly display normally graded rhythmites a few centimeters to-several tens of centimeters thick.

Clastic dikes. Clastic dikes are vertical to subvertical sedimentary structures that cross-cut normal sedimentary layering and could locally affect the vertical and horizontal movement of water and contaminants. Clastic dikes are a common geologic feature of Pleistocene flood deposits of the Hanford formation, though no clastic dikes have been observed in WMA C. Clastic dikes on the Hanford Site have been described in detail in BHI-01103, *Clastic Injection Dikes of the Pasco Basin and Vicinity: 2 Geologic Atlas Series*.

Additional information on the structural geology of the Pasco Basin, stratigraphy of the Hanford Site, and geology of the Central Plateau can be found in:

- PNNL-12261, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington*

- PNNL-13858, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-West Area and Vicinity, Hanford Site, Washington*

- PNNL-15955, *Geology Data Package of the Single-Shell Tank Waste Management Areas of the Hanford Site*
- RHO-BWI-ST-4, *Geologic Studies of Columbia Plateau Status Report October 1979*
- DOE/RL-2002-39, *Standardized Stratigraphic Nomenclature for Port Ringold Formation Sediments Within the Central Pasco Basin*
- WHC-SD-EN-TI-012, *Geologic Setting of the 200 East Area: An Update*
- RPP-RPT-58339, *Phase 2 RCRA Facility Investigation Report for Waste Management Area C*

1.2.2 General WMA C Vadose Zone Conditions

This section provides general background information related to the WMA C vadose zone components including the nature of geologic materials comprising the vadose zone, and infiltration and recharge rates for meteoric water. Also provided is a brief discussion about the factors controlling moisture movement in the vadose zone and the groundwater impact pathway.

The vadose zone is defined as the region that extends from the ground surface to the water table. Key features, processes, and events operating within the local-scale vadose zone system of the WMA C area play a key role in controlling contaminant migration from WMA facilities through the vadose zone to underlying groundwater. Further discussion and detail regarding the site conditions at WMA C can be found in the following documents:

- RPP-RPT-46088, *Flow and Transport in the Natural System at Waste Management Area C*
- PNNL-14656, *Borehole Data Package for Four CY 2003 RCRA Wells 299-E27-4, 299-E27-21, 299-E27-22, and 299-E27-23 at Single-Shell Tank, Waste Management Area C, Hanford Site, Washington*
- PNNL-15503, *Characterization of Vadose Zone Sediments Below the C Tank Farm: Borehole C4297 and RCRA Borehole 299-E27-22*
- RPP-14430, *Subsurface Conditions Description of the C and A-AX Waste Management Areas.*
- RPP-RPT-58339, *Phase 2 RCRA Facility Investigation Report for Waste Management Area C*

The single-shell tanks (SST) and associated facilities at WMA C were constructed in Hanford formation sediments. Seven hydrogeologic units, including the underlying Columbia River Basalt Group, have been identified beneath WMA C, as discussed in RPP-14430 and PNNL-15955. The primary hydrogeologic geologic units overlying the underlying basalt bedrock in the area of WMA C include the following units, from oldest to youngest (i.e., depth to surface):

- A sandy gravel sequence belonging to the Ringold Formation referred to as unit A
- A sandy gravel deposit of the Cold Creek unit
- A lower gravel-dominated unit belonging to the Hanford formation
- A sand-dominated sequence belonging to the Hanford formation
- An upper gravel-dominated sequence belonging to the Hanford formation, and
- Recent deposits composed of eolian sands and silts and local backfill.

The geology of the vadose zone underlying WMA C constitutes the media through which the contaminants move and provides the basis with which to interpret and extrapolate the physical and geochemical properties that control the migration and distribution of contaminants. Of particular interest are the interrelationships between the coarser- and finer-grained facies, and the degree of contrast in their physical and geochemical properties.

Previous work in WMA C has identified a number of potential naturally-occurring preferential pathways for water flow and transport in the vadose zone. These have included the occurrence of broad stratigraphic features and heterogeneities such as river channel deposits, or changes in contrasting soil texture that could enhance moisture movement and/or contaminant transport. Unsaturated flow of moisture in the vadose zone is highly dependent upon interconnectivity and size of pores in sediment. The Hanford formation, which makes up the bulk of the vadose zone beneath WMA C, is highly heterogeneous with thin laterally discontinuous fine grained layers and lenses common. Lateral migration of moisture and, therefore, contaminants, is likely at the interface between fine and coarse grained sediments. The lateral discontinuity of many fine grained lenses may create preferential pathways for moisture flow (PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*).

The long-term movement of water and transport of dissolved materials through the vadose zone under natural conditions is driven foremost by precipitation that infiltrates below the zone of evaporation and the influence of plant roots. This moisture carries with it available dissolved chemical species as it makes its way to the water table. Two primary features of the vadose zone soil that affect the migration of soil contaminants are infiltration, which is the rate at which meteoric water (i.e., rain or snowmelt) enters the soil at the surface; and recharge, which is the fraction of infiltrating water that reaches the groundwater on an annual basis. Recharge from precipitation is highly variable, both spatially and temporally. It ranges from near zero to greater than 100 millimeters per year, depending on climate, vegetation, and soil texture (“Variations in Recharge at the Hanford Site” [Gee et al. 1992], PNL-10285, *Estimated Recharge Rates at the Hanford Site*). The highest rates of recharge from precipitation are associated with areas for which surface conditions are dominated by coarse-textured soil with little or no vegetation; such conditions are found in all SST WMAs, including the area in and around WMA C.

Potential man-made preferential pathways may include about 70 dry wells drilled at WMA C. The wells are not a direct contributor to vadose zone water contamination; rather they provide a potential preferential pathway for the rapid downward movement of any existing contamination through the vadose zone (RPP-RPT-46088).

1.2.3 Conceptual Site Model

WMA C includes the 241-C Tank Farm (C Farm), which is surrounded by security fencing. Although the WMA C boundary is typically represented by the fenceline surrounding C Farm, WMA C includes media contaminated by releases from the RCRA-regulated C Farm tank system.

WMA C features include:

- Twelve 100-series SSTs, each with 2,006,000 L (530,000 gal) operating capacity
- Four 200-series SSTs, each with 208,000 L (55,000 gal) operating capacity
- Waste transfer lines
- Multiple drywells around each 100-series SST used as leak detection systems
- Tank ancillary equipment, including diversion boxes, catch tanks, and related structures
- Associated unplanned releases (UPRs) to the soil.

These and additional features are shown in Figure 1-2.

From 1946 through the 1970s, WMA C was used for receiving, storing, and processing a variety of waste streams associated with spent fuel reprocessing at the Hanford Site. Following active use of the SSTs for receiving waste, pumpable liquids were removed from the SSTs, and the SSTs were declared inactive. Waste remained in the SSTs until later waste retrieval actions were initiated to retrieve waste. These operations are further described in RPP-RPT-58339, *Phase 2 RCRA Facility Investigation Report for Waste Management Area C* (Phase 2 RFI report).

Unplanned releases at WMA C have led to soil contamination. Most of the UPRs occurred in the 1960s and 1970s during active tank farm operations and were discovered through monitoring activities. The UPRs are further described in RPP-ENV-33418, *Hanford C-Farm Leak Inventory Assessments Report*. Unplanned release areas at WMA C are shown relative to the tanks and subsurface structures in Figure 1-2.

The conceptual site model establishes a framework for evaluating corrective measures within the context of the 200-BP-5 Groundwater Operable Unit cleanup activities and related facility closure actions per 78 FR 75913, "Record of Decision: Final Tank Closure of Waste Management and Environmental Impact Statement for the Hanford Site, Richland, Washington" ("TC&WM EIS Record of Decision" [EIS ROD]).

The conceptual site model for the CMS was developed using available characterization data presented in the Phase 2 RFI report, historical data, inventory estimates from past leaks (RPP-ENV-33418), and the WMA C BRA. This model is based on current site conditions at WMA C, which have not changed since completion of the Phase 2 RFI, and elements described in other documents (e.g., Phase 2 RFI report, WMA C BRA, Phase 2 RFI work plan).

This model is based on the following general, conceptual understanding of soil contamination at WMA C, as shown in Figure 1-3:

- **Historical Releases:** Historical operations have led to UPRs of tank and pipeline waste to subsurface soil. The earliest documented releases may have occurred in the 1950s. Mobile portions of these releases have been migrating downward to groundwater for approximately 50 years.

- **Surface Vadose Zone Soil:** In accordance with the BRA, surface soil is defined as 0 to 1 m [0 to 3 ft] of depth.

- **Shallow Vadose Zone Soil:** In accordance with the BRA, shallow soil is defined as 0 to 4.3 m (0 to 15 ft) of depth.

- **Deep Vadose Zone Soil:** In accordance with the BRA, deep soil is defined as deeper than 4.3 m (15 ft) to groundwater.

- **Pipeline Releases:** Pressurized, buried pipeline releases originated approximately 2.4 m (8 ft) below ground surface and migrated vertically, becoming the unplanned release sites UPR-200-E-81, UPR-200-E-82, and UPR-200-E-86.

- **Unplanned Releases:** Shallow soil contamination from a variety of tank waste sources is widely distributed, but associated contaminant inventories are relatively minor, with the exception of inventories associated with UPR-200-E-81, UPR-200-E-82, and UPR-200-E-86.

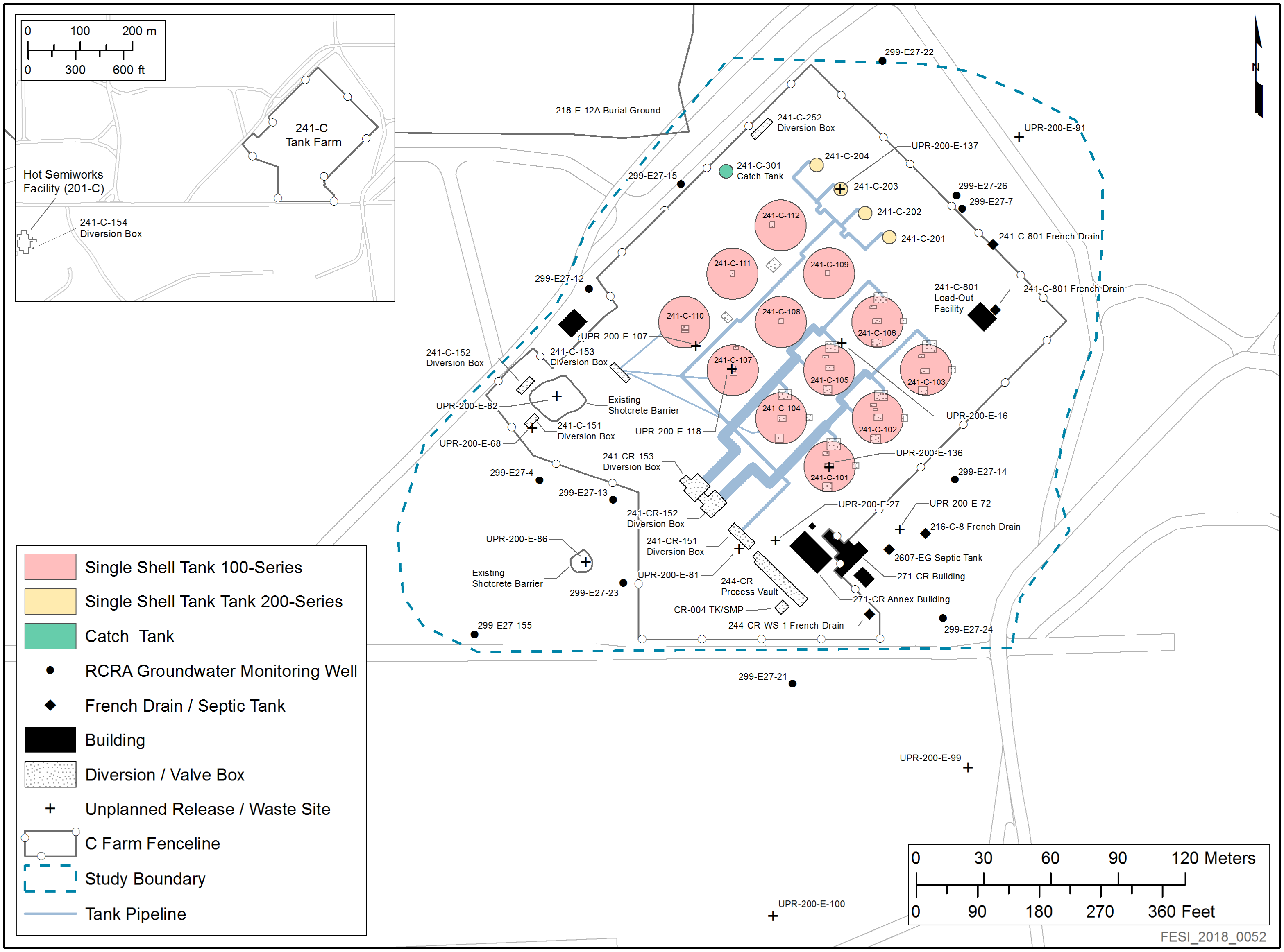
- **Deeper Releases:** Releases associated with cascade lines and tank inlets originated approximately 6 m (20 ft) below ground surface, primarily moving vertically downward, deeper into the vadose zone.

- **Contaminant Mobility:** In C Farm, contaminant mobility is generally greater vertically than laterally. Mobility varies depending on geologic material and inventories released. Mobile contaminants likely are distributed throughout the vadose zone.

- **Unconfirmed Deep Contamination:** The locations and depths of contamination inventories are not well defined in deeper portions of the vadose zone. These inventories may be discerned based on influences of different constituent mobility rates, heterogenic soil conditions and their hydraulic properties, and recharge.

- **Recharge Effects:** Contaminant mobilization deeper into the vadose zone is driven by precipitation recharge, with minimal constituent interaction with the soil. Locally, precipitation over the tanks' tops is directed laterally to the tanks' perimeters, causing enhanced recharge as a "shadow effect" around the tanks.

Figure 1-2. Waste Management Area C Features



- **Contaminant Reactivity with Soil:** Contaminant migration has been observed for nonreactive to slightly reactive constituents.

- **Contaminant Concentrations Exceed Risk Thresholds:** Concentrations of the immobile contaminants (i.e., 137Cs and 126Sn) in the shallow vadose zone exceed risk thresholds for industrial exposure scenarios at discreet locations (Phase 2 RFI report). Direct-contact risk values at UPR-200-E-81, UPR-200-E-82, and UPR-200-E-86 are estimated to exceed risk threshold values by 3 to 7 orders of magnitude for radiological contaminants. Based on inventory estimates for past leaks the non-radiological risks and hazards are also anticipated to exceed threshold values for these UPRs.

- **Vertical Migration Rates:** Under natural recharge conditions to the Hanford formation, 60Co vertical migration rates of 0.3 to 1 m (1 to 3 ft) per year have been observed near WMA C and WMA B-BX-BY (RPP-8321, *Analysis and Summary Report of Historical Dry Well Gamma Logs for the 241-C-Tank Farm – 200 East Area*).

The WMA C BRA report presents the potential health impacts to human and ecological receptors from exposure to both non-radiological and radiological contaminants present in the soil at WMA C. Human health risk assessment addresses potential exposures to industrial worker, construction worker, maintenance/surveillance worker, trespasser, hypothetical on-site residential receptors and two Native American residential receptors. Potential exposures to non-radiological and radiological contaminants detected in shallow vadose soils have been evaluated for various exposure pathways.

The WMA C BRA resulted in four COPCs being retained as constituents of concern (COCs) to be addressed. These four COCs are ^{99}Tc, nitrate, ^{137}Cs, and ^{126}Sn. Nitrate in groundwater is retained based on the presence of nitrate in groundwater, and ^{99}Tc in groundwater is retained based on RPP-RPT-59197, *Analysis of Past Tank Waste Leaks and Losses in the Vicinity of Waste Management Area C at the Hanford Site, Southeast Washington*. Cesium-137 and ^{126}Sn in soil are retained based on direct contact pathway.

Localized areas were identified where UPRs resulted in shallow soil contamination at concentrations that exceed risk thresholds. The contamination at depth (at or near the water table) is widely distributed and not well defined spatially. The potential groundwater impacts described in the WMA C BRA indicate that peak groundwater impacts from past releases at WMA C are anticipated to occur in approximately 2019. This indicates that the mobile contaminants associated with past leaks at WMA C have migrated to depth and are near the groundwater. Groundwater COPCs were evaluated, but, groundwater will not be included in the corrective action; rather, decisions regarding groundwater remediation will be coordinated with the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) actions for 200-BP-5 and 200-PO-1 Operable Units.

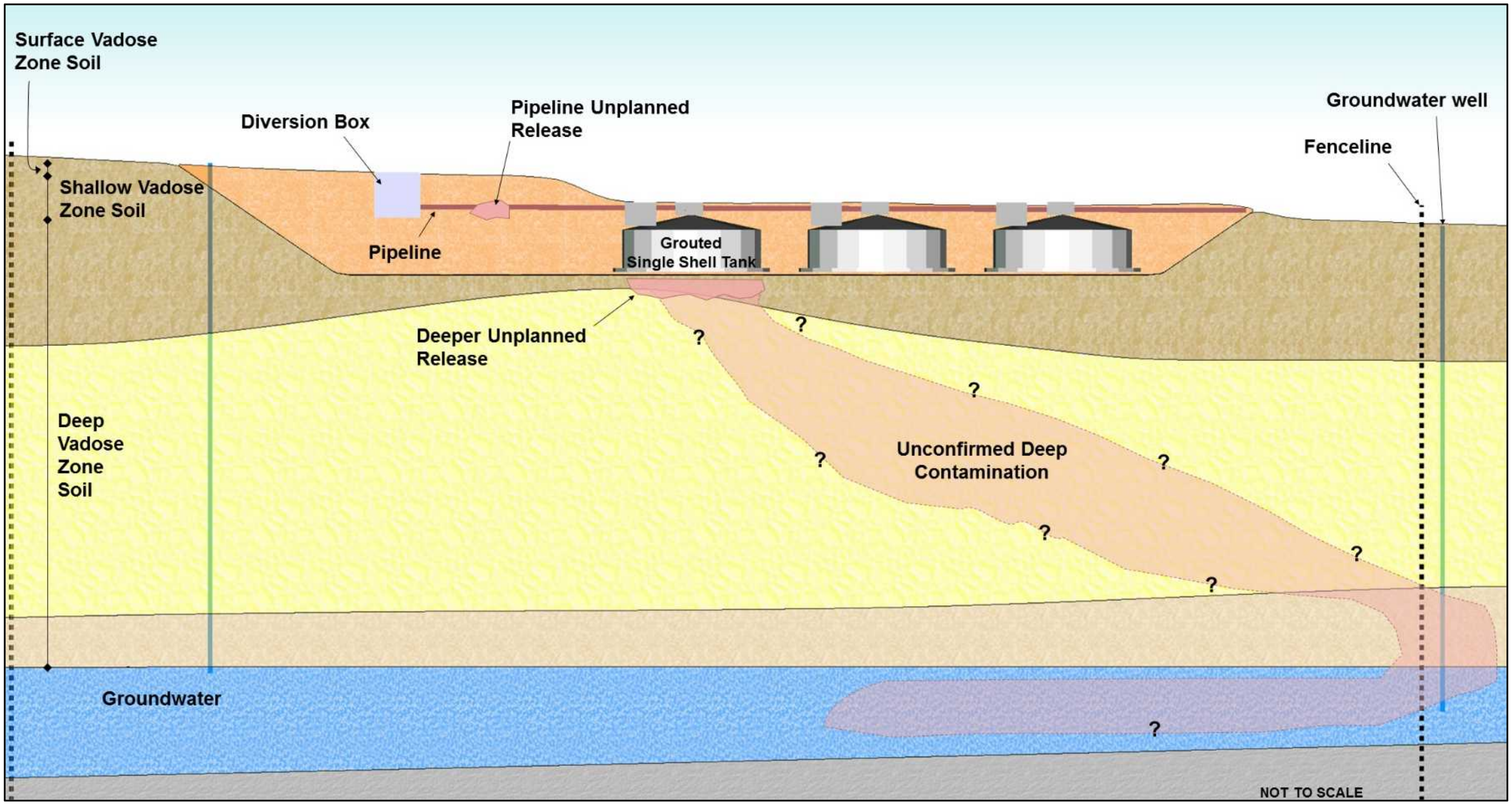
1.2.4 Current and Likely Future Land Use

WMA C is located within Hanford's Central Plateau. Central Plateau land-use has been designated as Industrial-Exclusive. The nearest inhabited residences are used for residential farming on land approximately 13 miles to the north and east of WMA C. The nearest City of Richland corporate boundary is approximately 13 miles southeast of WMA C. The nearest residential community is within the City of Richland, approximately 16 miles to the south-southeast.

In 64 FR 61615, “Record of Decision: Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)”, DOE establishes land use for the Central Plateau geographic area (including WMA C) as Industrial-Exclusive. 64 FR 61615 defines “Industrial-Exclusive” as an area “suitable and desirable for treatment, storage, and disposal of hazardous, dangerous, radioactive, non-radioactive wastes, and related activities.”

The Industrial-Exclusive designation allows for continued waste management operations occurring within the Central Plateau geographic area. The Tri-Parties agree to assume the Industrial-Exclusive designation for at least 50 years beyond issue of 64 FR 61615, issued in 1999, and that this land use is not anticipated to change substantially up to that point, in accordance with DOE/EIS-0222-SA-01, *Supplement Analysis, Hanford Comprehensive Land-Use Plan Environmental Impact Statement*.

Figure 1-3. Waste Management Area C Conceptual Site Model.



*Source: RPP-RPT-59379, “Waste Management Area C Phase 2 Corrective Measures Study Report.”

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2.0 METHODS AND APPROACH

This section provides a summary of the methods and approach used to conduct the WMA C CMS technologies screening. The evaluation criteria established to conduct the screening are described in Section 2.1. The methods and structure used to develop the inventory of technologies for screening, as well as the collection of supporting information, is described in Section 2.2. The three-phased screening process is briefly described in Section 2.3. Additional information about the methods and approach may be found in the WMA C CMS, Section 2.0.

2.1 EVALUATION CRITERIA AND WMA C SPECIFIC REQUIREMENTS

Prior to collecting an inventory of technologies for screening, evaluation criteria were developed and site specific requirements were identified, as discussed in this section. The development of corrective measures alternatives and identification of a preferred alternative involved satisfying Model Toxics Control Act (Revised Code of Washington 70.105D, "Hazardous Waste Cleanup — Model Toxics Control Act"), RCRA corrective action, and CERCLA evaluation criteria. As a result, screening evaluation criteria considered the requirements of these regulations. However, the development of corrective measures alternatives and consideration of these regulatory criteria are not described in this document, and may be found in the WMA C CMS.

2.1.1 Screening Evaluation Criteria

Evaluation criteria that would be used to assess technologies were established based on regulatory guidance and a review of previous technology screenings that were conducted both on and off the Hanford Site. The primary evaluation criteria used throughout the technology screening process are listed below.

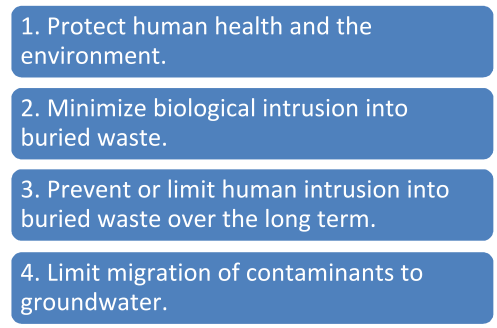
- Technical Maturity
- Applicability to WMA C Conditions
- Effectiveness for WMA C Site Conditions
- Long-term Effectiveness and Permanence
- Short-term Effectiveness
- Reduction of Toxicity, Mobility, and Volume
- Implementability
- Relative Cost

In addition to the criteria above, site specific objectives and requirements were considered during the screening. These are addressed in the Section 2.1.2.

2.1.2 WMA C Specific Requirements

The purpose of the WMA C CMS technology screening was to support the development of corrective measures alternatives. These alternatives were designed to meet corrective action objectives (CAOs) and applicable or relevant and appropriate requirements (ARARs) specific to WMA C. The CAOs specific to WMA C are identified in detail in Section 2.1 of the WMA C CMS and summarized in Figure 2-1. The ARARs specific to WMA C were identified through an iterative process during the development of the CMS, and are listed in Appendix D of the WMA C CMS. Technologies that would not support these CAOs and ARARs were eliminated during the screening process.

Figure 2-1. Corrective Action Objectives Defined in the WMA C CMS



2.2 TECHNOLOGIES INVENTORY DEVELOPMENT

The initial inventory of technologies considered for potential use in developing CMS corrective measures alternatives included over 100 technologies. A complete list of these technologies, along with a brief description of each, is provided in Appendix A. The methods used to develop this inventory are described in the following subsections.

2.2.1 Structure and Organization

For ease of collecting and storing information, technology type categories and subcategories were developed, as shown in Figure 2-2. These categories are similar to those used in other Hanford Site studies, such as RPP-ENV-34028, *Central Plateau Vadose Zone Remediation Technology Screening Evaluation* and the Deep Vadose Zone Project.

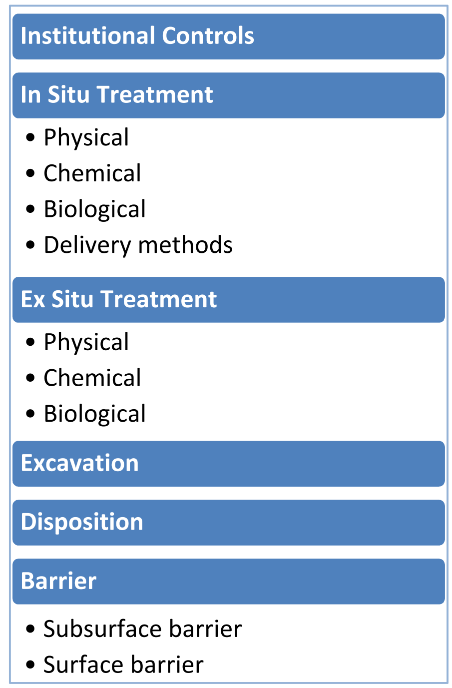
The technology categories and the screening evaluation criteria (Section 2.1.1) were used to develop a matrix into which technology types and information that would be needed to evaluate each type were collected. The research and review process involved in collecting this information is described in Section 2.2.2.

The technology type categories used for inventory development fit into broader general response action (GRA) categories. Both technology type and GRA categories were used at different times throughout the screening process. GRA categories are used to categorize actions required for implementation, which may require more than one technology or type of technology.

The GRA categories used in the WMA C CMS technology screening are listed below.

- No Action
- Institutional Controls
- Containment
- Treatment
- Removal
- Disposal

Figure 2-2. Technology Type Categories and Subcategories



These categories are briefly described in the following subsections (Sections 2.2.1.1 through 2.2.1.6), and additional information may be found in Section 2.0 of the WMA C CMS. GRA categories were used to construct the following GRAs during WMA C CMS alternatives development: no action; institutional controls; containment; removal and disposal; and removal, treatment and disposal. Additional details about GRAs and alternatives development may be found in the WMA C CMS, Sections 2.2 and 3.0, respectively.

2.2.1.1 *No Action*

This was considered for potential use at WMA C, but is not considered a technology. It was retained for evaluation as required to comply with CERCLA.

2.2.1.2 *Institutional Controls*

Institutional controls were considered for potential use at WMA C and retained for screening, but are not considered technologies. Types of institutional controls considered include access controls (e.g., security fencing), land use restrictions (e.g., deed and zoning restrictions), and administrative controls (e.g., WMA C Work Control Process).

2.2.1.3 *Containment*

Both surface and subsurface barriers were considered for potential use and retained for screening at WMA C. Surface barriers evaluated include geomembrane barriers, evapotranspiration barriers, and asphalt or concrete caps. Subsurface barriers evaluated include horizontal barriers; vertical barriers such as grout walls, sheet pile walls, and slurry walls; and jet injection barriers.

Barriers are effective at limiting access and/or limiting migration of surface and subsurface contaminants. Barriers may require maintenance to remain reliable over the long-term (i.e., repair of cracks will be required to prevent deterioration).

Proper maintenance and surveillance monitoring are required to promote the long-term effectiveness of a surface barrier system. Performance and maintenance monitoring generally are required to be conducted throughout the design life of a containment structure, and may be reduced through appropriate and optimal design to control long-term effectiveness and operating costs.

2.2.1.4 *Treatment*

Both in situ and ex situ treatment technologies were considered for potential application at WMA C and retained for screening. In situ technologies are used to treat contamination in place, eliminating the need for removal. In situ technologies typically afford a degree of safety to workers during implementation but require extensive understanding of local subsurface conditions. Ex situ technologies are used to treat media that has been removed from its original location. Ex situ technologies require greater consideration of protection of human health and the environment during implementation but may be implemented on or off-site, and do not require a substantial understanding of local subsurface conditions. Categories of treatment technologies considered include:

- **Physical:** Application of physical processes to induce removal, stabilization, immobilization, or degradation of contaminants. Specific technologies identified for screening include electrokinetic mobilization and recovery, thermal technologies like volatilization or vitrification, separation technologies like soil flushing with aqueous solutions, and solidification and stabilization.

- **Chemical:** Introduction of chemicals to react with contaminants or the surrounding matrix to reduce contaminant toxicity or mobility. Specific technologies identified for screening include immobilization, sequestration, oxidation/reduction, in situ mineral recovery, and hybrid delivery of treatment chemicals.

- **Biological:** Using biological organisms and processes to degrade, stabilize immobilize, or otherwise treat contaminated media. Biotechnologies identified for screening include microbial biodegradation, biological reduction, and supported growth biological reactors.

- **Delivery methods:** In addition to injection and extraction wells, this type of technology includes those designed to enhance the delivery of amendments and reagents to specific subsurface locations. Methods identified for screening include the use of foam, shear thinning fluid, and gas-phase delivery.

2.2.1.5 *Removal Technologies*

Excavation technologies were identified for the purpose of removing WMA C contaminated soil and retained for screening. Conventional excavation, remotely controlled excavation, and soil vacuuming were considered for physical soil removal. Because this type of technology would need to be evaluated for its ability to be implemented at various depths (surface to deep vadose zone), subtypes may be categorized as a deep or shallow type of excavation technology. Retaining wall technologies were evaluated for excavations to greater depth (up to 13.7 m [45 ft]). Minimizing worker exposure was a key consideration in the selecting excavation technologies.

2.2.1.6 *Disposal Technologies*

Disposal includes waste packaging, transport, and disposal at an appropriate facility, such as a landfill. On-site and off-site disposal options were identified and retained for screening. The on-site disposal facility retained for screening was the Environmental Restoration Disposal Facility (ERDF). The off-site disposal facility retained for screening was the Waste Control Specialist, LLC (WCS), facility in Andrews, Texas, which offers treatment and storage of Class A, B, and C low-level radioactive waste, hazardous waste, and byproduct materials.

The non-radiological and radiological inventory (level of radioactivity, activity concentration, and total activity) are principal criteria used to determine specific requirements for packaging and transporting soil waste. The receiving facility may not accept soil waste that has not been pre-treated in accordance with a facility's waste acceptance criteria.

2.2.2 Resources Utilized for Inventory Development

Technologies with the potential to address WMA C COCs were identified through an intensive research and review process. This process involved gathering information from multiple sources, as described in Section 2.0 of the WMA C CMS. Sources included those shown in Figure **2-3**.

Figure 2-3. Technology Identification Resources

Many technologies used in the screening described here were taken from the U.S. Environmental Protection Agencies' Hazardous Waste Clean-Up Information[1] website and the Deep Vadose Zone Technologies Public Information Exchange Summary[2].

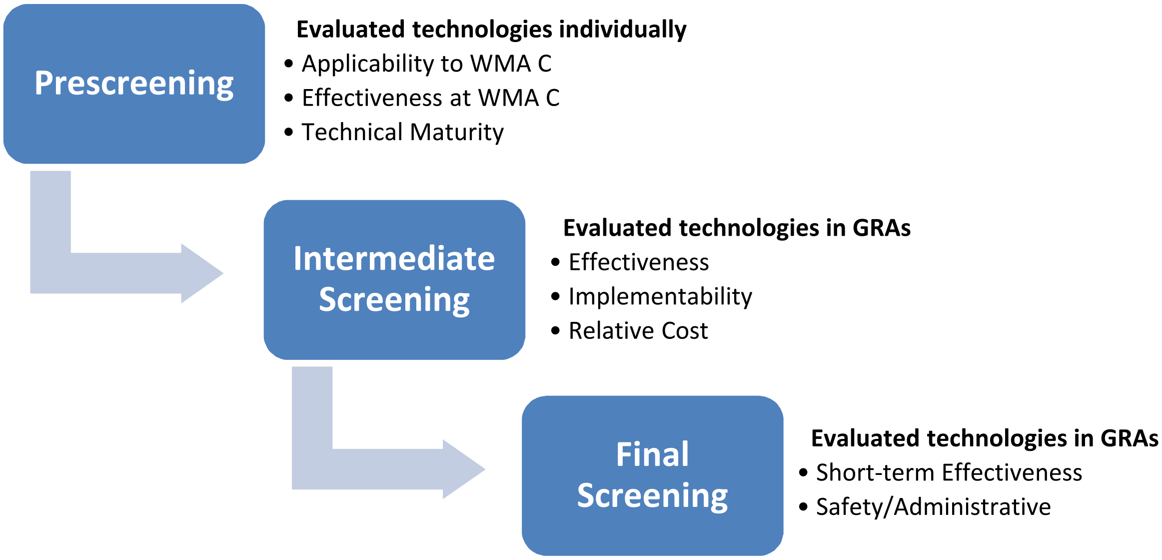
All of the technologies included in the Deep Vadose Zone Project technology screening were carried into the WMA C CMS technology screening, with the exception of physical separation as a broad category. The WMA C CMS technology screening evaluated soil sorting and screening, which is considered one type of physical separation.

2.3 SCREENING PROCESS

After an inventory of technologies was developed, the technologies were evaluated using a three-stage screening process. The first stage was the prescreening, which involved evaluating each individual technology. During the second and third stages of the screening process, technologies were considered in GRA groupings, as applicable. Each stage of screening included a subset of the evaluation criteria discussed in Section 2.1.1. Figure 2-4 shows the criteria that were evaluated during the three screening stages.

[1] https://www.epa.gov/remedytech/hazardous-waste-clean-information-clu-line-characterization-and-remediation-databases
[2] https://www.hanford.gov/page.cfm/DeepVadoseZone

Figure 2-4. Criteria Evaluated at Each Screening Stage



The three stages included the screening process, along with the results of each stage, are described in greater detail in Section 3.0 (prescreening), Section 4.0 (intermediate screening), and Section 5.0 (final screening) of this document.

CAOs and ARARs were considered at all stages of the screening process; however, ARARs were added throughout the screening process, as needed, as a better understanding was gained of the relationship between site conditions and the implementation of GRAs.

3.0 PRESCREENING

All technologies collected during the inventory process were evaluated individually in a prescreening (Appendix A includes the entire inventory of technologies organized by GRA and technology type categories). Section 3.1 discusses the methods used to perform the prescreening, and Section 3.2 presents the results of the prescreening.

3.1 METHODS

Information collected during the inventory process was used to evaluate each technology, independently, against the criteria shown in Figure 3-1.

Figure 3-1. Evaluation Criteria Used During Prescreening Process

Prescreening Criteria

- Applicability at WMA C
- Effectiveness at WMA C
- Technical Maturity

The applicability of each technology for use at WMA C was evaluated by researching its potential to address WMA C COC/COPCs and meet WMA C CAOs. Technologies with the potential to address multiple WMA C COCs and meet WMA C CAOs were considered most applicable. Technologies that were not applicable to WMA C COCs were not carried through the prescreening.

At the prescreening stage, each technology's potential effectiveness at WMA C was evaluated at a general level. The evaluation included a general consideration of potential to address contaminants in the WMA C vadose zone and a review of previous performance. More specific factors considered during this evaluation included considering the technology's potential performance in WMA C specific soil conditions (e.g., moisture content, heterogeneity) potential effectiveness and ease of deployment at varying depths (surface to deep vadose zone), general long-term effectiveness (e.g., irreversible, or requiring additional treatment; relatively low maintenance required, or maintenance intensive), and ability to treat large volumes of soil. Technologies with previous past performance effectiveness in soils similar to WMA C vadose zone soils, at variable depths, and for large quantities of soil, were considered most effective. Technologies that were not considered potentially effective for use in the WMA C vadose zone were not carried through the prescreening.

Technical maturity was determined by evaluating the stage of development of each technology. Technologies that had been previously used at field scale at Hanford were considered the most mature for use at WMA C. Technologies that were still in the research and development stage and had not been tested at field scale were considered the least mature for use at WMA C, and were not carried through the prescreening. Some technologies eliminated at this time could be proven effective in the future for use in vadose zone conditions such as those at WMA C.

3.2 PRESCREENING RESULTS

The results of the prescreening are presented in Table 3-1, below. Sections 3.2.1 through 3.2.6 provide details regarding the construction of this table.

Table 3-1. Prescreened Technologies and Results

General Response Category	Technology Type	Technology Subtype	Technical Maturity	Applicability	Effectiveness	Retained through Prescreening?
No Action	Not applicable	None	Y	Y	N	**N**
Institutional Control	Access Controls	Site Access Controls	Y	Y	Y	**Y**
	Access Controls	WMA C Access Controls	Y	Y	Y	**Y**
	Administrative Controls	Site-Wide Integrated Safety Management System Program	Y	Y	Y	**Y**
	Administrative Controls	WMA C Work Control Process	Y	Y	Y	**Y**
Containment	Subsurface Barrier	High-Density polyethylene geomembrane	Y	Y	N	**N**
		Horizontal Subsurface Barrier (HSSB)	Y	N	N	**N**
		Permeation Grouting - High pressure grout injection (e.g., silicate, acrylamide)	Y	Y	N	**N**
		Permeation Grouting - Molten Wax Injection	Y	Y	N	**N**
		Freeze Barrier	Y	N	N	**N**
		Jet Grouting	Y	N	N	**N**
		Vertical Grout Wall	Y	N	N	**N**
		Vertical Grout Wall – Auger Mixed	Y	N	N	**N**
		Vertical Sheet Pile Wall Barrier	Y	N	N	**N**
		Vertical Slurry Wall	Y	N	N	**N**
Containment	Surface Barrier	Hanford Surface Barrier	Y	N	N	**N**
		General Isolation Barrier	Y	Y	N	**N**
		Isolation Barrier - Soil/Rock	Y	N	N	**N**
		Revegetation or stone covers	Y	N	N	**N**
		Modified RCRA Subtitle C Barrier	Y	N	N	**N**
		Infiltration Surface Barrier - Treated Concrete Barrier	Y	Y	N	**N**
		Isolation Barrier -Concrete	Y	Y	Y	**Y**
		Interim Surface Barrier – Modified Asphalt	Y	Y	Y	**Y**
		Evapotranspiration (ET) Barrier (Capillary)	Y	Y	Y	**Y**
		High Density Polyethylene (HDPE) Geomembrane	Y	Y	N	**N**

Table 3-1. Prescreened Technologies and Results

General Response Category	Technology Type	Technology Subtype	Technical Maturity	Applicability	Effectiveness	Retained through Prescreening?
Disposal	Disposition	Backfill Excavations Using Ex Situ Treated Soil Material	Y	N	N	**N**
		Onsite Waste Disposal (ERDF/SWBG, or other applicable onsite disposal as available)	Y	Y	Y	**Y**
		Offsite Waste Disposal	Y	Y	Y	**Y**
Treatment	Ex Situ Treatment: Biological	Biological Reduction	Y	Y	N	**N**
		Microbial Biodegradation	Y	N	N	**N**
		Supported Growth Biological Reactors	Y	Y	N	**N**
	Ex Situ Treatment: Chemical	Oxidation/Reduction	Y	Y	N	**N**
		Sequestration	Y	Y	Y	**Y**
		Carbon Nanotubes	N	Y	N	**N**
		Carbonate Sequestration	Y	Y	Y	**Y**
		Immobilization	Y	Y	Y	**Y**
	Ex Situ Treatment: Chemical/Physical	Solidification & Stabilization	Y	Y	Y	**Y**
		Soil Flushing with Water or Chemicals	Y	Y	Y	**Y**
	Ex Situ Treatment: Physical	Mineral Recovery	Y	Y	Y	**Y**
		Molecular Sieves	N	Y	N	**N**
		Soil Sorting & Screening	Y	N	N	**N**
		Soil Vapor Extraction	Y	N	N	**N**
		Soil Washing	Y	Y	Y	**Y**
		Vitrification	Y	Y	N	**N**
		Volatilization	Y	N	N	**N**
	In Situ: Biological	Biological Reduction (general)	Y	Y	N	**N**
		Biological Reductive Dechlorination	N	N	N	**N**
		Biomineralization using Calcite Precipitating Bacterium	N	Y	N	**N**
		In-Situ Biological Reduction	N	Y	Y	**N**
		Microbial Bioremediation/Biodegradation	Y	N	N	**N**
		Monitored Natural Attenuation	Y	Y	N	**N**
		Supported Growth Biological Reactors	N	N	N	**N**
	In Situ: Chemical	Ammonia Gas	N	Y	Y	**N**
		Calcite Sequestration (immobilization)	N	Y	Y	**N**
		Calcium Polysulfide Injection (reduction)	N	Y	Y	**N**

Table 3-1. Prescreened Technologies and Results

General Response Category	Technology Type	Technology Subtype	Technical Maturity	Applicability	Effectiveness	Retained through Prescreening?
Treatment	In Situ: Chemical	Carbon Nanoparticles	N	Y	Y	**N**
		Carbon Nanoparticles (e.g., SAMMs and nanotubes)	N	Y	N	**N**
		Carbonate Sequestration (immobilization)	Y	N	N	**N**
		ISCO (chemical oxidation)	Y	Y	N	**N**
		Chemical Oxidation/Reduction	Y	Y	N	**N**
		Exotic Nanoparticles	N	N	N	**N**
		Ferrous Iron	N	Y	Y	**N**
		Gaseous Reduction (e.g., hydrogen sulfide or ammonia gas)	N	Y	N	**N**
		Nano-Zero Valent Iron	N	Y	Y	**N**
		Phosphate/Apatite Sequestration	Y	Y	N	**N**
		SAMMs (Self-Assembled Monolayers on Mesoporous Supports)	N	Y	Y	**N**
		Silicate Minerals	Y	Y	N	**N**
		Sodium Dithionite	Y	N	N	**N**
		Sulfide Salts and Minerals (i.e., ferrous sulfate/calcium polysulfide injection)	Y	N	N	**N**
		Surface/Subsurface Infiltration of Reactant/Sequestering Agent	Y	N	N	**N**
		Zeolites	Y	N	N	**N**
		Zero Valent Iron or other Zero Valent Metals	Y	Y	N	**N**
	In Situ: Physical	Deep Soil Mixing	Y	N	N	**N**
		Electrokinetic Mobilization and Recovery	N	Y	N	**N**
		Enhanced Volatilization	Y	N	N	**N**
		In Situ Uranium Recovery/Leaching (solution mining)	Y	N	N	**N**
		In Situ Vitrification	Y	N	N	**N**
		In-Situ Thermal Desorption	Y	N	N	**N**
		Jet Injection	Y	Y	N	**N**
		Perched Water Removal	Y	N	N	**N**
		Physical Separation	Y	N	N	**N**
		Pore Water Extraction	N	Y	Y	**N**
		Soil Flushing with Water or Chemicals	Y	N	N	**N**
		Soil Moisture Extraction/Desiccation	Y	N	N	**N**
		Soil Stabilization	Y	N	N	**N**

Table 3-1. Prescreened Technologies and Results

General Response Category	Technology Type	Technology Subtype	Technical Maturity	Applicability	Effectiveness	Retained through Prescreening?
Treatment	In Situ: Physical	Soil Vapor Extraction	Y	N	N	**N**
		Sorbent Extraction (Soil Wicking)	N	Y	N	**N**
		Volatilization	Y	N	N	**N**
	In Situ: Delivery method	Foam Delivery of Reactant/Sequestering Agent	N	N	N	**N**
		Gas-phase Delivery of Reactant/Sequestering Agent	Y	N	N	**N**
		Horizontal Injection/Extraction Wells	Y	Y	N	**N**
		Hybrid Electrokinetic Delivery of Reactant/Sequestering Agent	Y	N	N	**N**
		Shear Thinning Fluid Delivery of Reactant/Sequestering Agent	N	N	N	**N**
		Vertical Injection/Extraction Wells	Y	Y	N	**N**
Removal	Excavation	Conventional (Surface-Based) Excavation (also "Shallow Conventional Excavation")	Y	Y	Y	**Y**
		Deep Excavation Techniques: Soldier Piles and Lagging	Y	Y	Y	**Y**
		Deep Excavation Techniques: Tunneling	Y	Y	Y	**Y**
		Caissons for Soil Stability	Y	Y	Y	**Y**
		Cofferdams for Soil Stability	Y	Y	Y	**Y**
		Deep Excavation Techniques: Deep-Mixed Walls for Soil Stability	Y	Y	Y	**Y**
		Deep Excavation Techniques: Diaphragm/Slurry Walls for Soil Stability	Y	Y	Y	**Y**
		Deep Excavation Techniques: Dragline Excavators/ Conventional Shaft Sinking	Y	Y	Y	**Y**
		Drilling and Soil Replacement	Y	Y	Y	**Y**
		Deep Excavation Techniques: Jet Grouting Walls for Soil Stability	Y	Y	Y	**Y**
		Deep Excavation Techniques: Reinforced Concrete Walls for Soil Stability	Y	Y	Y	**Y**
		Deep Excavation Techniques: Secant Pile Walls for Soil Stability	Y	Y	Y	**Y**
		Deep Excavation Techniques: Sheet Piling or Sheet Pile Walls for Soil Stability	Y	Y	Y	**Y**

Table 3-1. Prescreened Technologies and Results

General Response Category	Technology Type	Technology Subtype	Technical Maturity	Applicability	Effectiveness	Retained through Prescreening?
Removal	Excavation	Deep Excavation Techniques: Sloping and/or Benching for Soil Stability	Y	Y	Y	**Y**
		Deep Excavation Techniques: Soil Nail Walls for Soil Stability	Y	Y	N	**N**
		Excavation Techniques: tangent pile walls	Y	Y	Y	**Y**
		Remote Excavation	Y	Y	Y	**Y**
		Retaining Wall Technologies	Y	Y	Y	**Y**
		Vacuum Excavation	Y	Y	Y	**Y**

ERDF = Environmental Restoration Disposal Facility
ET = evapotranspiration
HDPE = high-density polyethylene
HSSB = horizontal subsurface barrier
ISCO = in situ chemical oxidation
RCRA = *Resource Conservation and Recovery Act of 1976*
SAMM = self-assembled monolayers on mesoporous supports
SWBG = solid waste burial ground
WMA = Waste Management Area

3.2.1 No Action

A no action response was eliminated from further screening due to inability to meet CAOs.

3.2.2 Institutional Controls

Institutional Controls are considered a requisite for all interim actions that may be considered for WMA C and were retained through the prescreening.

3.2.3 Containment Technologies

Surface geomembrane barriers were not retained because previous implementation at Hanford proved an industrial safety hazard due to moisture causing slipping hazards.

Native soil and stone/rock barriers have some relevance to the final closure cap but were not retained for corrective measures as they would not effectively address WMA C CAOs or COPC/COCs.

Jet grouting and horizontal subsurface barriers are designed to prevent downward migration of contaminants, but require perfect placement to create an effective seal, so were not retained due to the difficulty in constructing barriers below the existing WMA C infrastructure and the presence of contamination distributed in the soil. Other subsurface barrier technologies considered were not retained due to their inability to prevent downward contaminant migration (e.g., high-density polyethylene geomembrane, freeze barrier, molten wax injection, vertical grout walls).

Evapotranspiration barriers, and asphalt or concrete caps were retained through the initial screening as isolation barriers and infiltration barrier systems. Such systems use low-permeability materials to limit surface-water infiltration, thereby controlling moisture-driven transport of underlying contaminants. They also provide additional physical separation between the contaminated soil and potential receptors.

Vertical barriers (i.e, grout walls, sheet pile walls, slurry walls) were eliminated from further screening as they do not apply to WMA C conditions and would not effectively address WMA C CAOs.

Isolation barriers are good at preventing exposures to human health and the environment, but are not protective of groundwater, and have limited effectiveness with WMA C COPC/COCs. As a result, this general class of technologies was eliminated during the prescreening. However, concrete isolation barrier technology, a subtype of the broader isolation barrier category, was retained for further screening.

Although both types of surface barriers have been used on site, only the modified asphalt interim surface barrier was retained through the prescreening. The geomembrane surface barrier was not retained because the surface becomes slick during the winter so becomes a safety hazard.

3.2.4 Treatment Technologies

Many treatments were not retained beyond the initial screening due to lack of technical maturity (e.g., carbonate sequestration, carbon nanotubes), incompatibility with the WMA C vadose zone (e.g., electrokinetic mobilization and recovery is most effective in soils with a higher moisture content), incompatibility with WMA C COCs (e.g., soil vapor extraction), or implementability challenges (e.g., biological treatments). Reduction/oxidation technologies were not retained because reduction is potentially reversible and could require repeated treatments. The use of sulfur-based technologies was not retained as these require injection of sulfurous minerals, and during the time of the screening, sulfur dioxide was considered a COPC at WMA C.

A number of in situ treatment technologies were initially considered to be potentially viable for addressing mobile contaminants, including phosphate/apatite sequestration, clay minerals, gas-phase delivery, and jet injection. However, none were retained for further consideration given the current understanding of the nature and extent of contamination at WMA C. Implementation of the in situ treatment technologies would require a well-defined contamination zone for technology deployment which is not available for WMA C. Therefore, the technologies could not be effectively deployed to address the mobile COPC/COCs in the vadose zone.

Ex situ treatment technologies were evaluated for use in stabilizing soil contamination following excavation. Vitrification was not retained due to the level of infrastructure required and implementation cost. Supported growth biological reactors were not retained as these are typically used in saturated conditions or with vapors, and have limited applicability to WMA C vadose zone conditions. Molecular sieves and soil sorting and screening were considered impractical based on the volume of soil to be excavated and complexity of soil contamination. Soil vapor extraction and volatilization were not considered applicable to WMA C COPC/COCs. Oxidation and reduction technologies were not retained due to the potential reversibility of the technology, and possible need for repeated treatments.

Ex-situ solidification/stabilization was retained based on potential implementability and effectiveness. Large volumes of soil could be processed with minimal process waste resulting from treatment.

3.2.5 Removal Technologies

Soil nail walls were not retained due to the poor cohesiveness of the soils at WMA C. All other excavation technology types were retained through the prescreening.

3.2.6 Disposal Technologies

On-site and offsite disposal were considered, and both types were retained through the prescreening. Backfill using ex situ treated soil was not retained as it would not be protective of groundwater.

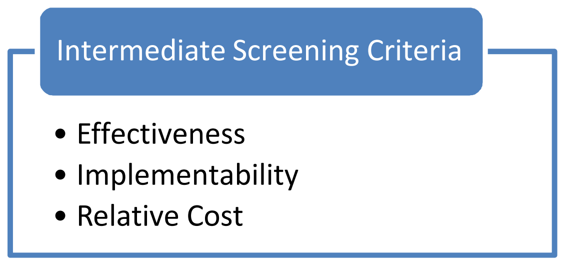
4.0 INTERMEDIATE SCREENING

Section 4.1 discusses the methods used to perform the intermediate screening, and Section 4.2 presents the results of the intermediate screening.

4.1 METHODS

For the intermediate screening, the remaining technologies were grouped into GRA to evaluate their potential application at WMA C. Some technologies were considered in more than one GRA (e.g., remote excavation using tangent pile walls and remote excavation using sloping and benching). During this screening, the GRAs were evaluated as by the criteria shown in Figure **4-1**. The GRAs groupings included no action; institutional controls; containment; removal and disposal; and removal, treatment and disposal. These GRAs are described in greater detail in the WMA C CMS.

Figure 4-1. Criteria Evaluated During the Intermediate Screening Process.



Effectiveness was evaluated more specifically during the intermediate screening than in the prescreening. This included consideration of the potential of GRA groups to address contaminants in the WMA C vadose zone, CAOs, and applicable ARARs.

Implementability was evaluated by considering whether a GRA could be implemented at WMA C given site conditions such as buried tanks, pipelines, and geology.

Relative cost was evaluated by assessing the capital and operation and maintenance costs of each GRA. For the purposes of this evaluation, relative costs were categorized as high, moderate, or low. If several technologies met the effectiveness and implementability criteria during the intermediate criteria, those with a higher relative costs were not retained for the final screening.

Technologies were eliminated during the intermediate screening if they did not meet the evaluation criteria as part of one or more GRAs.

4.2 RESULTS

The results of the intermediate screening are presented in Table 4-1, below. Sections 4.2.1 through 4.2.5 provide details regarding the construction of this table.

Table 4-1. Results of the Intermediate Screening Stage

General Response Action	Technology Type	Technology Subtype	Effectiveness	Implementability	Relative Cost	Retained through Intermediate Screening?
Containment	Subsurface Barrier	Evapotranspiration Barrier (Capillary)	Y	N	High	**N**
	Surface Barrier	Isolation Barrier – Concrete	Y	Y	Low	**Y**
		Interim Surface Barrier – Modified Asphalt	Y	Y	Moderate	**Y**
Removal and Disposal: Disposition	Disposal Option	Offsite Waste Disposal	Y	Y	High	**N**
		Onsite Waste Disposal (ERDF/SWBG, or other applicable onsite disposal as available)	Y	Y	Low	**Y**
Institutional Control	Access Controls	Site Access Controls	-	-	-	**Y**
		WMA C Access Controls	-	-	-	**Y**
		Site-Wide Integrated Safety Management System Program	-	-	-	**Y**
		WMA C Work Control Process	-	-	-	**Y**
RTD: Ex Situ Treatment	Chemical Treatment	Carbonate Sequestration	Y	N	High	**N**
		Immobilization	Y	N	High	**N**
		Sequestration	Y	N	High	**N**
	Physical Treatment	Mineral Recovery	Y	N	High	**N**
		Soil Washing	N	N	Low	**N**
	Chemical/Physical	Solidification & Stabilization	Y	Y	Low	**Y**
		Soil Flushing with Water or Chemicals	Y	N	Moderate	**N**
RTD: Removal	Excavation	Conventional (Surface-Based) Excavation (also "Shallow conventional excavation)	Y	Y	Low	**Y**
		Deep Excavation - Soldier Piles and Lagging	Y	N	High	**N**
		Deep Excavation - Tunneling	Y	N	High	**N**
		Deep Excavation Using Caissons for Soil Stability	N	N	High	**N**
		Deep Excavation Using Cofferdams for Soil Stability	N	N	High	**N**
		Deep Excavation Using Deep-Mixed Walls for Soil Stability	Y	N	High	**N**

Table 4-1. Results of the Intermediate Screening Stage

General Response Action	Technology Type	Technology Subtype	Effectiveness	Implementability	Relative Cost	Retained through Intermediate Screening?
RTD: Removal	Excavation	Deep Excavation Using Diaphragm/Slurry Walls for Soil Stability	Y	N	High	**N**
		Deep Excavation Using Dragline Excavators/ Conventional Shaft Sinking	N	N	High	**N**
		Deep Excavation Using Drilling and Soil Replacement	N	N	High	**N**
		Deep Excavation Using Jet Grouting Walls for Soil Stability	Y	N	High	**N**
		Deep Excavation Using Reinforced Concrete Walls for Soil Stability	Y	N	High	**N**
		Deep Excavation Using Secant Pile Walls for Soil Stability	Y	N	High	**N**
		Deep Excavation Using Sheet Piling or Sheet Pile Walls for Soil Stability	Y	Y	Moderate	**Y**
		Deep Excavation Using Sloping and/or Benching for Soil Stability	Y	Y	Low	**Y**
		Excavation using tangent pile walls	N	N	Moderate	**N**
		Remote Excavation	Y	Y	High	**Y**
		Retaining Wall technologies	N	N	Low	**N**
		Vacuum Excavation	Y	Y	High	**Y**

ERDF = Environmental Restoration Disposal Facility
RTD = remove, treat, and dispose
SWBG = solid waste burial ground
WMA = waste management area

4.2.1 Institutional Controls

Institutional Controls are considered a requisite for all interim actions that may be considered for WMA C and were retained through the intermediate screening.

4.2.2 Containment Technologies

The use of an evapotranspiration basin was not retained due to implementability concerns. The areas north and west of WMA C are lower in elevation than WMA C, making them logical choices for a drainage basin. Unfortunately, these areas north and west of WMA C consist of large contamination areas that are not suitable for excavation and placement of an evapotranspiration basin. Areas to the south and east of WMA C are higher in elevation so a passive drainage system could not be used. The use of an active pumping system to convey barrier runoff would require both preventative and possibly correct maintenance over time, escalating the relative cost of the technology.

4.2.3 Treatment Technologies

A number of ex situ treatment technologies were not retained due to potential complications with implementability and high relative cost compared to ex situ solidification and stabilization, which was retained through the intermediate screening. Technologies eliminated on this basis included sequestration in general, including carbonate sequestration; immobilization; and mineral recovery.

Ex situ soil washing and soil flushing were not retained because the complexity of WMA C soil contamination would require multiple treatment trains during implementation and generate significant liquid waste volumes.

4.2.4 Removal Technologies

A number of excavation technologies were not retained beyond the intermediate screening due to implementability concerns. Technologies such as jet grout walls, caissons, deep mixed walls, secant/tangent pile walls, and diaphragm walls were not retained as they introduce high amounts of grout or slurry that may potentially absorb and spread contamination. Drilling and soil replacement, secant pile walls, and conventional shaft sinking were not retained due to potential to spread contamination. Dragline excavation was not considered because it would require significant setbacks to reach required depths and would be difficult to implement around existing infrastructure (e.g., exposed ventilation pipes). Cofferdams and tunneling are widely used excavation practices, but are typical of construction projects rather than soil remediation and would encounter setbacks due to site infrastructure.

The application of most excavation technologies is complicated by the fact that soil contamination is not well defined at WMA C. The high cost of deep excavation technologies is compounded by this fact, effectively meaning the entire area within WMA C would require excavation in order to be sure the contaminated areas were addressed. Excavation beneath the tanks would be impossible to implement.

Conventional excavation, remote excavation, and vacuum excavation were retained through the intermediate screening. Sheet piling (also known as sheet pile walls) and sloping and benching were retained as deep excavation stabilizing techniques.

4.2.5 Disposal Technologies

On-site and offsite disposal were considered, and on-site disposal was considered to be the least expensive and most easily implementable of the two technologies. Offsite disposal was not retained for further evaluation.

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5.0 FINAL SCREENING

Based on the prescreening and intermediate screening, nine technologies were carried forward to the final screening stage and were evaluated against the criteria shown in Figure 5-1. The definitions of these criteria are as follows:

- **Long-term Effectiveness and Permanence:** The assessment of alternatives against this criterion evaluates the long-term effectiveness of alternatives in maintaining protection of human health and the environment after response objectives have been met. In this CMS report, the evaluation criterion of long-term effectiveness and permanence relates to the period of time between the placement of the alternative and the construction of the final closure cap over WMA C.

- **Short-term Effectiveness:** The assessment against this criterion examines the effectiveness of alternatives in protecting human health and the environment during the construction and implementation of a remedy until response objectives have been met.

Figure 5-1. Criteria Evaluated During the Final Screening Process

Final Screening Criteria

- Long-term Effectiveness and Permanence
- Short-term Effectiveness
- Reduction of Toxicity, Mobility, and Volume
- Long-term Reliability
- Implementability
- Relative Cost

- **Reduction of Toxicity, Mobility, and Volume:** The assessment against this criterion evaluates the anticipated performance of the specific treatment technologies an alternative may employ.

- **Long-term reliability:** This assessment evaluates the ability of a technology to maintain the required level of protection over the long-term after it has been implemented.

- **Implementability:** This assessment evaluates the technical and administrative feasibility of alternatives and the availability of required goods and services.

- **Cost:** This assessment evaluates the capital and operation and maintenance costs of each alternative.

5.1 RESULTS

The results of the final screening are shown in Table 5-1, and briefly discussed in Sections 5.1.1 through 5.1.4. It is assumed that the institutional controls carried through the intermediate screening process will be included in all of the interim actions analyzed, so no further evaluation was necessary.

As a result of the final screening stage, vacuum excavation was removed from further consideration in developing process options for use in alternatives development. The final eight technologies are described, along with their applied process options, relative to their performance against effectiveness, implementability, and cost in Section 5.2.

Table 5-1. Results of the Final Screening Stage

Screening Criteria	Responsiveness to Screening Criteria[1]	Performance[2]	Retained/Not Retained
Concrete Isolation Barrier			
Effectiveness	Yes	Fair	
Long-term Effectiveness	Yes	Fair	
Short-term Effectiveness	Yes	Good	
Reduction of Toxicity, Mobility, or Volume of Wastes	Yes	Fair	Retained
Long-term Reliability	Yes	Fair	
Implementability	Yes	Good	
Cost	Low	Good	
Modified-Asphalt Surface Barrier			
Effectiveness	Yes	Fair	
Long-term Effectiveness	No	Poor	
Short-term Effectiveness	Yes	Good	
Reduction of Toxicity, Mobility, or Volume of Wastes	Yes	Fair	Retained
Long-term Reliability	No	Poor	
Implementability	Yes	Good	
Cost	Moderate	Good	
Conventional Excavation			
Effectiveness	Yes	Good	
Long-term Effectiveness	Yes	Good	
Short-term Effectiveness	Yes	Good	
Reduction of Toxicity, Mobility, or Volume of Wastes	Yes	Good	Retained
Long-term Reliability	Yes	Good	
Implementability	No	Poor	
Cost	Low	Good	

Table 5-1. Results of the Final Screening Stage

Screening Criteria	Responsiveness to Screening Criteria[1]	Performance[2]	Retained/Not Retained
Remotely Operated Excavation Equipment			
Effectiveness	Yes	Good	Retained
Long-term Effectiveness	Yes	Good	
Short-term Effectiveness	Yes	Good	
Reduction of Toxicity, Mobility, or Volume of Wastes	Yes	Good	
Long-term Reliability	Yes	Good	
Implementability	No	Poor	
Cost	High	Poor	
Vacuum Excavation			
Effectiveness	No	Poor	Not Retained
Long-term Effectiveness	Yes	Good	
Short-term Effectiveness	No[3]	Poor[3]	
Reduction of Toxicity, Mobility, or Volume of Wastes	Yes	Good	
Long-term Reliability	Yes	Good	
Implementability	No	Poor	
Cost	High	Poor	

Table 5-1. Results of the Final Screening Stage

Screening Criteria	Responsiveness to Screening Criteria[1]	Performance[2]	Retained/Not Retained
Standard Sloping and Benching Systems			
Effectiveness	Yes	Good	Retained
Long-term Effectiveness	Yes	Good	
Short-term Effectiveness	Yes	Good	
Reduction of Toxicity, Mobility, or Volume of Wastes	Yes	Good	
Long-term Reliability	Yes	Good	
Implementability	Yes	Good	
Cost	Low	Good	
Sheet Pile Walls			
Effectiveness	Yes	Good	Retained
Long-term Effectiveness	Yes	Good	
Short-term Effectiveness	Yes	Good	
Reduction of Toxicity, Mobility, or Volume of Wastes	Yes	Good	
Long-term Reliability	Yes	Good	
Implementability	Yes	Good	
Cost	Moderate	Fair	
RTD: Disposal of Excavated Material			
Effectiveness	Yes	Good	Retained
Long-term Effectiveness	Yes	Good	
Short-term Effectiveness	Yes	Good	
Reduction of Toxicity, Mobility, or Volume of Wastes	Yes	Good	
Long-term Reliability	Yes	Good	
Implementability	Yes	Good	
Cost	Low	Good	

Table 5-1. Results of the Final Screening Stage

Screening Criteria	Responsiveness to Screening Criteria[1]	Performance[2]	Retained/Not Retained
RTD: Ex Situ Solidification and Stabilization			
Effectiveness	Yes	Good	Retained
Long-term Effectiveness	Yes	Good	
Short-term Effectiveness	Yes	Good	
Reduction of Toxicity, Mobility, or Volume of Wastes	Yes	Good	
Long-term Reliability	Yes	Good	
Implementability	Yes	Good	
Cost	Low	Good	

Notes:
1 To indicate relative **cost** of each technology, the semi-quantitative system uses a rating of low to moderate to high.
2 To indicate relative **performance** of the technologies against the evaluation criteria, the qualitative system uses a rating of poor to fair to good.
3 High airborne contamination.
RTD = remove, treat, and dispose.

5.1.1 Containment Technologies

The two containment technologies retained during this screening include a concrete isolation barrier and a modified-asphalt surface barrier. Both barrier types have been successfully constructed in WMA tank farms, and the cost of implementation is low to moderate.

5.1.2 Treatment Technologies

Ex situ solidification and stabilization of contaminated soil will include the addition of clean soil and/or grout to ensure the waste container radiological dose rates are acceptable for transport and disposal. Application of water or fixative will suppress but not completely eliminate airborne contaminates during excavation and waste box loading. Administrative controls and personal protective equipment will be required to minimize the spread of contamination and exposure to radiation. Although an additional control will solve one issue, the control easily complicates the process thus adding other issues (i.e., supplied air for breathing limits worker visibility and mobility while operating equipment; increases the risk of heat related illness; and increases the time necessary to accomplish even simple tasks thus increasing exposure to radiation). These factors make soil treatment and cost intensive.

5.1.3 Removal Technologies

Three excavation technologies were evaluated along with two excavation support technologies. The excavation technologies include conventional excavation, remotely operated excavation equipment and vacuum excavation. Excavation has been used to remove contaminated soil on the Hanford Site. The cost of excavation is dependent on the design and equipment selected.

Two excavation technologies evaluated were retained for developing process options. Conventional excavation and remotely operated excavation could permanently reduce soil contamination at WMA C. Conventional excavation can be implemented at a low cost.

Vacuum excavation was not retained for development of process options. There is a high probability of airborne contamination with this technology. Carrying contaminated particulates in a high volume airflow poses hazards to site workers and the environment.

Vacuum excavation has been successfully implemented in other WMAs for low contamination areas. Excavation is discontinued when radioactive contamination is detected. The contamination is mitigated prior to continued excavation. The use of vacuum technology to target high contamination areas would be unprecedented. The technology is also incomplete because it is unclear how the soil would be discharged from the guzzler for treatment and disposal.

Hazards associated with the application of vacuum technology to contaminated areas would require thorough evaluation and controls. The hazard evaluation and controls will be dependent on the knowledge of contaminates, dose rate and volume of the COCs encountered. Soil characterization has provided some knowledge of COCs, but soil contamination is not homogeneous so the extent of the contamination would not be known until it was excavated. These factors make vacuum excavation hazardous to workers and cost intensive.

Two excavation support technologies were evaluated. These support technologies include standard sloping and benching systems and sheet pile walls. These support technologies are relatively cost effective and can be implemented on-site.

5.1.4 Disposal Technologies

Both on-site and offsite disposal technologies were evaluated. Disposal is discussed in greater detail in Section 2.4.5.4 of the WMA C CMS. On-site disposal will be the least expensive and most expeditious disposal path.

5.2 RETAINED TECHNOLOGIES AND PROCESS OPTIONS

Applicable technologies have been identified for each GRA for use at WMA C. The remedial technologies retained for WMA C are described in this section. The application of the technologies at WMA C form process options.

Eight process options were developed from the eight technologies that were retained. To develop alternatives, a screening of applicable technologies was performed. CERCLA criteria guiding the development of alternatives provides for using effectiveness, implementability, and cost. The eight process options retained to support corrective measures alternatives development are:

1. Institutional controls,
2. Environmental monitoring,

3. Isolation barriers,
4. Infiltration barrier systems,
5. Conventional or remotely operated excavation,
6. Standard excavation sloping and benching,
7. Sheet pile walls, and
8. Ex situ solidification and stabilization.

These eight process options were used to develop the corrective measures alternatives described in Section 3.0 of the WMA C CMS.

5.2.1 Institutional Controls

Institutional controls are applied to limit public access, control worker access and activities, and environmental contact with contaminated soil and groundwater contaminants at WMA C. Institutional controls involve implementing legal, administrative, and/or informational devices, and barriers such as fencing.

The DOE's site-wide institutional control plan, DOE/RL-2001-41, *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions and RCRA Corrective Actions*, describes institutional controls to be used to restrict public access to the Hanford Site in general. Additional institutional controls restrict access to the Central Plateau for as long as necessary to protect human health. Other institutional controls support effectiveness over time. Additional controls are administered to limit access and control work activities within WMA C. The maintenance of such institutional controls will likely fall to each successive generation.

5.2.2 Environmental Monitoring

Groundwater and air environmental monitoring is described in Sections 1.6.4 and 1.6.5 of the WMA C CMS, respectively. Environmental monitoring will continue to be conducted into the foreseeable future.

Groundwater monitoring representative of groundwater conditions beneath WMA C will continue under the 200-BP-5 Groundwater Operable Unit monitoring program. Monitoring results are used to determine if residual contaminants associated with WMA C are migrating, and if contaminant concentrations greater than acceptable exposure levels could reach potential receptors. Proper use of monitoring data can alert DOE to impending exceedances of acceptable exposure levels and health and safety parameters. Current levels of environmental monitoring would be maintained under all of the alternatives. Additional monitoring requirements may be identified as a part of corrective action implementation.

Monitoring provides a method for tracking changes in contamination levels and location over time. Monitoring of areas that have impacted groundwater typically includes groundwater monitoring. However, groundwater monitoring is not addressed in the WMA C CMS and is deferred to the 200-BP-5 Groundwater Operable Unit remedial investigation/feasibility study.

An alternative that includes environmental monitoring will also include a contingency plan to identify actions taken if the monitoring results suggest the selected alternative is not protective, or is not performing as anticipated. Contingency plans can be developed during the corrective measure design phase of the project for measuring and assessing metrics that reflect the appropriateness and ongoing effectiveness of the selected alternative. Contingency plans conducted to support environmental monitoring may be triggered by observations of unacceptable conditions that may interfere with protection of human health and the environment.

5.2.3 Containment

The effectiveness of a modified asphalt (pavement) or a concrete surface barrier made these the favored process options for horizontal containment. Standard asphalt pavement and concrete alone would not prevent infiltration to reach subsurface contamination. However, permeability can be increased by adding amendments during material preparation to generate modified-asphalt or concrete mixtures, as discussed in RPP-RPT-38323, *Tank Farm Interim Surface Barrier Materials and Runoff Alternatives Study*.

Modified asphalt barriers use adapted paving construction practices to install layers of pavement mixtures over contaminated soil to reduce surface water infiltration. A base layer of compacted fill material is placed over the ground surface to create a smooth, graded surface to support the pavement surface barrier. The barrier surface is then graded to develop a storm water runoff capture system that diverts runoff to an engineered storm water management system. Surface barrier edges may be curbed to prevent surface runoff from preferentially saturating the leading edges of the barrier, thereby preventing enhancement of localized infiltration.

Such barriers would need to be maintained, since the underlying native soil or soil fill material layer can become overgrown with weeds, decreasing the barrier drainage effectiveness.

5.2.4 Treatment

Several remedial technologies were evaluated based on their ability to treat WMA C soil contaminants to the extent that exposure risks are reduced for humans and ecological receptors. Ex situ solidification and stabilization is retained as a treatment for excavated soil. This treatment would involve altering the properties of the soil; physically binding contaminants to reduce mobility; and reduce the potential for exposure.

5.2.5 Removal

The retained removal technologies are removal by conventional and remotely controlled methods along with supporting functions. Remotely controlled excavation is necessary when physical, chemical, and/or radiological hazards preclude worker contact with the contaminated media.

Remotely controlled excavation activities may employ long-reach equipment (e.g., trackhoe, boom-mounted drum grappler) or computer-controlled, remotely-operated equipment to allow excavation and container management from a safe distance. Remotely controlled excavation has been deployed at a number of sites where radiological or explosive wastes demanded remote operations.

5.2.5.1 *Benching and Sloping*

Both benching and sloping systems are used to prevent cave-ins to an excavation and thereby protect workers. Benching consists of cutting one or more steps into the side-walls of an excavation, usually with vertical or near-vertical surfaces between levels. Sloping requires cutting sidewalls into relatively smooth, angled planes dipping toward the excavation at a specific (or lesser) angle depending on various soil types, anticipated weather conditions, and surface or shallow to intermediate vadose zone loads that may affect the soil in the area of the trench. Sloping and benching may be used together or as standalone methods. Benching and sloping actions are applicable to both conventional and remote-controlled excavation methods.

5.2.5.2 *Sheet Pile Walls*

Sheet pile walls are used to support excavation by retaining soil using prefabricated sheet sections that are typically connected by interlocking edges. These sheet sections are sequentially installed by being vibrated or hammer driven into the ground, with each successive lateral section interlocking to the adjacent section. Additional lateral support may be achieved using bracing or anchors to tie the wall into the supporting soil behind the excavation.

5.2.5.3 *Backfilling Support Function*

Non-contaminated, imported soil fill material would be used to backfill excavations. If permitted, removed, contaminated soil treated aboveground to less than action levels may be returned to the excavation.

5.2.5.4 *Waste Disposal*

Disposal includes waste packaging, transport, and disposal to an appropriate facility, such as a landfill. The chemical and radionuclide inventory (level of radioactivity, activity concentration, and total activity) are principal criteria used to determine specific requirements for packaging and transporting soil waste. The receiving facility may not accept soil waste that has not been pre-treated in accordance with a facility's waste acceptance criteria. Data collected during the Phase 2 RFI would be used for initial disposal planning, while real-time analysis of the waste would be performed before transport.

The preference for WMA C soil waste is transport and disposal to the Hanford Site ERDF, which is regulated by U.S. Environmental Protection Agency. ERDF accepts waste from throughout the Hanford Site. Hanford waste is transported to the facility by a fleet of trucks traveling between the waste sites and the landfill. Using ERDF and the on-site transportation routes keeps Hanford waste on the Hanford Site and away from the Columbia River, major roads, and members of the general public. In order to dispose of waste at ERDF the waste must meet the ERDF waste acceptance criteria, and in addition a CERCLA decision document is required.

Alternatively, if the soil waste cannot be accepted by ERDF, appropriate documentation would need to be developed to transport the waste for disposal to an off-site facility, such as the WCS, facility in Andrews, Texas. WCS offers an off-site disposal option, if ERDF cannot receive WMA C soil. The 1,338-acre WCS site includes the Texas Compact Waste Facility, the WCS Federal Waste Facility, the Byproducts and Hazardous Waste Facility, among others. The WCS site offers treatment and storage of Class A, B, and C low-level radioactive waste, hazardous waste, and byproduct materials.

Both facilities place restrictions on the waste types, specific characteristics, and volumes received by requiring that waste acceptance criteria are met and volume constraints are maintained per their operating licenses. In addition, U.S. Department of Transportation requirements would apply for all hazardous waste transport, whether the soil waste is dispositioned on-site or off site. Transportation and disposal conditional exemption(s) may apply to the waste that meets specified conditions, including treatment to land disposal restriction treatment standards per Title 40, *Code of Federal Regulations*, Part 266, "Standards for the Management of Specific Hazardous Wastes and Specific Types of Hazardous Waste Facilities" (40 CFR 266).

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6.0 SUMMARY

This document describes the technology screening process that was performed during the development of WMA C CMS. An iterative, three-step screening process was used to evaluate each technology.

Evaluation criteria used to assess the technologies were established based on regulatory guidance and a review of previous technology screenings conducted both on and off the Hanford Site. Over 100 remediation technologies were identified for potential application within the WMA C vadose zone.

The initial prescreening process involved individually evaluating each technology in the technology inventory. Prescreening criteria included applicability, effectiveness and technological maturity. Thirty-five technologies were retained for further evaluation after the prescreening.

The intermediate screening process evaluated the retained technologies from the prescreening process. Intermediate screening criteria included effectiveness, implementability and relative cost. Nine technologies were retained for further evaluation after the intermediate screening. Four institutional control technologies were also retained but were included in all of the interim actions analyzed so no further evaluation was necessary.

The final screening process retained eight technologies for inclusion in development of process options. The final screening criteria included long-term effectiveness and performance; short-term effectiveness; reduction of toxicity, mobility, and volume; implementability; and cost. The technologies remaining include concrete isolation barrier, modified-asphalt surface barrier, conventional excavation, remotely operated excavation equipment, standard sloping and benching system, sheet pile walls, disposal of excavated material, and ex situ solidification and stabilization.

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Appendix A

Prescreened Technologies

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Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Containment	Subsurface Barrier	High-Density polyethylene geomembrane	Geomembranes can be installed as standalone barriers or in conjunction with other containment systems (slurry wall, vibrating beam). Standalone geomembranes are typically constructed of high-density polyethylene (HDPE), with varying installation methods: trenching machine, vibrating insertion plate, or segmented trench box.
		Horizontal Subsurface Barrier (HSSB)	Emplaced horizontal barriers are placed beneath existing in situ contaminants. They minimize movement of contaminants, restrict infiltration of groundwater, and are constructed of similar materials with similar technologies.
		Permeation Grouting-High pressure grout injection (e.g., silicate, acrylamide)	Grouting technique to transform granular soils into sandstone-like masses by void-filling with low viscosity grout.
		Permeation Grouting – Molten Wax Injection	Injection of molten thermoplastic wax, resulting in an impermeable material. Super permeating molten wax is delivered by (1) heating the soil and (2) injecting the wax.
		Freeze Barrier	Involves placement of cooling media distribution systems into the soil layer below the contamination to freeze soil pore water and reduce mobilization of contaminants.
		Jet Grouting	Physical technology to limit interconnected porosity at a specific depth and thickness through jet grouting. High pressure injection of a grout slurry into soil in order to mix the material with grout. The resulting soil material is called "soil-crete."
		Vertical Grout Walls	Grout walls are formed by high-pressure injection of grout directly into the soil matrix (permeation grouting) or in conjunction with drilling (jet grouting) at regularly spaced intervals to form a continuous low-permeability wall.
		Vertical Grout Wall – Auger Mixed	Grout is injected or mixed into soil with auger-like blades to create a wall of relatively low permeability.
		Vertical Sheet Pile Wall Barrier	Sheet pile walls are constructed by driving vertical strips of steel, precast concrete, aluminum, or wood into the soil, forming a subsurface barrier wall.

Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Containment	Subsurface Barrier	Vertical Slurry Wall	Slurry walls are formed by vertically excavating a trench filled with a slurry that forms a continuous low-permeability barrier.
	Surface Barrier	Hanford Surface Barrier	Barriers are generally designed to be impermeable to prevent surface water infiltration through the vadose zone and limit contaminant leaching to groundwater. May also prevent direct contact to contaminants.
		Interim Surface Barrier	Interim surface barriers are emplaced to temporarily reduce surface water infiltration through vadose zone.
		Isolation Barrier – Soil/Rock	Capping an isolated contaminated sediment bed with sand, gravel, silt or crushed rock debris.
		Revegetation or stone covers	A vegetative or stone cover would be reestablished in areas that have been regraded or capped to decrease erosion and protect the integrity of the cap.
		Modified RCRA Subtitle C Barrier	A multiple-layer surface barrier with at least a low permeability layer and a drainage layer. Designed to be impermeable to prevent surface water infiltration through the vadose zone and limit contaminant mobilization and transport to groundwater. Applicable for hazardous waste, category 3 and category 1 (mixed) low-level waste. Modifications to a RCRA C barrier designed to be site specific. Number of layers can vary from 4 to 7.
		Infiltration Surface Barrier – Treated Concrete Barrier	Treated concrete surface barrier creates a water-resistant barrier to prevent liquids from infiltrating the surface.
		Isolation Barrier – Concrete	A single layer paved surface. Designed to be impermeable to prevent surface water infiltration through the vadose zone and limit contaminant mobilization and transport to groundwater. Such barriers are designed for an operational life of a minimum of 75 years and prevent direct exposure to contaminants. Configured to route surface precipitation and run-off away from underlying subsurface contamination.

Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Containment	Surface Barrier	Interim Surface Barrier – Modified Asphalt	Modified asphalt barrier consists of installing an asphalt cap over the contamination using commercial paving techniques.
		Evapotranspiration (ET) Barrier Capillary	Capillary barrier, which consists of a fine-grained soil layer overlying a relatively coarse-grained soil layer. The distinct textural interface in capillary ET barriers between the fine and coarse soil layers creates a capillary break, which increases the water holding capacity of the fine-grained soil over that associated with unimpeded vertical drainage. Water will not flow into the coarse layer until the water content approaches saturation in the fine-grained soil layer. If the textural interface is sloped, water will move laterally in the fine-soil layer above the interface, which provides an additional mechanism for water removal.
		Surface Barrier – High Density Polyethylene (HDPE) Geomembrane	A durable, ultra violet and chemical resistant liner material used for water containment applications.
Institutional Control	Access Controls	Site Access Controls	Controls in place to prevent unauthorized access that could cause exposure to hazards and interfere with safe working procedures.
		WMA C Access Controls	Controls in place to prevent unauthorized access to WMA C that could cause exposure to hazards and interfere with safe working procedures.
	Administrative Controls	Site-Wide Integrated Safety Management System Program	A framework to integrate safety into all aspects of work activities to improve safety and work performance at all DOE sites.
		WMA C Work Control Process	Work control processes are the guidelines by which field work is planned, evaluated, and conducted at the tank farm facility.

Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Disposal	Disposition	Backfill Excavations Using Ex Situ Treated Soil Material	Excavation and ex-situ treatment followed by onsite disposal (backfill).
		Offsite Waste Disposal	Disposal of excavated soil at offsite landfill. Required for wastes that onsite disposal is not acceptable.
		Onsite Waste Disposal (ERDF/SWBG, or other applicable onsite disposal as available)	Disposal of excavated soil at onsite landfill (e.g. ERDF). Treatment performed at the facility as required to meet land disposal restrictions.
Removal	Excavation	Conventional (Surface-Based) Excavation (also “Shallow Conventional Excavation”)	Removal of material using standard commercial excavators.
		Deep Excavation Techniques: Soldier Pile and Lagging Wall	The method is also commonly known as "Berliner Wall" when steel piles and timber lagging is used and are the most inexpensive systems compared to other retaining walls.
		Deep Excavation Techniques: Tunneling	Completely enclosed tunnel except for openings for egress, commonly at each end. Tunnel is created by cut-and-cover, boring, pipe jacking, or box jacking.
		Caissons for Soil Stability	Land caisson is an open concrete section at the top and bottom, and it is lowered into its position by excavating inside and adding in-situ concrete section on top. Caissons can be used in cases where the soil contains large boulders which obstruct penetration of piler or bored piles, and large lateral forces may needed.
		Cofferdams for Soil Stability	A cofferdam is a temporary earth retaining structure to be able to make excavation for construction activities. Use to support heavy vertical and horizontal loads (e.g., typically used near water bodies). Contiguous, tangent, secant piles or diaphragm walls are constructed in circular shapes, and no internal bracing or anchoring is used to form the cofferdam.
		Deep Excavation Techniques: Deep-Mixed Walls for Soil Stability	Similar to Jet Grout walls but uses a technique specially developed for wall construction where H sections are used for reinforcement.

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Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Removal	Excavation	Deep Excavation Techniques: Diaphragm/Slurry Walls for Soil Stability	Diaphragm walls (similar to slurry walls) provide structural support and water tightness. It is commonly used for many deep excavations. The wall is constructed panel by panel in full depth.
		Deep Excavation Techniques: Dragline Excavators/ Conventional Shaft Sinking	Draglines are a primary excavating method used in many surface mining operations worldwide. Draglines are the largest single bucket excavators, capable of reaching depths up to 76.2 meters (250 feet).
		Drilling and Soil Replacement	Drilling and soil replacement involves constructing hollow spaces using drilling techniques and replacing the existing soil with filling materials. A series of large diameter holes are drilled in the area of contamination. After the hole is drilled it is backfilled with a low strength soil-cement mixture that can backfill the hole without requiring compaction.
		Deep Excavation Techniques: Jet Grout Walls for Soil Stability	Retaining walls are made by single to triple row of jet grout columns or deep mixed columns. Single reinforcing bar is placed in the central hole opened for jet grout columns. Anchors, nails or struts may be used for support.
		Deep Excavation Techniques: Reinforced Concrete Walls for Soil Stability	A type of stage excavation wall usually supported by ground anchors. Soils with some cohesion are suitable because each stage is first excavated before formwork and concrete placement.
		Deep Excavation Techniques: Secant Pile Walls for Soil Stability	Secant pile walls are formed by constructing intersecting reinforced concrete piles. The piles are reinforced with either steel rebar or with steel beams and are constructed by either drilling under mud or augering.
		Deep Excavation Techniques: Sheet Piling or Sheet Pile Walls for Soil Stability	Uses thin steel sections with interlocked watering grooves at the sides, and they are driven into soil by hammering or vibrating.
		Deep Excavation Techniques: Sloping and/or Benching for Soil Stability	Excavation is advanced by sloping and/or benching walls. Large lay backs are required for deeper open pit excavations. Technique can be combined with other shoring techniques to achieve greater excavation depths.

Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Removal	Excavation	Deep Excavation Techniques: Soil Nail Walls for Soil Stability	Excavation is made step by step. Shotcrete (concrete projected at high velocity through a hose) is common for facing; wire mesh may be used. Soft facing may be also possible using geotextiles. A hole is drilled, ordinary steel bars are lowered, and grout is placed without pressure. Requires cohesive soil and unsaturated or minimal water flow conditions.
		Excavation Techniques: Tangent Pile Wall	Tangent pile walls are a variation of secant pile walls and soldier pile walls. However, tangent pile walls are constructed with no overlap and ideally one pile touches the other.
		Remote Excavation	Remote excavation uses a telerobotic excavator to remove material.
		Retaining Wall Technologies	Structural system that retains soil and water and prevents it from collapsing into the open excavation.
		Vacuum Excavation	Vacuum excavation is digging by using a vacuum to break apart material with high-pressure water or air.
Treatment	Ex Situ Treatment: Biological	Biological Reduction	Hazardous chemicals are rendered inert by physically spraying or injecting a chemical specific biocide that will promote a biological reaction within the chemical converting the chemical from one species to another.
		Microbial Biodegradation	Microorganisms are sprayed onto the soil surface or injected into the vadose zone to degrade contamination.
		Supported Growth Biological Reactors	An engineered device or system that supports a biologically active environment which functions to degrade contaminants in groundwater or soil.
	Ex Situ Treatment: Chemical	Carbonate Sequestration	Sequestration of waste carbon via chemical reactions between carbon dioxide and metal oxides, resulting in carbonates which can be permanently kept out of active environmental carbon stocks.
		Immobilization	A process in which highly mobile aqueous phase contaminants are transformed into a solid, stable form which becomes part of the soil matrix.

Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Treatment	Ex Situ Treatment: Chemical	Carbon Nanotubes	Cylindrical carbon molecules are used as a sorbent for the remediation of various organic and inorganic pollutants.
		Oxidation/Reduction	Excavated soils with high concentrations of contaminants can be chemically oxidized or reduced to convert contaminants into less toxic, less mobile forms. The type of reagent selected for reduction or oxidation will depend on the contaminants present.
		Sequestration	Contaminant removal by converting the contaminant to a stable, immobile state.
	Ex Situ Treatment: Chemical/Physical	Solidification / Stabilization	Contaminants are physically bound or enclosed within a stabilized mass, or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility.
		Soil flushing with water or chemicals	The extraction of contaminants from the soil with water or other chemicals. Soil flushing is accompanied by passing the extraction fluid through soils using an injection or infiltration process.
	Ex Situ Treatment: Physical	Molecular Sieves	Microporous molecules, constructed from natural or synthetic zeolites, are used as adsorbents for separation and removal of minerals from soils.
		Soil Sorting & Screening	Clean soil fractions are separated from the contaminated based upon radioactive energy emissions from the soil. Soil passes under an array of radiation detectors that are used to determine the radioactivity present.
		Soil Vapor Extraction	A physical treatment process for in situ remediation of volatile contaminants in vadose zone based on mass transfer of contaminant from the solid and liquid phases into the gas phase, with subsequent collection of the gas phase contamination at extraction wells
		Soil Washing	Separation of soil particles followed by mechanical abrasion or washing to remove surface contamination. Final contaminated fraction is typically treated by technologies such as solidification/stabilization prior to disposal.
		Mineral Recovery	Treatment methods involving the extraction of targeted minerals from the aqueous phase.

Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Treatment	Ex Situ Treatment: Physical	Vitrification	Process that converts excavated soil and other materials into stable crystalline substances. The thermal treatment process is typically performed inside a chamber using plasma torches or electric arc furnaces to melt the soil.
		Volitilization	Chemical substances in the soil can be volitilized through air sparging, vacuum extraction, hot air or steam extraction, thermally enhanced microwave, or thermally enhanced radio frequency to remove contamination.
	In Situ: Biological	Biological Reduction (general)	Bioreduction is an alternative method for establishing reducing conditions within the vadose or saturated zone to immobilize redox sensitive contaminants of concern.
		Biological Reductive Dechlorination	Bioremediation, via the addition of an organic substrate, will reductively dechlorinate carbon tetrachloride. The substrate must be distributed to contact the carbon tetrachloride and allow reaction to occur.
		Biomineralization using Calcite Precipitating Bacterium	Heavy metal sequestration in bioprecipitated calcium carbonate deposits has been demonstrated for a range of metals using a urea hydrolysis mechanism
		In-Situ Biological Reduction	Biological reduction of contaminants may occur as part of metabolic processes, or reduced as a microbial response to the toxicity of the contaminant. Microbially reduced species (e.g., iron and sulfur) may also reduce contaminants. Specific microbial groups mediate U(VI) reduction and nitrate attenuation in subsurface sediments co-contaminated with U(VI) and nitrate.
		Microbial Bioremediation/Biodegradation	Microbial bioremediation uses microorganisms or microbial enzymes to detoxify contaminants in the soil and other environments.
		Monitored Natural Attenuation	Reliance on natural processes to achieve remediation objectives within a designated time frame. Contaminants are often monitored in order to track progress and make sure that contamination does not increase.

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Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Treatment	In Situ: Biological	Supported Growth Biological Reactors	Bioreactors are used primarily to treat volatile organic compounds and fuel hydrocarbons in soil and groundwater. In-situ bioreactors can also be used to provide a cometabolite for degradation of hazardous by-products produced during the degradation process of some of the chlorinated solvents. This type of bioreactor contains adapted microbes that mineralize the organic compounds of interest. The microbes are trapped onto a biological support medium.
	In Situ: Chemical	Ammonia Gas	Involves the injection of ammonia gas to increase pH to dissolve silica. The pH naturally decreases to ambient conditions over time and aluminosilicate minerals precipitate and possibly coat and immobilize various contaminants.
		Calcite Sequestration (immobilization)	Microbially-induced calcite precipitation for removal of heavy metal pollution.
		Calcium Polysulfide Injection	Injection of calcium polysulfide to convert hexavalent chromium to a trivalent chromium hydroxide.
		Carbon Nanoparticles	Carbon nanoparticles may assist in detecting trace levels of contaminants in field settings, contributing to effective remediation.
		Carbon nanoparticles (e.g., SAMMs and nanotubes)	Carbon nanotubes are nanomaterials known for its exceptional properties, like high surface area and adsorption capacity. Carbon nanotubes can successfully increase the adsorption capacity of the soil and consequently improve the immobilization of heavy metals in the soil matrix.
		Carbonate Sequestration	Substitution into rhombohedral (e.g., calcite) or orthorhombic (e.g., aragonite) carbonate minerals can sequester the contaminants. Solid solutions tend to be more stable than pure end members. Carbonate minerals are often near saturation in the vadose zone.
		ISCO (Chemical Oxidation)	Subsurface delivery of chemical oxidant (e.g., hydrogen peroxide, ozone, permanganate, persulfate, percarbonate) to degrade organic contaminants. Oxidants cause chemical destruction of toxic organic chemicals. Petroleum hydrocarbons and polycyclic aromatic hydrocarbons can be treated with a variety of oxidants (including peroxide, percarbonate, persulfate, and ozone).

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Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Treatment	In Situ: Chemical	Chemical oxidation/reduction	In situ chemical oxidation involves injecting oxidants and potentially co-amendments directly into the source zone to react with the contaminants.
		Exotic Nanoparticles	"High tech" in situ reagents are the custom-tailored nanoparticle "getter" materials designed to sequester specifically hard-to-treat contaminants.
		Ferrous Iron	Can reduce hexavalent chromium, Tc(VII), or potentially other contaminants. The reduction mechanism may be through a homogeneous reaction solution or be a surface mediated heterogeneous reaction.
		Gaseous Reduction (e.g., hydrogen sulfide or ammonia gas)	Gas-phase reductants such as hydrogen sulfide are easily transported through the vadose zone and can reduce contaminants.
		Nano-zero valent iron	Zero valent iron (ZVI) reduces and immobilizes redox sensitive contaminants by creating a strong reducing zone. Oxygen and nitrate are also typically consumed. For groundwater applications, ZVI barriers are commonly emplaced by trenching, and the iron used can be simple iron filings. More advanced techniques use micron-size iron particles to inject the iron into a continuous treatment zone.
		Phosphate/Apatite Sequestration	Stabilization of metals by chemically binding them into new stable phosphate phases (apatite minerals) and other relatively insoluble phases in the soil, sediment or in a permeable reactive groundwater barrier. Phosphates are a viable form for uranium sequestration (fixing in place) and can promote sequestration by iron and aluminum oxides.
		SAMMs (Self-Assembled Monolayers on Mesoporous Supports)	A self-assembled monolayer is a one-molecule thick layer of material that bonds to a surface in an ordered way as a result of physical or chemical forces during a deposition process
		Silicate minerals	Silicate minerals are able to increase soil pH, decrease the chemical-extractable fractions and bioavailability of heavy metals in soils, and reduce the heavy metal contents in edible parts of plants.
		Sodium Dithionate	Inject sodium dithionate to reduce ferric iron to ferrous iron, to create a reductant barrier for hexavalent chromium in saturated systems.

Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Treatment	In Situ: Chemical	Sulfide Salts and Minerals (i.e., ferrous sulfate/calcium polysulfide injection)	Calcium polysulfide is an effective reductant for hexavalent chromium but mobilization by the dithionate solution is likely to occur so some impacts on groundwater can be expected. Polysulfide can also reduce uranium and technetium but those elements are more easily reoxidized in the vadose zone than chromium.
		Surface/Subsurface Infiltration of reactant/Sequestering Agent	Reagent is applied to ground surface to treat contaminants within the vadose zone. Surface infiltration can be done through drip irrigation, trenches, and shallow basin systems. Systems are generally designed to be 0.3 meters (12 inches) below the surface and covered to be protected. Can be applied to bottom of excavations to target deeper vadose zone and smear zone soils more effectively.
		Zeolites	Zeolites are microporous, aluminosilicate minerals commonly used as commercial adsorbents and catalysts.
		Zero valent Iron or other Zero Valent Metals	This technology involves the injection of powdered ZVI in a water-based slurry into the subsurface target treatment zone. Pneumatic injection of ZVI can be used to treat a source zone, a dissolved plume, or as a barrier to reduce further migration.
	In Situ: Physical	Deep Soil Mixing	Large mixing augers (1.5 to 3 meters [5 to 10 feet] in diameter) or horizontally rotating heads are used to blend and homogenize reactants with soil. The reactants may be chemical reductants, biological substrate, or solidification/stabilization agents
		Electrokinetic Mobilization and Recovery	Application of an electric field in the soil induces contaminant mobilization through electromigration, electroosmosis, or electrophoresis. This application is attractive for low-permeability soils that are difficult to flush.
		Enhanced Volatilization	The addition of heat to increase the solubility or vapor pressure of contaminants, facilitating faster and more complete remediation.
		In-Situ Uranium Recovery/Leaching (solution mining)	Recovers uranium by dissolving it with a solution and pumping the solution to the surface for removal. This technology is most widely used for uranium mining in saturated conditions.

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Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Treatment	In Situ: Physical	In-Situ Vitrification	Thermal treatment process that converts soil and other materials into stable crystalline substances. Contaminants are incorporated into the glass structure, which is generally strong, durable, and resistant to leaching. Particularly suitable for sites with high concentrations within 6 to 9 meters (20 to 29 feet) of soil surface.
		In-Situ Thermal Desorption	Direct application of heat (e.g., using electrical heater elements, electrical resistive heating, injection of hot air, steam or hot water, radio frequency, etc.) to increase the temperature of soil and destroy or volatilize organic compounds. Volatile organic compound capture required.
		Jet Injection	Similar to jet grouting under the containment technology response action, high pressure injection of a reactive grout slurry into soil in order to hydraulically mix the soil with the slurry. Fluidization of the soil is preferred.
		Perched Water Removal	Water perched above low-permeability areas within the vadose zone is pumped before it migrates to groundwater. Wells must be correctly placed to adequately capture the extent of the perched water.
		Physical separation	Using technologies that separate the contaminants from the soil solids.
		Pore Water Extraction	Subsurface water within the unsaturated zone containing mobile contaminants is extracted. Soil gas with entrained water is extracted from the subsurface through a well using high vacuum to induce high vapor extraction rates.
		Soil Flushing with Water or Chemicals	Identical to soil flushing with water, except for addition of chemicals (e.g., surfactants) to enhance mobilization of contaminants with lower solubility.
		Soil Moisture Extraction/Desiccation	Removing water from vadose zone by injecting hot dry air or nitrogen gas and removing moist air to create a capillary barrier that impedes migration of contaminants by preventing their aqueous-phase transport.

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Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Treatment	In Situ: Physical	Soil Stabilization	Soil mixing is used in the improvement of the strength of soil as well as the remediation of chemical contaminatnts in soil. In Situ Solidification/Stabilization reduces the mobility of hazardous contaminants in the environement through physical and chemical means. Soil stabilization/Solidification traps or immobilizes contaminants in the soil or sludge instead of removing them or destroying them.
		Soil Vapor Extraction	Soil vapor is extracted through vertical or horizontal extraction wells to induce contaminant mass transfer from soil to soil vapor, and remove contaminant mass from soil vapor. Vapor is treated separately (granular activated carbon, thermal oxidizer, etc.) or directly discharged to atmosphere, if appropriate.
		Sorbent Extraction (Soil Wicking)	Various soild sorbents can be used as a suitable trap for direct accumulation of organic compounds from aqueous solutions.
		Volatilization	Volatilization is the process of converting a chemical substance from a liquid or solid state to a gaseous or vapor state. Volatilization processes can include: Air sparging, vacuum extraction, Hot air or steam extraction, thermally enhanced microwave, thermally enhanced radio frequency
	In Situ: Delivery Method	Foam Delivery of Reactant/Sequestering Agent	Surfactant foam could be used for flushing, liquid chemical deliver, or delivery of nanoparticles to minimize the gravitational effects impacting reagent distribution.
		Gas-phase Delivery of Reactant/Sequestering Agent	A gaseous mixture of chemical reagent is injected into and drawn through the vadose zone to reduce or stabilize mobile contaminants. Gaseous delivery to the deep vadose zone has advantages because of the ease of transport through the sediments with minimal effect from gravitational and capillary forces.

Table A-1. Technologies Prescreened

General Response Action	Technology Type	Technology Subtype	Description
Treatment	In Situ: Delivery Method	Horizontal Injection/Extraction Wells	Delivery of amendments or extraction of soil vapor using horizontal wells. Wells are installed using horizontal drilling techniques.
		Hybrid Electrokinetic Delivery of Treatment Chemicals	Mobilization of fluids to target areas by application of electric fields
		Shear Thinning Fluid Delivery of Reactant/Sequestering Agent	Shear thinning fluids could be used to enhance amendment and/or reagent delivery to low permeability zones.
		Vertical Injection/Extraction Wells	Delivery of amendments using conventional vertical wells.

DOE = U.S. Department of Energy
ERDF = Environmental Restoration Disposal Facility
ET = evapotranspiration
HDPE = high-density polyethylene
HSSB = horizontal subsurface barrier
ISCO = in situ chemical oxidation
RCRA = *Resource Conservation and Recovery Act of 1976*
SAMM = self-assembled monolayers on mesoporous supports
SWBG = solid waste burial ground
WMA = Waste Management Area
ZVI = zero valence iron

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