ECF-100BC1-16-0085
Revision 1

COST ESTIMATE INPUTS FOR REMEDIAL INVESTIGATION/FEASIBILITY STUDY ALTERNATIVES FOR 100-BC-1, 100-BC-2, AND 100-BC-5 OPERABLE UNITS

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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Terms

ARAR	applicable, relevant, or appropriate requirement
bgs	below ground surface
C90	90th percentile concentration
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
COC	contaminant of concern
Cmax	maximum concentration
Cr(VI)	hexavalent chromium
Cr(III)	trivalent chromium
CSM	conceptual site model
cy	cubic yard
FS	feasibility study
HDPE	high density polyethylene
IC	institutional control
MNA	monitored natural attenuation
O&M	operation and maintenance
OU	operable unit
P&T	pump and treat
PRG	preliminary remediation goal
OU	operable unit
PRZ	periodically rewetted zone
RI	remedial investigation
RTD	removal, treatment (as necessary), and disposal
SSL	soil screening level
TCE	trichloroethene
VOC	volatile organic compound

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1 Purpose

The purpose of this environmental calculation brief is to describe the key assumptions and quantity inputs that support development of remedial action alternative cost estimates for DOE/RL-2010-96, *Remedial Investigation/Feasibility Study for the 100-BC-1, 100-BC-2, and 100-BC-5 Operable Units* (hereinafter called the 100-BC RI/FS). The feasibility study (FS) cost estimate quantity inputs are derived from site features, physical parameters, and characteristics of the 100-BC-1 and 100-BC-2 source operable units (OUs) and the 100-BC-5 groundwater OU, and the remedial action alternative descriptions presented in Chapter 9 of the 100-BC RI/FS. The FS cost estimates are prepared to an expected accuracy of -30 to +50 percent (-30/+50%) and are used as part of the detailed and comparative analysis of remedial alternatives performed as described in the 40 CFR 300.430(e), "National Oil and Hazardous Substances Pollution Contingency Plan," "Remedial Investigation/Feasibility Study and Selection of Remedy." This analysis is used to support identification of a preferred alternative in a proposed plan.

2 Background

This environmental calculation brief supports development of remedial action alternative cost estimates for the identified 100-BC source (OU1 and OU2) waste sites and the 100-BC-5 groundwater OU contaminant plumes (remedial action target areas). A range of alternatives was developed in the FS for each target area based on the nature of threat posed by each waste site. The potential threats/exposure pathways include human health direct contact risk in the top 4.6 m (15 ft) of soil, groundwater and/or surface water quality protection, and exceedance of a contaminant of concern (COC) groundwater or surface water quality applicable, relevant, or appropriate requirement (ARAR).

2.1 Remedial Action Target Areas Carried Forward into the Feasibility Study

Table 1 lists the 7 waste sites that were carried forward to the FS (100-B-34, 116-C-1, 118-B-1, 118-B-8:4, 116-B-5, 116-B-6A, and 116-B-16), the basis for remedial action, the COCs associated with each waste site, and the year the radionuclide concentration(s) will decay to a cumulative excess lifetime cancer risk of less than 1.0×10^{-4}. These waste sites were carried forward into the FS based on the presence of shallow (e.g., less than 4.6 m [15 ft] below ground surface [bgs]) direct contact risk and/or deep (e.g., greater than 4.6 m [15 ft] bgs) direct contact risk exceeding the upper bound of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) 10^{-4} to 10^{-6} risk range, and/or potential to impact groundwater quality above a soil screening level (SSL) or preliminary remediation goal (PRG) based concentration.

Table 2 lists the waste sites (100-B-5, 100-B-14:1, 100-B-8:1, 100-C-6:1, 100-B-8:2, 100-C-6:2, 100-C-6:3, 100-C-6:4, 100-B-21:4, 116-B-1, 116-B-11, 116-B-14, 116-B-2, 116-B-3, 116-B-4, 116-C-2A, 116-C-2B, 116-C-2C, 116-C-3, 116-C-5, 118-B-6, 118-C-1, and 118-C-3:2) that were carried forward to the FS based on direct contact risk for deep radionuclide contamination only that will be addressed through a deep excavation restriction institutional control (IC). Table 3 lists the key characteristics of each groundwater COC plume and, based on the conceptual site model (CSM), the characteristics of residual hexavalent chromium (Cr(VI)), and strontium-90 groundwater sources present in the periodically rewetted zone (PRZ).

Table 1. 100-BC-Source (OU 1/2) Waste Sites Carried Forward into the Feasibility Study

Waste Site Evaluated in the FS	Basis for Action	COCs and Year Cumulative Risk Decays to less than 1×10^{-4}
100-B-34 Radioactive Process Sewer (three pipeline segments from previously remediated waste sites)	a) Reactor cooling effluent pipeline (two eastern segments) Presumed human health direct contact risk in shallow soil (<4.6 m [15 ft] bgs) based on process history and data for original waste site 100-C-6:1.	Cs-137, Eu-152, and Sr-90 (shallow soil and pipeline, year 2055)
	Presumed human health direct contact risk in deep soil (>4.6 m [15 ft] bgs).	Cs-137, Eu-152, and Sr-90 (deep soil and pipeline, year 2055)
	b) Sodium dichromate transfer pipeline segment (one western segment): Presumed human health direct contact risk in shallow soil (<4.6 m [15 ft] bgs) based on process history and direct observation for original waste site 100-B-28.	Cr(VI) (shallow soil and pipeline, year indefinite)
	Presumed groundwater and surface water protection SSL* and PRG* exceedances.	Cr(VI) (shallow soil and pipeline, year indefinite)
116-C-1 Trench	Human health direct contact risk in deep soil (>4.6 m [15 ft] bgs).	Cs-137, Eu-152, Eu-154, Co-60, Ni-63, and Sr-90 (deep soil, year 2485)
	Waste site soil exceeds the groundwater protection SSL* for Sr-90.	Sr-90 (deep soil, year 2034)
118-B-1	Human health direct contact risk in shallow soil (<4.6 m [15 ft] bgs).	Sr-90 and Cs-137 (shallow soil, year 2040)
	Human health direct contact risk in deep soil (>4.6 m [15 ft] bgs).	Tritium (deep soil, year 2081)
	Waste site soil exceeds the groundwater protection SSL* based on site-specific model using data for borehole A2-3.	Tritium (deep soil, year 2051)
118-B-8:4 Subsite	Human health direct contact risk in shallow soil (<4.6 m [15 ft] bgs)	Cs-137, Eu-152, Sr-90 (year 2203)
	Human health direct contact risk in deep soil (>4.6 m [15 ft] bgs).	C-14, Sr-90 (year 32021)
116-B-5 Crib	Human health direct contact risk in shallow soil (<4.6 m [15 ft] bgs.	Eu-152 (shallow soil, year 2021)
116-B-6A Crib and 116-B-16 Tank	Human health direct contact risk in shallow soil (<4.6 m [15 ft] bgs).	Cs-137, Sr-90 (shallow soil, year 2045)
	Human health direct contact risk in deep soil (>4.6 m [15 ft] bgs).	Cs-137, Eu-152, and Sr-90 (deep soil, year 2095)

bgs = below ground surface
C-14 = carbon-14
Co-60 = cobalt-60
Cs-137 = cesium-137
COC = contaminant of concern
Eu-152 = europium-152
Eu-154 = europium-154
FS = feasibility study
Ni-63 = nickel-63
OU = operable unit
PRG = preliminary remediation goal
Sr-90 = strontium-90
SSL = soil screening level

*The term "SSL" refers to a PRG value calculated for an irrigation land use scenario. The term "PRG" refers to a PRG value calculated for conservation land use with native vegetation.

Table 2. Waste Sites Carried Forward into the Feasibility Study with Direct Contact Risk for Deep Radionuclide Contamination Only that will be Addressed with a Deep Excavation Restriction Institutional Control

Waste Site(s)	Radionuclides Contributing to Risk Greater Than 1×10^{-4}	Year Cumulative Risk Decays to Less Than 1×10^{-4} or Year IC to be Maintained
100-B-5 100-B-5 RI Soil Boring	Cs-137, Eu-152, Sr-90 Cs-137, Sr-90	2083 2082
100-B-14:1	C-14	12110
100-B-8:1 and 100-C-6:1	Cs-137, Eu-152, Sr-90	2055
100-B-8:2, 100-C-6:2, 100-C-6:3, and 100-C-6:4	Cs-137, Eu-152, Sr-90	2065
100-B-21:4	Cs-137, Eu-152, Sr-90	2112
116-B-1	Cs-137, Eu-152, Sr-90	2112
116-B-11	Cs-137, Co-60, Eu-152, Eu-154, Ni-63, and Sr-90	2247
116-B-14	Cs-137, Eu-152, Sr-90	2030
116-B-2	Cs-137, Sr-90	2112
116-B-3	Cs-137, Sr-90	2075
116-B-4	Cs-137, Co-60, Eu-152, Eu-154	2152
116-C-2A, 116-C-2B, and 116-C-2C	Cs-137, Co-60, Eu-152, Ni-63, and Sr-90	2228
116-C-3	Cs-137, Sr-90	2109
116-C-5 116-C-5 RI Soil Boring	Cs-137, Co-60, Eu-152, Eu-154, Ni-63, Sr-90 Cs-137	2137 2057
118-B-6 118-B-6 RI Soil Boring	Tritium Sr-90, tritium	2032 2042
118-C-1	C-14	8698
118-C-3:2	Cs-137, Eu-152, Sr-90	2254

C-14 = carbon-14
Co-60 = cobalt-60
Cs-137 = cesium-137
Eu-152 = europium-152
Eu-154 = europium-154
IC = institutional control
Ni-63 = nickel-63
Sr-90 = strontium-90

Table 3. Conceptual Site Model PRZ Sources and Groundwater COC Plume Information

Parameter	Cr(VI) Area 1[a]	Cr(VI) Area 2[b]	Sr-90 Area 1[c]	Sr-90 Area 2[d]
PRZ Sources				
Estimated size of remedial action target area (m^2 [ft^2])	Not applicable	5,200 (59,201)	1,025 (11,025)	24,400 (259,410)
Groundwater COC Plumes				
Parameter	**Cr(VI)**	**Sr-90**	**Tritium**	**TCE**
Plume size[e] (ha (ac) > PRG)	8.5 (21)	55.3 (137)	0[f] (0)	Well 199-B5-11[g]
PRG – aquifer	48 µg/L	8 pCi/L	20,000 pCi/L	4 µg/L
PRG – shoreline	10 µg/L	Not applicable	Not applicable	Not applicable
Shoreline length (m (ft) > PRG)	1,900 (6,200)	Not applicable	Not applicable	Not applicable

a. Cr(VI) Area 1 located near previously remediated waste sites 100-C-7 and 100-C-7:1.

b. Cr(VI) Area 2 located near previously remediated waste site 116-B-11.

c. Sr-90 Area 1 located at west end of previously remediated waste site 116-C-1.

d. Sr-90 Area 2 is a broad area overlying the higher concentration portion of the Sr-90 plume.

e. COC plume information is based on 2015 conditions.

f. Concentrations are currently below PRGs but this constituent was identified as COC in the human health risk assessment based on a groundwater PRG exceedance in the 2010 to 2015 data set (well 199-B8-6, located downgradient of waste site 118-B-1).

g. Concentrations in the 2010 to 2015 data set below PRGs but this constituent was identified as COC based on a PRG exceedance in October/November 2016 at deep unconfined zone well 199-B5-11.

COC = contaminant of concern

Cs-137 = cesium-137

PRG = preliminary remediation goal

Sr-90 = strontium-90

TCE = trichloroethene

2.2 Remedial Action Alternative Descriptions

Remedial action alternatives developed for evaluation in the FS are based on the identified exposure pathways, contaminated environmental media, and remedial action objectives described in Chapter 8 of the 100-BC RI/FS (DOE/RL-2010-96). The seven alternatives that were developed include the following:

- **Alternative 1: No Action.** This alternative is required by 40 CFR 300.430(e)(6). The No Action Alternative, which serves as a baseline for comparing other remedial action alternatives, is retained throughout the FS process. No action means that no remediation would be implemented to address the waste sites, groundwater COC plumes, or the Cr(VI) and Sr-90 PRZ sources. All existing groundwater monitoring and data evaluation and reporting would be discontinued, and existing ICs lifted. No conceptual designs or cost estimates are prepared for Alternative 1 because no actions are proposed.

- **Alternative 2: Natural Attenuation with ICs and Removal, Treatment (as necessary), and Disposal (RTD) for Waste Sites; and Monitored Natural Attenuation (MNA) with ICs for Groundwater.** This alternative uses an array of limited actions that build off the waste site interim actions. The primary components of this alternative include the following:
  - Natural attenuation, combined with ICs, to minimize the potential for shallow soil direct contact exposure at waste sites: 100-B-34 (eastern segments), 118-B-1, 118-B-8:4, 116-B-5, and 116-B-6A/116-B-16.
  - RTD to address shallow soil direct contact exposure and groundwater/surface water protection SSL/PRG exceedance at waste site 100-B-34 (western segment).
  - An IC prohibiting excavation to minimize the potential for deep soil radionuclide direct contact exposure at waste sites 100-B-34 (eastern segments), 116-C-1, 118-B-1, 118-B-8:4, and 116-B-6A/116-B-16.
  - Natural attenuation, combined with deep excavation ICs, to minimize the potential for deep soil direct contact exposure at the 23 deep waste sites listed in Table 2.
  - An IC prohibiting irrigation at waste sites with exceedances of groundwater protection SSLs (116-C-1 and 118-B-1).
  - MNA with ICs for the Cr(VI) and Sr-90 groundwater plumes and natural attenuation for the Cr(VI) and Sr-90 PRZ sources until groundwater PRGs are met.
  - MNA with ICs for trichloroethene (TCE) until groundwater PRG is met.
  - MNA with ICs for tritium in groundwater to confirm the groundwater PRG is met.
  - Installation of 10 new monitoring wells: 6 shallow wells in year 1 and four deep wells in year 6.
  - Groundwater sampling and analysis, data evaluation, and reporting to confirm that the remedy is protective and that natural attenuation processes are reducing COC concentrations in accordance with expectations. The groundwater monitoring program also provides a basis for determining when remedial action is complete and ICs can be removed.
- **Alternative 3: Natural Attenuation with ICs and RTD for Waste Sites; and Pump and Treat (P&T) with MNA and ICs for Groundwater.** Alternative 3 is the same as Alternative 2 for the waste sites but uses P&T for remediation of Cr(VI) contaminated groundwater. The primary components of this alternative include the following:
  - Natural attenuation combined with ICs to minimize the potential for shallow soil direct contact exposure at waste sites 100-B-34 (eastern segments), 118-B-1, 118-B-8:4, 116-B-5, and 116-B-6A/116-B-16.
  - RTD to address shallow soil direct contact exposure and groundwater/surface water protection SSL/PRG exceedance at waste site 100-B-34 (western segment).
  - An IC prohibiting excavation to minimize the potential for deep soil radionuclide direct contact exposure at waste sites 100-B-34 (eastern segments), 116-C-1, 118-B-1, 118-B-8:4, and 116-B-6A/116-B-16.

- Natural attenuation, combined with deep excavation ICs, to minimize the potential for deep soil direct contact exposure at the 23 deep waste sites listed in Table 2.
- An IC prohibiting irrigation at waste sites with exceedances of groundwater protection SSLs (116-C-1 and 118-B-1).
- MNA with ICs for tritium in groundwater to confirm the groundwater PRG has been met.
- P&T for Cr(VI) for 40 years with co-extraction of Sr-90 to control plume migration to the river and to remediate the Cr(VI) plume through extraction, treatment, and reinjection.
- MNA with ICs for TCE until the groundwater PRG is met.
- Installation of 10 new monitoring wells: 6 shallow wells in year 1 and four deep wells in year 6.
- MNA with ICs for the balance of the Sr-90 groundwater plume remaining after 40 years of P&T, and natural attenuation for the Cr(VI) and Sr-90 PRZ sources until groundwater PRGs are met.
- Groundwater sampling and analysis, data evaluation, and reporting to confirm that the remedy is protective and that natural attenuation processes are reducing COC concentrations in accordance with expectations. The groundwater monitoring program also provides a basis for determining when remedial action is complete and ICs can be removed.

Under Alternative 3, P&T for Cr(VI) with co-extraction of Sr-90 is used to clean up the Cr(VI) remedial action target area. Extracted groundwater is pumped from four shallow and two deep extraction wells to a 100-BC transfer station and then pumped through an aboveground pipeline to the existing 100-KW Building. It is assumed the 100-KW treatment system will complete its mission by 2019. The existing KW treatment system would be re-purposed by refurbishing existing components, such as tanks and instrumentation and control hardware, and installing new, larger capacity ion-exchange systems to remove Cr(VI). The ion exchange systems would use ResinTech® SIR-700 resin to remove Cr(VI). The treated groundwater would be returned to 100-BC at a 1,500 L/min (400 gal/min) flow rate via an aboveground pipeline and then reinjected into the aquifer using four injection wells to enhance flow-path control, aquifer flushing, and hydraulic containment.

- **Alternative 4: Natural Attenuation with ICs and Aggressive RTD for Waste Sites; and P&T with MNA and ICs for Groundwater.** This alternative includes a combination of RTD, MNA, and ICs for the waste sites. The remedial action components for groundwater are the same as described for Alternative 3. The primary components of Alternative 4 include the following:
  - Natural attenuation combined with ICs to minimize the potential for shallow soil direct contact exposure at waste sites 118-B-1 and 116-B-5.
  - RTD to address shallow soil direct contact exposure at waste sites 100-B-34 (all pipeline segments), 118-B-8:4, and 116-B-6A/116-B-16. RTD at 100-B-34 (western segment) also addresses the groundwater/surface water protection SSL and PRG exceedance.
  - Deep RTD to the total depth of contamination at waste site 116-C-1 to address the groundwater protection SSL exceedance for Sr-90 while also addressing a potential Sr-90 PRZ source to groundwater.

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- An IC prohibiting excavation to minimize the potential for deep soil radionuclide direct contact exposure at waste sites 100-B-34 (eastern segments), 118-B-1, 118-B-8:4 and 116-B-6A/116-B-16.
- Natural attenuation, combined with deep excavation ICs, to minimize the potential for deep soil direct contact exposure at the 23 deep waste sites listed in Table 2.
- An IC prohibiting irrigation at waste site 118-B-1 to address the groundwater protection SSL exceedance for tritium.
- MNA with ICs for tritium in groundwater to confirm the groundwater PRG has been met.
- MNA with ICs for TCE until the groundwater PRG is met.
- P&T for the Cr(VI) groundwater plume for 40 years with MNA with ICs for the balance of the Sr-90 groundwater plume following P&T cessation, and natural attenuation for the Cr(VI) and Sr-90 PRZ sources, until groundwater PRGs are met.
- Installation of 10 new monitoring wells: 6 shallow wells in year 1 and four deep wells in year 6.
- Groundwater sampling and analysis, data evaluation, and reporting to confirm that the remedy is protective and that natural attenuation processes are reducing COC concentrations in accordance with expectations. The groundwater monitoring program also provides a basis for determining when remedial action is complete and ICs can be removed.

Under Alternative 4, P&T for Cr(VI) with co-extraction of Sr-90 is used to clean up the Cr(VI) remedial action target area. Extracted groundwater is pumped from four shallow and two deep extraction wells to a 100-BC transfer station and then pumped through an aboveground pipeline to the existing 100-KW Building. It is assumed the 100-KW treatment system will complete its mission by 2019. The existing KW treatment system would be re-purposed by refurbishing existing components, such as tanks and instrumentation and control hardware, and installing new, larger capacity ion-exchange systems to remove Cr(VI). The ion exchange systems would use ResinTech SIR-700 resin to remove Cr(VI). The treated groundwater would be returned to 100-BC at a 1,500 L/min (400 gal/min) flow rate via an aboveground pipeline and then reinjected into the aquifer using four injection wells to enhance flow-path control, aquifer flushing, and hydraulic containment.

- **Alternative 5: Natural Attenuation with ICs and RTD for Waste Sites; and Cr(VI) Source Treatment with P&T, and MNA with ICs for Groundwater.** This alternative includes the same waste site components as Alternatives 2 and 3. To address groundwater COCs, Alternative 5 includes 15 years of P&T for Cr(VI) with co-extraction of Sr-90 and targeted in situ treatment to address the Cr(VI) PRZ source, thus shortening the P&T timeframe. The primary components of this alternative include the following:
  - Natural attenuation, combined with ICs, to minimize the potential for shallow soil direct contact exposure at waste sites 100-B-34 (eastern pipeline segments), 118-B-1, 118-B-8:4, 116-B-5, and 116-B-6A/116-B-16.
  - RTD to address shallow soil direct contact exposure and groundwater/surface water protection SSL/PRG exceedance at waste site 100-B-34 (western pipeline segment).

- An IC prohibiting excavation to minimize the potential for deep soil radionuclide direct contact exposure at waste sites 100-B-34 (eastern segments), 116-C-1, 118-B-1, 118-B-8:4, and 116-B-6A/116-B-16.
- Natural attenuation, combined with deep excavation ICs, to minimize the potential for deep soil direct contact exposure at the 23 deep waste sites listed in Table 2.
- An IC prohibiting irrigation at waste sites with exceedances of groundwater protection SSLs (116-C-1 and 118-B-1).
- MNA with ICs for tritium in groundwater to confirm the groundwater PRG has been met.
- MNA with ICs for TCE until the groundwater PRG is met.
- P&T for Cr(VI) for 15 years with co-extraction of Sr-90 to control plume migration to the river and to remediate the Cr(VI) plume through extraction, treatment, and reinjection. The extraction well layout is similar to Alternatives 3 and 4, except there are five shallow wells and two deep wells pumping at slightly lower rates.
- In situ treatment of the Cr(VI) PRZ source (Cr(VI) Area 2 in Table 3) during first year of P&T operations.
- MNA with ICs for the balance of the Sr-90 groundwater plume remaining after 15 years of P&T, and natural attenuation for the Sr-90 PRZ source (Areas 1 and 2 in Table 3) until groundwater PRGs are met.
- Installation of 10 new monitoring wells: 6 shallow wells in year 1 and four deep wells in year 6.
- Groundwater sampling and analysis, data evaluation, and reporting to confirm that the remedy is protective and that natural attenuation processes are reducing COC concentrations in accordance with expectations. The groundwater monitoring program also provides a basis for determining when remedial action is complete and ICs can be removed.

Under Alternative 5, P&T for Cr(VI) with co-extraction of Sr-90 is used to clean up the Cr(VI) remedial action target area. Extracted groundwater is pumped from five shallow and two deep extraction wells to a 100-BC transfer station and then pumped through an aboveground pipeline to the existing 100-KW Building. It is assumed the 100-KW treatment system will complete its mission by 2019. The existing KW treatment system would be re-purposed by refurbishing existing components, such as tanks and instrumentation and control hardware, and installing new, larger capacity ion-exchange systems to remove Cr(VI). The ion exchange systems would use ResinTech SIR-700 resin to remove Cr(VI). The treated groundwater would be returned to 100-BC at a 1,500 L/min (400 gal/min) flow rate via an aboveground pipeline and then reinjected into the aquifer using four injection wells to enhance flow-path control, aquifer flushing, and hydraulic containment. Following 15 years of P&T operations, MNA and ICs are used to address the remaining portion of the Sr-90 plume.

This alternative uses in situ treatment of the Cr(VI) PRZ source to accelerate achievement of the surface water protection PRGs for Cr(VI) within a shorter timeframe compared to Alternatives 3 and 4. Substrate injection, assumed to be calcium polysulfide, will be performed using temporary injection wells to promote in situ reduction of Cr(VI) to trivalent chromium (Cr(III)) upgradient of the extraction wells. Assuming in situ treatment occurs during the first year of P&T, the simulated duration required for P&T operations to achieve and maintain Cr(VI) concentrations below the

10 μg/L surface water protection PRG at the shoreline is 15 years. MNA will also contribute to achieving cleanup levels for Sr-90 following cessation of P&T operations.

- **Alternative 6: Natural Attenuation with ICs and Aggressive RTD for Waste Sites; and Cr(VI) Source Treatment with P&T, and MNA with ICs for Groundwater.** Alternative 6 includes the same waste site components as Alternative 4. Groundwater remedial action components and in situ source treatment for Cr(VI) are the same as Alternative 5. The primary components of this alternative include the following:
  - Natural attenuation, combined with ICs, to minimize the potential for shallow soil direct contact exposure at waste sites 118-B-1 and 116-B-5.
  - RTD to address shallow soil direct contact exposure at waste sites 100-B-34 (all pipeline segments), 118-B-8:4, and 116-B-6A/116-B-16. RTD at 100-B-34 (western segment) also addresses the groundwater/surface water protection SSL and PRG exceedance.
  - Deep RTD to the total depth of contamination at waste site 116-C-1 to address the groundwater protection SSL exceedance for Sr-90 while also addressing a potential Sr-90 PRZ source to groundwater.
  - An IC prohibiting excavation to minimize the potential for deep soil radionuclide direct contact exposure at waste sites 100-B-34 (eastern segments), 118-B-1, 118-B-8:4, and 116-B-6A/116-B-16.
  - Natural attenuation, combined with deep excavation ICs, to minimize the potential for deep soil direct contact exposure at the 23 deep waste sites listed in Table 2.
  - An IC prohibiting irrigation at waste site 118-B-1 to address the groundwater protection SSL exceedance for tritium.
  - MNA with ICs for tritium in groundwater to confirm the groundwater PRG has been met.
  - MNA with ICs for TCE until the groundwater PRG is met.
  - P&T for Cr(VI) for 15 years with co-extraction of Sr-90 to control plume migration to the river and to remediate the Cr(VI) plume through extraction, treatment, and reinjection. The extraction well layout is similar to Alternatives 3 and 4, except there are five shallow wells and two deep wells pumping at slightly lower rates.
  - In situ treatment of a portion of the Cr(VI) PRZ source (Cr(VI) Area 2 in Table 3) during first year of P&T.
  - MNA with ICs for the balance of the Sr-90 groundwater plume remaining after 15 years of P&T, and natural attenuation for the Sr-90 PRZ source until groundwater PRGs are met.
  - Installation of 10 new monitoring wells: 6 shallow wells in year 1 and four deep wells in year 6.
  - Groundwater sampling and analysis, data evaluation, and reporting to confirm that the remedy is protective and that natural attenuation processes are reducing COC concentrations in accordance with expectations. The groundwater monitoring program also provides a basis for determining when remedial action is complete and ICs can be removed.

Under Alternative 6, P&T for Cr(VI) with co-extraction of Sr-90 is used to clean up the Cr(VI) remedial action target area. Extracted groundwater is pumped from five shallow and two deep extraction wells to a 100-BC transfer station and then pumped through an aboveground pipeline to the existing 100-KW Building. It is assumed the 100-KW treatment system will complete its mission by 2019. The existing KW treatment system would be re-purposed by refurbishing existing components, such as tanks and instrumentation and control hardware, and installing new, larger capacity ion-exchange systems to remove Cr(VI). The ion exchange systems would use ResinTech SIR-700 resin to remove Cr(VI). The treated groundwater would be returned to 100-BC at a 1,500 L/min (400 gal/min) flow rate via an aboveground pipeline and then reinjected into the aquifer using four injection wells to enhance flow-path control, aquifer flushing, and hydraulic containment. Following 15 years of P&T operations, MNA and ICs are used to address the remaining portion of the Sr-90 plume.

This alternative uses in situ treatment of the Cr(VI) PRZ source to accelerate achievement of the surface water protection PRGs for Cr(VI) within a shorter timeframe compared to Alternatives 3 and 4. Substrate injection, assumed to be calcium polysulfide, will be performed using temporary injection wells to promote in situ reduction of Cr(VI) to Cr(III) upgradient of the extraction wells. Assuming in situ treatment occurs during the first year of P&T, the simulated duration required for P&T operations to achieve and maintain Cr(VI) concentrations below the 10 μg/L surface water protection PRG at the shoreline is 15 years. MNA will also contribute to achieving cleanup levels for Sr-90 following cessation of P&T operations.

- **Alternative 7: Natural Attenuation with ICs and Aggressive RTD for Waste Sites; and Cr(VI) and Sr-90 Source Treatment with P&T, and MNA with ICs for Groundwater.** Alternative 7 includes the same waste site and groundwater components as Alternative 6 with the addition of in situ treatment for Sr-90 at waste site 116-C-1 (instead of RTD) and the Sr-90 PRZ source areas. The primary components of this alternative include the following:
  - Natural attenuation, combined with ICs, to minimize the potential for shallow soil direct contact exposure at waste sites 118-B-1 and 116-B-5.
  - RTD to address shallow soil direct contact exposure at waste sites 100-B-34 (all pipeline segments), 118-B-8:4, and 116-B-6A/116-B-16. RTD at 100-B-34 (western segment) also addresses the groundwater/surface water protection SSL and PRG exceedance.
  - An IC prohibiting excavation to minimize the potential for deep soil radionuclide direct contact exposure at waste sites 118-B-1, 118-B-8:4, 116-B-5, and 116-B-6A/116-B-16.
  - Natural attenuation, combined with deep excavation ICs, to minimize the potential for deep soil direct contact exposure at the 23 deep waste sites listed in Table 2.
  - An IC prohibiting irrigation at waste site 118-B-1 to address the groundwater protection SSL exceedance for tritium.
  - MNA with ICs for tritium in groundwater in the area downgradient from waste site 118-B-1 to confirm the groundwater PRG has been met.
  - MNA with ICs for TCE until the groundwater PRG is met.
  - P&T for Cr(VI) for 15 years with co-extraction of Sr-90 to control plume migration and to remediate the Cr(VI) plume through extraction, treatment, and reinjection. The extraction well

layout is similar to Alternatives 3 and 4, except there are five shallow wells and two deep wells pumping at slightly lower rates.

- In situ treatment of the Cr(VI) PRZ source (Cr(VI) Area 2 in Table 3) during first year of P&T operations.
- In situ treatment of two Sr-90 PRZ source areas: Area 1 (waste site 116-C-1), which exceeds groundwater protection SSLs and is a potential PRZ source of Sr-90 to groundwater; and Area 2, which overlies the Sr-90 plume.
- MNA and ICs for the balance of the Sr-90 plume remaining after 15 years of P&T.
- Installation of 10 new monitoring wells: 6 shallow wells in year 1 and four deep wells in year 6.
- Groundwater sampling and analysis, data evaluation, and reporting to confirm that the remedy is protective and that natural attenuation processes are reducing COC concentrations in accordance with expectations. The groundwater monitoring program also provides a basis for determining when remedial action is complete and ICs can be removed.

Under Alternative 7, P&T for Cr(VI) with co-extraction of Sr-90 is used to clean up the Cr(VI) remedial action target area. Extracted groundwater is pumped from five shallow and two deep extraction wells to a 100-BC transfer station and then pumped through an aboveground pipeline to the existing 100-KW Building. It is assumed the 100-KW treatment system will complete its mission by 2019. The existing KW treatment system would be re-purposed by refurbishing existing components, such as tanks and instrumentation and control hardware, and installing new, larger capacity ion-exchange systems to remove Cr(VI). The ion exchange systems would use ResinTech SIR-700 resin to remove Cr(VI). The treated groundwater would be returned to 100-BC at a 1,500 L/min (400 gal/min) flow rate via an aboveground pipeline and then reinjected into the aquifer using four injection wells to enhance flow-path control, aquifer flushing, and hydraulic containment. Following 15 years of P&T operations, MNA and ICs are used to address the remaining portion of the Sr-90 plume.

This alternative uses in situ treatment of the Cr(VI) PRZ source to accelerate achievement of the surface water protection PRGs for Cr(VI) within a shorter timeframe compared to Alternatives 3 and 4. Substrate injection, assumed to be calcium polysulfide, will be performed using temporary injection wells to promote in situ reduction of Cr(VI) to Cr(III) upgradient of the extraction wells. Assuming in situ treatment occurs during the first year of P&T, the simulated duration required for P&T operations to achieve and maintain Cr(VI) concentrations below the 10 µg/L surface water protection PRG at the shoreline is 15 years. MNA will also contribute to achieving cleanup levels for Sr-90 following cessation of P&T operations.

Alternative 7 includes apatite jet injection technology to sequester Sr-90 present in the vadose zone and PRZ. Treatment will target Treatment Area 1, a 1,025 m^2 (11,025 ft^2) area at the west end of the 116-C-1 Trench, and Treatment Area 2, a 24,400 m^2 (259,410 ft^2) area overlying the Sr-90 plume near the plume axis. The depth to groundwater (thus the PRZ) ranges seasonally from approximately 9 m (29.5 ft) to 12.5 m (41 ft) bgs. For 100-BC, a system capable of injecting solutions at pressures up to 400 bars (5,800 psi) will be used. This high-pressure system will mix the soil with the injection solution to an estimated maximum radial distance of 2 m (6 ft) from the injection nozzle. Roughly 306 injections will be needed for Treatment Area 1; 7,205 injections will be needed for Treatment Area 2.

2.3 Remedial Action Timeframes

The remedial action alternatives described previously achieve PRGs at the individual waste sites and groundwater COC plumes over a range of timeframes. With respect to the Cr(VI) and Sr-90 groundwater plumes, the lower end of the remediation timeframe range was defined through numerical modeling based on the time required for the 90th percentile concentration (C90), within the model domain, to decline to the PRG. The upper end of the remediation timeframe is defined by the time required for the maximum concentration (Cmax), within the model domain, to decline to the PRG. Table 4 provides a summary of the estimated timeframes, based on C90 and Cmax, for Cr(VI) and Sr-90 concentrations to decline to their respective PRGs within the aquifer and along the shoreline for each remedial action alternative.

As shown in Table 4, the duration of P&T under Alternatives 3 and 4 is 40 years. The 40-year P&T period is required even though the estimated timeframe to achieve the Cr(VI) PRG of 48 µg/L in the aquifer and the 10 µg/L PRG along the shoreline is 5 years and 15 years based on Cmax and C90, respectively. The additional 25 years of pumping after the C90 concentration for Cr(VI) is achieved along the shoreline is required to maintain compliance with the 10 µg/L PRG. Due to the residual Cr(VI) sources present in the PRZ, Cr(VI) concentrations are predicted by the model to rebound above the 10 µg/L PRG along the shoreline without pumping. Therefore, for the purposes of defining remedial action durations for cost estimating purposes, a 40-year timeframe was used for the P&T component of Alternatives 3 and 4. For Alternatives 5, 6, and 7, a 15-year duration is required due to in situ Cr(VI) PRZ source treatment. The 15-year duration reflects the time required for the C90 and Cmax Cr(VI) along the shoreline to decline below the 10 µg/L PRG.

C90 and Cmax remediation timeframes for tritium and TCE were not calculated for the groundwater remedial action alternatives. Tritium was not simulated in the model because concentrations have remained below PRGs since 2013 (e.g., last exceedance occurred in 2012). Based on an assessment of the leaching threat that soil contamination poses to groundwater and surface water, the 118-B-1 waste site is projected to potentially cause a future exceedance of the tritium groundwater PRG based on a hypothetical irrigation land use as a bounding condition. Tritium is not projected to cause an exceedance based on a conservation land use that includes native vegetation. Therefore, for the purposes of estimating groundwater monitoring timeframes, a zero year MNA performance monitoring duration was assumed for tritium under Alternatives 2 through 7. TCE was not simulated in the model because it was detected above its PRG in only one well in 2016. Using groundwater flow paths and velocity inferred from the 100-BC groundwater fate and transport model, a one-dimensional analysis (100-BC RI/FS, Appendix F, ECF-100BC5-16-0084) indicates that TCE concentrations will be reduced by one-half within 25 years (approximately year 2040). Based on the 2016 exposure point concentration of 6.7 µg/L, TCE concentrations are projected to fall below the 4 µg/L PRG by the year 2040.

For groundwater monitoring purposes, the following remedial action timeframes were used:

- Cr(VI): 60 years for Alternative 2, 40 years for Alternatives 3 and 4, and 15 years for Alternatives 5, 6, and 7. There is an additional 5-year compliance period that begins following completion of the 60-year remedial action period.
- Strontium-90: 70 years for Alternatives 2 through 7. There is an additional 5-year compliance period that begins following completion of the 70-year remedial action period.
- Tritium: 0 years for Alternatives 2 through 7. However, there is a 5-year compliance period.
- TCE: 25 years for Alternatives 2 through 7. There is an additional 5-year compliance period that begins following completion of the 25-year remedial action period.

ECF-100BC5-16-0059, *2016 Modeling of RI/FS Design Alternatives for 100-BC-5*, presents the calculations and modeling results used for developing remedial action alternatives and estimating remedial action alternative completion timeframes. These timeframes are estimates based on current information. The actual timeframes may vary, depending on the final configuration of the selected alternative, as determined during remedial design, the aquifer's response to the remedy, and the scope and effectiveness of remedial process optimization.

Table 4. Comparison of Groundwater Remedial Action Timeframe Estimates

COC	PRG	Estimated Time to Achieve PRG[a] (years)							
		Alternative 1		Alternative 2		Alternative 3 and Alternative 4 (40 years pumping)		Alternative 5, Alternative 6, and Alternative 7 (15 years pumping)	
		Cmax	C90	Cmax	C90	Cmax	C90	Cmax	C90
Cr(VI) (aquifer)	48 µg/L	15	0	15	0	5	0	5	0
Cr(VI) (shoreline)	10 µg/L	60	30	60	30	40[b]	40[b]	15	15
Sr-90 (aquifer)	8 pCi/L	70	60	70	60	70	60	70	60
		Alternatives 2, 3, and 5				Alternatives 4, 6, and 7			
Tritium (aquifer)	20,000 pCi/L	0[c]				0[c]			
TCE[d] (aquifer)	4 µg/L	Up to 25[d]				Up to 25[d]			

a. The estimated C90 durations presented in ECF-100BC5-16-0059, *2016 Modeling of RI/FS Design Alternatives for 100-BC-5*, were rounded up to the nearest 5-year increment (if <50 years) or rounded up to the nearest 10-year increment (if >50 years) to reflect uncertainties in actual versus simulated alternative performance.

b. Although the estimated Cmax and C90 timeframes are 15 years, model results indicate P&T would be required for approximately 40 years to maintain concentrations below the 10 µg/L PRG at the shoreline. Concentrations rebound above the 10 µg/L PRG at the shoreline for P&T durations <40 years.

c. Groundwater tritium concentrations are currently below the PRG.

d. One-dimensional analysis (DOE/RL-2010-96, *Remedial Investigation/Feasibility Study for the 100-BC-1, 100-BC-2, and 100-BC-5 Operable Units*, Appendix F, ECF-100BC5-16-0084) indicates that TCE concentrations will be reduced by one half within 25 years (approximately year 2040). Based on the 2016 EPC concentration (6.7 µg/L), the PRG for TCE (4 µg/L) will be met by 2040.

C90 = 90th percentile concentration
Cmax = maximum concentration
Cr(VI) = hexavalent chromium
P&T = pump and treat
PRG = preliminary remediation goal
Sr-90 = strontium-90
TCE = trichloroethene

3 Methodology

Development of the cost inputs for the 100-BC OU alternatives requires simple calculations performed in Microsoft Excel® spreadsheets. Due to the basic nature of these calculations, development of a detailed methodology for each calculation was not conducted. Chapter 4 provides the key inputs and assumptions that support each calculation and Chapter 6 summarizes the spreadsheet calculations.

® Excel is a registered trademark of the Microsoft Corporation, Redmond, Washington.

4 Assumptions and Input

This chapter describes the overall assumptions applicable to the 100-BC alternatives. The information used in the following sections and accompanying tables were obtained from Chapters 8, 9, and 10 of the 100-BC RI/FS (DOE/RL-2010-96) and ECF-100BC5-16-0059.

4.1 Waste Site Information

Assumptions and input for the waste sites include the following:

- Table 5. Summarizes where specific waste site information can be found in Appendix A and Appendix B, and the approach used in calculating quantity inputs to the cost estimate.
- Table A-1. Describes each waste site carried forward into the FS and the remedial action technologies that are employed to address the waste site under Alternatives 2 to 7. This includes the time required for IC maintenance until radioactive decay reduces radionuclide COC concentrations to PRGs for the 7 waste sites carried into the FS with shallow direct contact risk and/or potential to impact groundwater (in addition to the deep radionuclide contamination). Table A-1 excludes the 23 waste sites with deep zone radionuclide direct contact risk only.
- Table B-1. For the 7 waste sites carried forward into the FS, this table provides information on the aerial extent and depth of contamination that is used to estimate the volume of contaminated material to be excavated under alternatives that employ RTD, where applicable. These aerial extents and depths of contamination are the same as those to be managed for alternatives that employ natural attenuation with ICs.
- Table B-2. Provides information on the 29 waste sites (6 FS waste sites from Table A-1 and 23 deep radionuclide only waste sites from Table 2) where a deep excavation IC will be applied to waste sites with radionuclide contamination at depths greater than 4.6 m (15 ft). This includes the time required (IC duration) before radionuclide concentrations decline below their PRG.

4.2 Strontium-90 and Cr(VI) PRZ Source Information

Assumptions and input for the Sr-90 and Cr(VI) PRZ sources include the following:

- Table 6. Summarizes general information about each of the PRZ source areas.
- Table A-2. Describes each source area and the remedial action technologies applied to it under Alternatives 2 through 7.
- Table B-3. Provides information on the aerial extent and depth of contamination and volumes of reagent that are assumed for treatment under Alternatives 5 and 6 (Cr(VI) PRZ source) and Alternative 7 (Cr(VI) and Sr-90 PRZ source). Alternative 7 also includes Sr-90 in situ treatment at the 116-C-1 waste site in lieu of RTD employed under Alternative 6.

Table 5. Waste Site Quantity Inputs and Assumptions

Input Parameter	Reference Source / Or General Equation
Alternatives with RTD – Excavation Information	
Area of Contamination	Appendix B, Table B-1
Depth to Bottom of Contamination	
Depth to Top of Contamination	
Length	
Width	
Construction Notes	Engineering judgment
Total Volume of Excavation (yd^3) = waste material + overburden	Calculated by Estimator
Total Volume of Contaminated Material (yd^3) (calculated as [Depth to Bottom of Contamination – Depth to Top of Contamination] x Waste Site Area ÷ 27 ft^3 / yd^3	
Expected Safety Level	Standard
Alternatives with Natural Attenuation with Excavation Institutional Controls – Duration Information	
Waste Sites (<4.6 m [15 ft])	Appendix A, Table A-1 (column 3)
Waste Sites (>4.6 m [15 ft])	Appendix A, Table A-1 (column 4) and Appendix B, Table B-2
Alternatives with Irrigation Restrictions – Duration Information	
Waste Sites with Groundwater/Surface Water Protection SSL Exceedance	Appendix A, Table A-1 (column 5)
Waste Sites with Groundwater/Surface Water Protection PRG Exceedance	Appendix A, Table A-1 (column 6)

PRG = preliminary remediation goal

RTD = removal, treatment (as necessary), and disposal

SSL = soil screening level

Table 6. Strontium-90 and Cr(VI) PRZ Source Treatment Quantity Inputs and Assumptions

Input Parameter	Reference Source / Or General Equation
In Situ Stabilization for Strontium-90 Vadose Zone/PRZ	
Area of Contamination	Engineering Judgment/Conceptual Site Model (Appendix B, Table B-3)
Depth to Top of Contamination	CVP Packages and Engineering Judgment/Conceptual Site Model (Appendix B, Table B-3)
Depth to Top of Treatment Zone	Based on Top of Contamination–CVP Packages and Engineering Judgment/Conceptual Site Model (Appendix B, Table B-3)
Depth to Bottom of Treatment Zone	Based on Depth to Bottom of PRZ–CVP Packages and Engineering Judgment/Conceptual Site Model (Appendix B, Table B-3)
Length	Engineering Judgment/Conceptual Site Model (Appendix B, Table B-3)
Width	
Treatment Zones	
Number of Injection Points/Spacing	Engineering Judgment (Appendix B, Table B-3)
Injection volume - per boring (total varies by treatment area)	Target concentration is 3.4 mg apatite per gram of soil. It is estimated that each boring will require an estimated 2,000 L (528 gal) of a blended phosphate and pre-formed apatite slurry. The phosphate solution consists of a mixture comprised of 85% disodium hydrogen phosphate (Na2HPO4) and 15% sodium dihydrogen phosphate (NaH2PO4) at a total aqueous concentration not to exceed of 100 millimoles. Pre-formed apatite is added to the phosphate slurry at a rate of 23.1 kg of apatite to 1,000 L (264 gal) of phosphate (SGW-47062, *Treatability Test Report for Field-Scale Apatite Jet Injection Demonstration for the 100-NR-2 Operable Unit*.
Safety Level	Standard
In Situ Reduction for Cr(VI) – Vadose Zone/PRZ	
Area of Contamination	Engineering Judgment/Conceptual Site Model (Appendix B, Table B-3)
Depth to Top of Contamination	
Depth to Top of Treatment Zone	Based on Top of Contamination–Engineering Judgment/Conceptual Site Model (Appendix B, Table B-3)
Depth to Bottom of Treatment Zone	Based on Depth to Bottom of PRZ–Engineering Judgment/Conceptual Site Model (Appendix B, Table B-3)
Treatment Zones	Engineering Judgment/Conceptual Site Model (Appendix B, Table B-3)
Number of Injection Points/Spacing	Engineering Judgment (Appendix B, Table B-3)
Injection Volume – total	57,700 L (15,240 gal)
Mixing Tank and Support Equipment	Trailer-Mounted Tank (18,927 L [5,000 gal]), 610 m (2,000 ft) of temporary HDPE piping, one transfer pump to pump water from river to mix tank, one transfer pump to pump reagent from mix tank to injection points. Assume one month of operations.
Safety Level	Standard

Cr(VI) = hexavalent chromium
CVP = cleanup verification package
HDPE = high density polyethylene
PRZ = periodically rewetted zone

4.3 Groundwater Plume Information

The key technologies employed for the Cr(VI) and Sr-90 groundwater plumes include ICs with MNA, and P&T. The key technologies employed for TCE and tritium include ICs with MNA. The assumptions and inputs associated with these technologies for each alternative are presented in Table B-4. The key assumptions associated with these technologies are summarized in the following sections.

4.3.1 ICs, MNA, and Groundwater Monitoring

ICs and MNA are employed for tritium and TCE in Alternatives 2 through 7. ICs and MNA are employed in Alternative 2 for Cr(VI) and Sr-90, and in Alternatives 3 to 6 to address the remnants of the Sr-90 plume following cessation of P&T operations. Remedy performance monitoring of the P&T system is also included in Table B-4 under the MNA category. The key assumptions for ICs include the following:

- ICs to prevent groundwater use for drinking, irrigation, or any other non-remediation purpose will be maintained for 75 years under Alternatives 2 through 7. This timeframe includes a 70-year allowance for Sr-90 concentrations to reach its PRG through radioactive decay and 5 years for compliance monitoring after the PRG is achieved.

Groundwater monitoring to assess performance of MNA and P&T alternatives assumes the following:

- Sampling of 32 existing wells and 6 new wells installed at the start of remedial action, with four additional new wells installed in year 5 of the remedial action.
- Existing wells are sampled annually for years 1 to 10. New wells are sampled quarterly during year 1 and annually for years 2 through 10.
- After year 10, only 20 wells are sampled.
- Wells are sampled biennially from years 10 to 60 for Cr(VI) and biennially from years 10 to 70 for Sr-90.
- During the 5-year compliance monitoring period, all wells are sampled semiannually. Compliance monitoring for tritium occurs in years 1 to 5, for TCE in years 25 to 30, for Cr(VI) in years 60 to 65, and for strontium in years 70 to 75.

4.3.2 Pump and Treat

The key assumptions and inputs for P&T technology employed under Alternatives 3 through 7 include the following:

- Alternatives 3 and 4 (Figures 1 and 2):
  - Four shallow (30 m [100 ft] deep each) extraction wells pumping at a rate of 284 L/min (75 gal/min) each and two deep (61 m [200 ft] deep each) extraction wells pumping at a rate of 189 L/min (50 gal/min) each for a total system rate of 1,515 L/min (400 gal/min).
  - Extracted groundwater is pumped from the individual wells to a 100-BC influent transfer station, which pumps the water to a re-purposed 100-KW treatment system that has been updated for 100-BC groundwater Cr(VI) removal. Sr-90 treatment is not required because the individual recovery well and combined flow Sr-90 concentration is less than the 8 pCi/L PRG per the groundwater modeling simulations presented in ECF-100BC5-16-0059.

  - Following treatment, the water is pumped from 100-K to the 100-BC effluent transfer station for distribution to the four injection wells (61 m [200 ft] deep each), which each receive a 379 L/min (100 gal/min) flow rate.
  - 40 years of operation.
  - Refurbishing the 100-BC transfer stations and the entire 100-KW treatment system after 25 years.
- Alternatives 5 through 7 (Figures 1 and 3):
  - Five shallow (30 m [100 ft] deep each) extraction wells pumping at a rate of 265 L/min (70 gal/min) each and two deep (61 m [200 ft] deep each) extraction wells pumping at a rate of 95 L/min (25 gal/min) each for a total system rate of 1,515 L/min (400 gal/min).
  - Extracted groundwater is pumped from the individual wells to a 100-BC influent transfer station, which pumps the water to a re-purposed 100-KW treatment system that has been updated for 100-BC groundwater Cr(VI) removal. Strontium-90 treatment is not required because the individual recovery well and combined flow Sr-90 concentration is less than the 8 pCi/L PRG per the groundwater modeling simulations presented in ECF-100BC5-16-0059.
  - Following treatment, the water is pumped from 100-K to the 100-BC effluent transfer station for distribution to four injection wells (61 m [200 ft] deep each), which each receive a 379 L/min (100 gal/min) flow rate.
  - 15 years of operation.

5 Software Applications

Excel 2013 was used to perform the calculations.

6 Calculation

This chapter provides sample calculations for various cost estimate quantity inputs associated with each alternative. The quantity input calculations are divided into three categories: waste sites, Sr-90 and Cr(VI) PRZ source, and groundwater plumes.

6.1 Waste Sites

The primary calculations for the waste sites include quantities for the following:

- Natural attenuation with ICs
- RTD

6.1.1 Natural Attenuation with ICs

The quantities for natural attenuation with ICs are figured on a per waste site basis, and includes a quantity input on the number of years the IC restricting excavation in shallow or deep soil or prohibiting irrigation needs to be maintained. There are six FS waste sites with 116-B-6A and 116-B-16 considered a single site. Table A-1 (columns 3, 4, 5, and 6) shows the years until which ICs need to be maintained. Waste site 100-B-34 includes a radioactive process sewer with two pipeline segments at an eastern location and a dichromate pipeline segment at a different western location. The dichromate pipeline is addressed using RTD under all alternatives and does not require an IC. Therefore, the quantity input for this item is six. In addition, there are 23 waste sites carried forward into the FS with direct contact risk for deep radionuclide contamination only. Table B-2 (column 4) shows the years until which ICs restricting deep excavation need to be maintained.

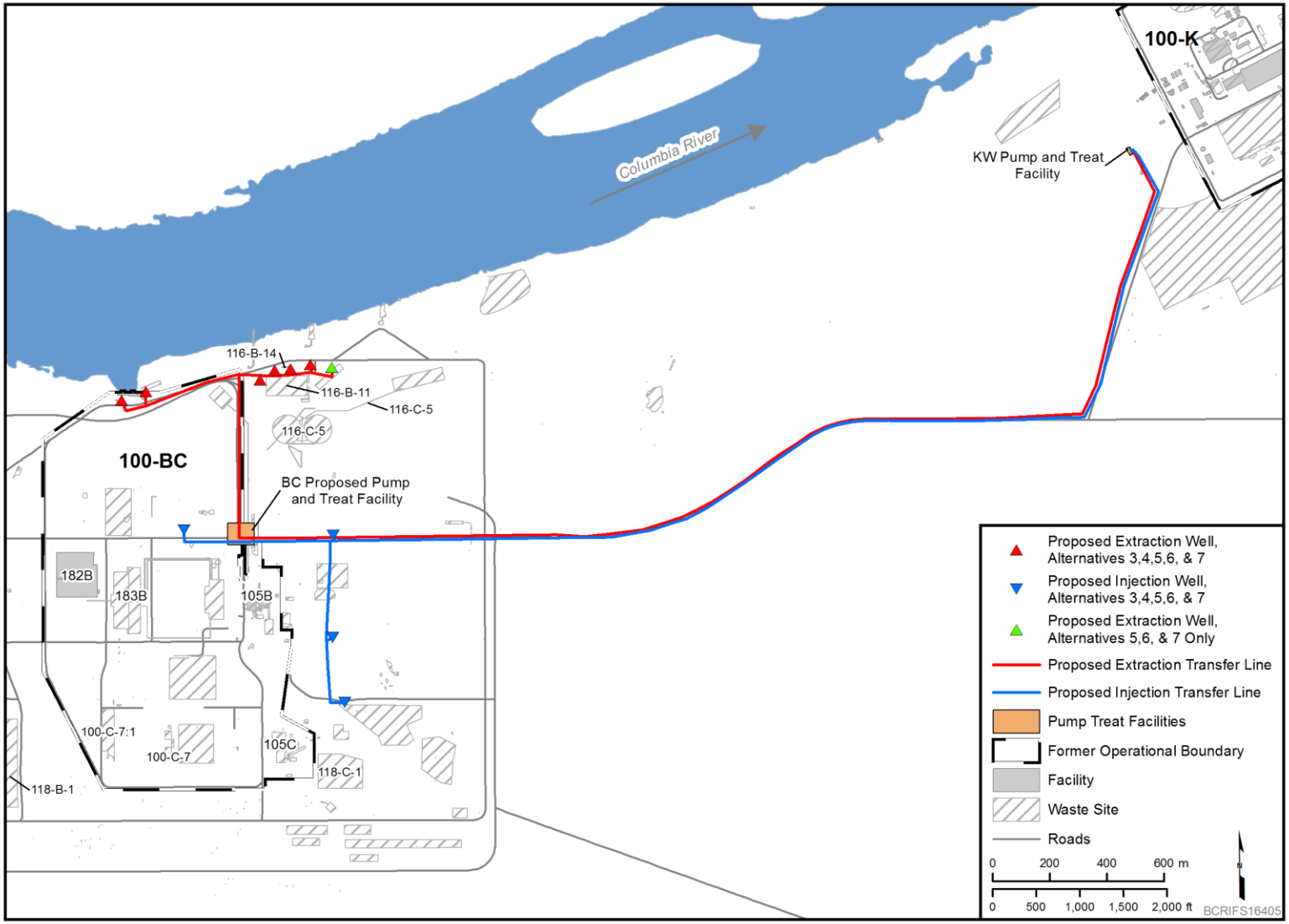

Figure 1. Pump and Treat Well and Piping Layout

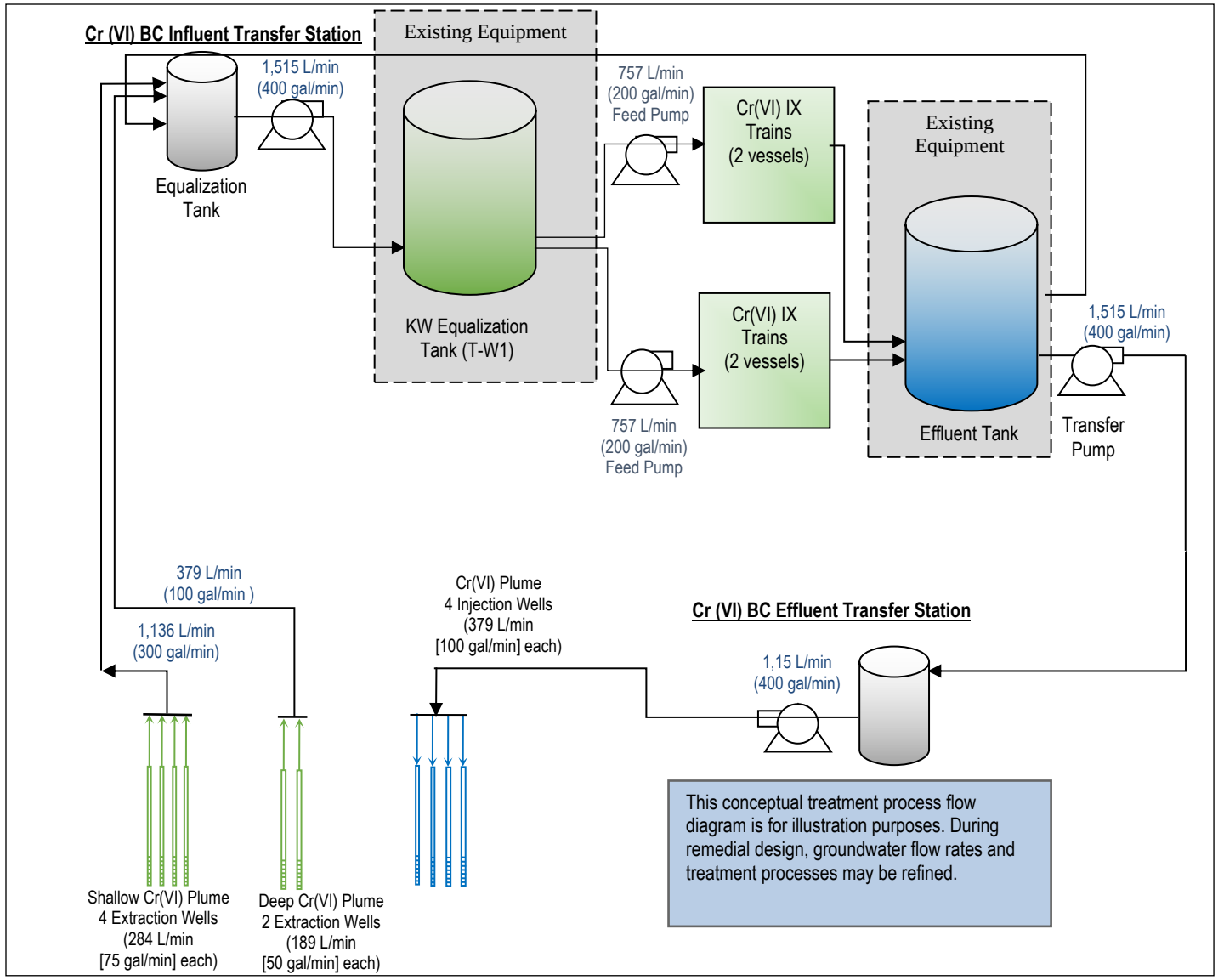

Figure 2. Alternative 3 and Alternative 4 Pump and Treat Process Flow Diagram

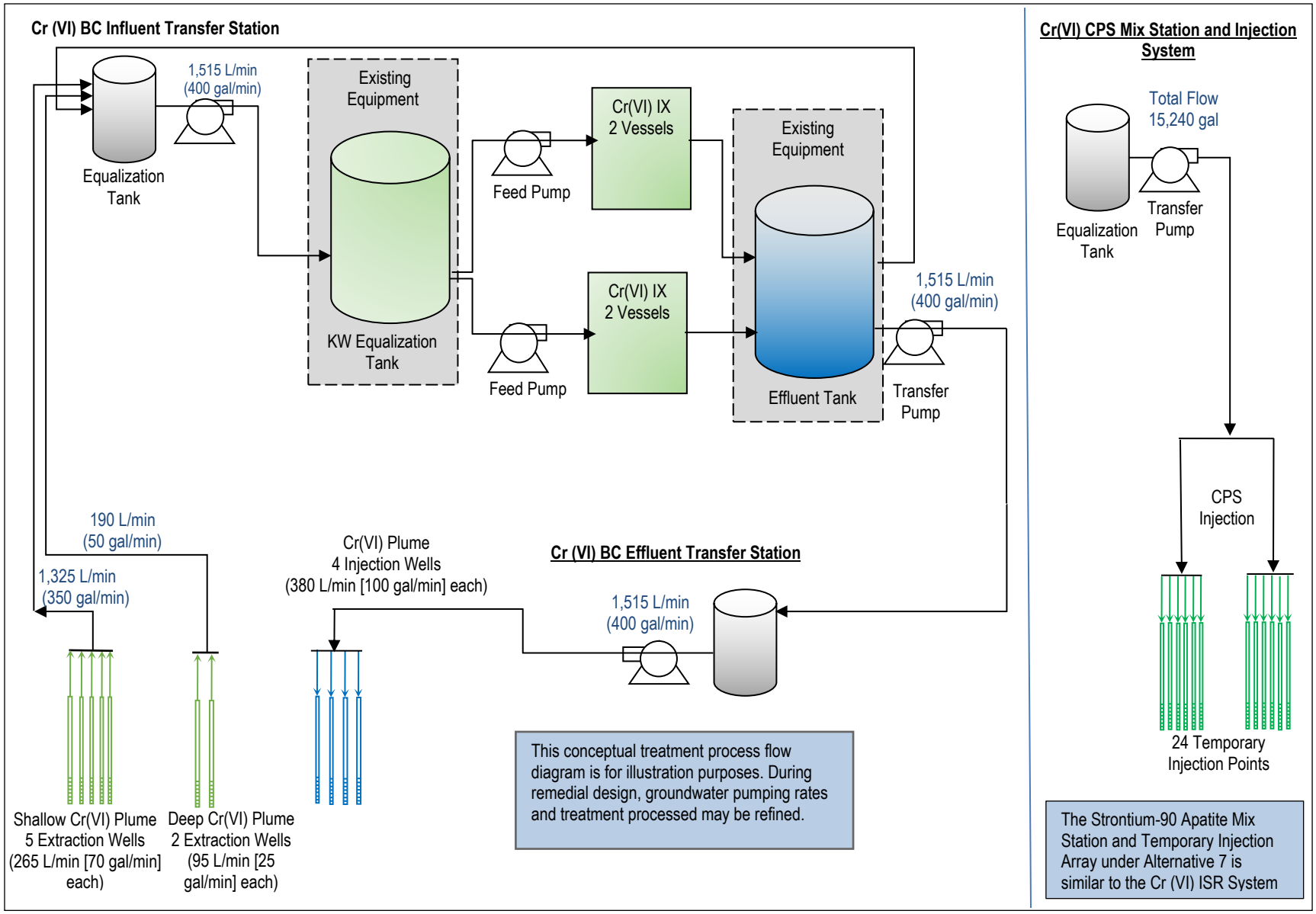

Figure 3. Alternative 5, Alternative 6, and Alternative 7 Pump and Treat Process Flow Diagram

Any IC durations greater than 150 years were only calculated to 150 years. For ICs durations less than 150 years, the actual time for those ICs was used.

6.1.2 Removal, Treatment (as Necessary), and Disposal

The quantities for RTD related activities (e.g., excavation, sampling and analysis, Environmental Restoration Disposal Facility disposal, and backfill) are all based on the volume of contaminated soil and noncontaminated soil expressed in units of cubic yards (cy). The contaminated soil quantities are based on the waste site specific area of contamination and depths shown in Table B-2 with the noncontaminated soil quantities determined separately by the Cost Estimator. The contaminated soil quantity for each waste site is calculated from the following:

$$\text{Contaminated Soil Volume (cy)} = \frac{(\text{Area of Contamination (ft2)} * \text{Contamination Interval (ft)})}{27\ \text{ft3/cy}}$$

The Contamination Interval is the depth range of contamination and is calculated from the maximum contamination depth minus the top of contamination.

The contaminated soil volumes for the waste sites where RTD is being performed under Alternatives 2 through 7 are shown in Table B-1. A rough order of magnitude cost to excavate and remove the contaminants at the waste sites with direct contact risk for deep radionuclide contamination was calculated. This includes FS waste sites 100-B-34 (eastern), 116-C-1, 118-B-1, 118-B-8:4, 116-B-6A/116-B-16, and the 23 sites in Table B-2.

6.2 Strontium-90 and Cr(VI) PRZ Source

The quantities for Sr-90 and Cr(VI) PRZ source treatment are based on the number of treatment areas. This includes two areas for Sr-90 and one area for Cr(VI), as described in Table B-3. The number of areas is based on the Sr-90 and Cr(VI) CSMs; therefore, no quantity calculation was performed.

6.3 Groundwater Plumes

The primary calculations for the Sr-90 and Cr(VI) groundwater plumes include quantities associated with construction of new remedy components and modification of existing remedy components (capital items), and quantities associated with annual operation and maintenance (O&M) of various remedy components. The quantities for these items are based on output from the groundwater model simulations described in ECF-100BC-16-0059, the assumptions presented in Chapter 4, and professional judgment, as follows.

Capital cost items include quantity calculations:

- New monitor well installations. The quantity input for this item is based on the total number of wells multiplied by the drilling and well construction footage per well. For Alternatives 2 through 7, six new monitor wells are installed in year 1 and four new wells in year 5. For the six new wells installed in year 1, at an assumed depth of 30 m (100 ft) per well, the total quantity for this item is 183 m (600 ft). For the four new wells installed in year 5, at an assumed depth of 61 m (200 ft) per well, the total quantity is 305 m (1,000 ft).

- New extraction well installations including pumps, associated piping, and equipment. The quantity input for this item is based on the total number of wells multiplied by the drilling and well construction footage per well. For Alternatives 3 and 4, this includes four shallow wells at 30 m (100 ft) deep each and two deep wells at 61 m (200 ft) deep each for a total footage of 244 m (800 ft). For Alternatives 5, 6, and 7, there are five shallow wells at 30 m (100 ft) per well and two deep wells at 61 m (200 ft) per well for a total footage of 274 m (900 ft). The pumps and associated equipment

quantities are based on the total number of wells, which is six for Alternatives 3 and 4, and seven for Alternatives 5, 6, and 7. This item also includes a 1,524 m (5,000 ft) allowance for 3-in. diameter high density polyethylene (HDPE) piping to transfer the water from the six wellheads under Alternatives 3 and 4, and the seven wellheads under Alternatives 5 to 7, to the 100-BC influent transfer station.

- New injection well installations including associated piping and equipment. The quantity input for this item is based on the drilling and well construction footage of 61 m (200 ft) per well for four wells or 244 m (800 ft) total for Alternatives 3 through 7. The associated equipment quantities are based on the total number of wells (4) for Alternatives 3 through 7.

- 100-BC influent transfer station. The quantity input for the 100-BC influent transfer station includes a 3,048 m (10,000 ft) allowance for 8-in. diameter HDPE to transfer the combined flow from all the extraction wells to the 100 KW treatment system equalization tank, one transfer pump, one 3,048 m (10,000 gal) polyethylene tank with level monitoring, and a shelter enclosure.

- 100-BC effluent transfer station. The quantity inputs for this item are the same as described for the influent station. This station receives 1,515 L/m (400 gal/min) of treated water from the 100-K treatment system(s) and distributes it to the four 100-BC injection wells.

- Modification of the existing KW treatment systems to treat groundwater from 100-BC under Alternatives 2 through 7. The existing KW treatment system would be modified by refurbishing existing components, such as tanks and instrumentation and control hardware, and installing new, larger capacity ion-exchange systems to remove Cr(VI). The quantity inputs for this item are determined by the Cost Estimator.

Annual O&M includes quantities for the following items:

- Maintenance of ICs. The quantity for this item is one based on one groundwater OU (100-BC-5).

- P&T operations. The quantity for this item is based on the number of years that the groundwater extraction, injection, and 100-K treatment system will need to operate, which is 40 years for Alternatives 3 and 4, and 15 years for Alternatives 5, 6, and 7. The P&T durations are defined in ECF-100BC-16-0059.

- Groundwater Sampling – Number of Wells Sampled. The quantity for this item varies over time as follows:

  – Years 1 to 5: This includes the number of existing wells sampled (32) + the number of new wells sampled (6) = 38

  – Years 6 to 10: This includes the number of existing wells sampled (38) + the number of new wells sampled (4) = 42

  – Years 11 to 60 or 11 to 70: Assumes that 15 existing wells + 5 of the new wells are sampled = 20

- Groundwater Samples per Event Remedial Action Performance Monitoring. This quantity varies over time and by COC, as follows:

  – Year 1: This includes annual sampling of the existing wells (32 samples) + quarterly sampling of the six new wells (24 samples) = 56 samples for Cr(VI), Sr-90, and volatile organic compounds (VOCs)

- Years 2 to 5: This includes annual sampling of the existing wells (32 samples) + annual sampling of the six new wells (6 samples) multiplied by the number of years (4 years) = 152 samples for Cr(VI), Sr-90, and VOCs
- Years 6 to 10: This includes annual sampling of the existing wells (32 samples) + annual sampling of the 10 new wells (10 samples) multiplied by the number of years (5 years) = 210 samples for Cr(VI), Sr-90, and VOCs
- Years 11 to End of Remedial Action (Out Years): This includes sampling of 20 wells every 2 years for the balance of the remedial action duration, which varies by Alternative and COC, as follows:
  - Alternative 2:
    - Cr(VI) - Years 11 to 60: 20 samples per event * 50 years ÷ 2 years per event = 500 samples
    - Strontium-90 - Years 11 to 70: 20 samples per event * 60 years ÷ 2 years per event = 600 samples
    - VOCs - Years 11 to 25: 20 samples per event * 15 years ÷ 2 years per event = 150 samples
  - Alternatives 3 and 4:
    - Cr(VI) - Years 11 to 40: 20 samples per event * 30 years ÷ 2 years per event = 300 samples
    - Strontium-90 - Years 11 to 70: 20 samples per event * 60 years ÷ 2 years per event = 600 samples
    - VOCs - Years 11 to 25: 20 samples per event * 15 years ÷ 2 years per event = 150 samples
  - Alternatives 5, 6, and 7:
    - Cr(VI) - Years 11 to 15: 20 samples per event * 5 years ÷ 2 years per event = 50 samples
    - Strontium-90 - Years 11 to 70: 20 samples per event * 60 years ÷ 2 years per event = 600 samples
    - VOCs - Years 11 to 25: 20 samples per event * 15 years ÷ 2 years per event = 150 samples

- Groundwater Samples per Event Compliance Monitoring. This quantity assumes a 5-year compliance monitoring period with samples collected semiannually. The estimated quantities vary by COC and were calculated as follows:
  - Tritium for Alternatives 2 through 7 – Years 1 to 5: This includes semiannual sampling of the existing wells (32 wells * 2 events = 64 samples) + semiannual sampling of six new wells (6 wells * 2 events = 12 samples) * 5 years = 380 samples
  - Cr(VI) for Alternative 2 – Years 61 to 65: This includes semiannual sampling of the existing wells (32 wells * 2 events = 64 samples) + semiannual sampling of the 10 new wells (10 wells * 2 events = 20 samples) * 5 years = 420 samples

- Cr(VI) for Alternatives 3 and 4 – Years 41 to 45: This includes semiannual sampling of the existing wells (32 wells * 2 events = 64 samples) + semiannual sampling of the 10 new wells (106 samples) * 5 years = 210 samples
- Cr(VI) for Alternatives 5, 6, and 7 - Years 16 to 20: This includes semiannual sampling of the existing wells (32 wells * 2 events = 64 samples) + semiannual sampling of the 10 new wells (10 samples) multiplied by the number of years (5 years) = 210 samples
- Strontium-90 for Alternatives 2 through 7 – Years 71 to 75: This includes semiannual sampling of the existing wells (32 wells * 2 events = 64 samples) + semiannual sampling of the 10 new wells (10 samples) multiplied by the number of years (5 years) = 210 samples
- VOCs for Alternatives 2 through 7- Years 26 to 30: This includes semiannual sampling of the existing wells (32 wells * 2 events = 64 samples) + semiannual sampling of 10 new wells (10 wells * 2 events = 20 samples) * 5 years = 420 samples

7 Results/Conclusions

The cost inputs, assumptions, and calculations presented in the previous sections were used to develop cost estimate quantity inputs for each alternative, and document cost estimate assumptions in standard estimating forms to be used by the estimator.

8 References

40 CFR 300.430, "National Oil and Hazardous Substances Pollution Contingency Plan," "Remedial Investigation/Feasibility Study and Selection of Remedy," *Code of Federal Regulations*. Available at: http://www.gpo.gov/fdsys/pkg/CFR-2010-title40-vol27/xml/CFR-2010-title40-vol27-sec300-430.xml.

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DOE/RL-2010-96, 2019, *Remedial Investigation/Feasibility Study for the 100-BC-1, 100-BC-2, and 100-BC-5 Operable Units*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

ECF-100BC5-16-0059, 2016, *2016 Modeling of RI/FS Design Alternatives for 100-BC-5*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0073927H.

SGW-47062, 2010, *Treatability Test Report for Field-Scale Apatite Jet Injection Demonstration for the 100-NR-2 Operable Unit*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1009270920.

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Appendix A

Feasibility Study Alternatives Matrix for 100-BC

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Tables

Table A-1. Basis for Action, COCs, Estimated Date Decay Achieves PRG, and Alternative Remedial Action Components A-1

Table A-2. Groundwater PRZ Source and Groundwater Plume Remedy Components for Remedial Action Alternatives A-4

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Table A-1. Basis for Action, COCs, Estimated Date Decay Achieves PRG, and Alternative Remedial Action Components

Waste Site Identification and Type	Description	Basis for Remedial Action and COCs (Estimated Year When PRG is Achieved[a])				Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Comments
		Shallow Soil >Direct Contact HH PRG	Deep Soil Rad>Direct Contact HH Cleanup Level[b]	Soil >GW/SW Protection SSL[c]	Soil >GW/SW Protection PRG[c]							
100-B-34 (Radioactive Process sewer and dichromate pipeline)[d]	Residual segments from other pipeline waste sites that could not be remediated due to the presence of overlying active utilities. 1. Eastern Location: Consists of two parallel segments of the former reactor cooling water effluent sewers from the 105-C Reactor. Two 15 m (50 ft) long segments of the parallel 1.5 m (60 in.) pipelines were left in place where they traversed beneath the active export water pipeline (the primary water supply for the 200 Area). The tops of these remaining pipeline segments are located approximately 3 m (10 ft) bgs. Based on remediation of the adjoining process sewers, the internal surfaces of the remaining segments are expected to contain elevated activity from mixed fission products in a thin layer of rust/scale. There was no known substantial leakage of the sewers at this location, but soil immediately surrounding the pipeline could contain mixed fission product contamination levels similar to or higher than activity levels measured in verification samples for the 100-C-6:1 site. 2. Western Location: Consists of a single segment of the sodium dichromate transfer line from the 183-C facility to the 183-B facility. The adjoining transfer pipeline was remediated as part of the 100-B-28 site, but two segments could not be removed due to the presence of overlying water utilities. The southern of these two segments was later incorporated into and removed as part of the 100-C-7:1 excavation, which included major water utility rerouting. The northern segment still remains, consisting of a 17-m (55-ft) long segment of 10-cm (4-in.) pipe. This segment is located 1.8 m (6 ft) bgs, beneath the fire suppression loop for remaining 100 BC facilities, including the 105-B Reactor museum. Potential residual concentrated sodium dichromate liquid within this segment was displaced and collected using grout. No significant leakage or soil contamination was observed as part of the 100-B-28 remediation, nor is expected for this remaining segment of the former transfer line.	Eastern segments: Cs-137, Eu-152, Sr-90 (year 2055)[e] Western segment: Cr(VI) (indefinite timeframe)[e]	Eastern segments: Cs-137, Eu-152, Sr-90 (year 2055)[e]	Western segment: Cr(VI) (indefinite timeframe)[e]	Western segment: Cr(VI) (indefinite timeframe)[e]	Eastern segments: Natural attenuation with ICs (shallow and deep excavation restrictions) Western segment: Reroute fire suppression line and RTD to 2.7 m (9 ft)	Eastern segments: Natural attenuation with ICs (shallow and deep excavation restrictions) Western segment: Reroute fire suppression line and RTD to 2.7 m (9 ft)	Eastern segments: Reroute water lines, RTD to 4.6 m (15 ft), and remove pipeline segments, ICs (deep excavation restrictions) Western segment: Reroute fire suppression line and RTD to 2.7 m (9 ft)	Eastern segments: Natural attenuation with ICs (shallow and deep excavation restrictions) Western segment: Reroute fire suppression line and RTD to 2.7 m (9 ft)	Eastern segments: Reroute water lines, RTD to 4.6 m (15 ft), and remove pipeline segments, ICs (deep excavation restrictions) Western segment: Reroute fire suppression line and RTD to 2.7 m (9 ft)	Eastern segments: Reroute water lines, RTD to 4.6 m (15 ft), and remove pipeline segments, ICs (deep excavation restrictions) Western segment: Reroute fire suppression line and RTD to 2.7 m (9 ft)	Eastern segment: Approximate depth to bottom of the 152.4 cm (60-in.) diameter reactor cooling water effluent pipeline segments is from 4.6 m (15 ft) to 5.5 m (18 ft). Because the pipeline was pressurized, it is assumed that contamination may occur in the shallow and deep soil surrounding the entire pipe diameter and as scale inside the pipe. Alternatives 4, 6, and 7 assume soil RTD to 4.6 m (15 ft) with removal of the two pipeline physical structure. Excavation procedures need to consider overlying utilities, which include the export water line main to the Central Plateau (106.7 cm [42 in.] diameter, top of pipe 1.8 m [6 ft] bgs). Western segment: Approximate maximum depth to bottom of sodium dichromate pipeline segments is 2.1 m (7 ft). Alternatives 2 through 7 assume removal of the pipeline segment and soil RTD to 2.7 m (9 ft). Excavation procedures need to consider overlying utilities, which include the fire suppression system line (25.4 cm [10-in.] diameter, top of pipe 1.2 m [4 ft] bgs). Assumed IC duration is 40 years for the radioactive process sewer.

Table A-1. Basis for Action, COCs, Estimated Date Decay Achieves PRG, and Alternative Remedial Action Components

Waste Site Identification and Type	Description	Basis for Remedial Action and COCs (Estimated Year When PRG is Achieved[a])				Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Comments
		Shallow Soil >Direct Contact HH PRG	Deep Soil Rad>Direct Contact HH Cleanup Level[b]	Soil >GW/SW Protection SSL[c]	Soil >GW/SW Protection PRG[c]							
116-C-1 Trench	Former process effluent disposal trench. Received contaminated cooling water throughout operations. Includes 700 million L (184 million gal) from the 100-BC Area Retention Basins after ruptured fuel elements were detected in the reactors. Received 40 billion L (more than 10 billion gal) of high-temperature reactor cooling water during a 150-day infiltration test in 1967.	N/A	Cs-137, Eu-152, Eu-154, Co-60, Ni-63, Sr-90 [year 2485]	Sr-90 [year 2034]	N/A	Natural attenuation with ICs (irrigation and deep excavation restrictions)	Natural attenuation with ICs (irrigation and deep excavation restrictions)	Deep RTD to 12 m (42 ft)	Natural attenuation with ICs (irrigation and deep excavation restrictions)	Deep RTD to 12 m (42 ft)	In situ treatment using Apatite Jet Injection; Natural attenuation with ICs (irrigation and deep excavation restrictions)	For Alternatives 4 and 6, RTD would eliminate the need for ICs restricting excavation and preventing irrigation. Previously remediated site. For Alternative 7, apatite injection target zone includes 1,025 m^2 (11,025 ft^2) area at inlet (west end) of trench to approximately 12.8 m (42 ft) bgs.
118-B-1 (Burial Ground)	The original 105-B Burial Ground contained six to eight trenches, but was expanded over its operational lifetime to 23 trenches. The site was to have received general reactor waste from the B Reactor including the following: aluminum tubes, lead bricks, thermocouples, vertical and horizontal aluminum thimbles, stainless-steel gun barrels, and expendables (e.g., plastic, wood, and cardboard). Spline silos were also constructed at the burial ground, which were vertical metal culverts, 3 to 3.7 m (10 to 12 ft) in diameter, built presumably to receive reactor poison splines and other metal wastes. In 1952, the burial ground received contaminated tritium pots, irradiated process tubing, contaminated fuel spacers (perfs), solid tritium wastes, and high-level liquid tritium wastes that were sealed in a 7.6 cm (3-in.) diameter iron pipe. In 1956, the second extension to the burial ground was added and was used for the burial of contaminated yokes from B Reactor. In the mid-1960s, the third extension was added to the north side of the original burial ground. Historical data on the contents of these trenches are not as detailed as with earlier extensions but are presumed to include "general" reactor and construction waste from modifications to the B Reactor. Waste materials from the Tritium Separation (P-10) Project were also buried here, including lithium-aluminum alloy, lead, mercury, aluminum cladding, and palladium. Based on sample results and observed waste forms during site remediation, elevated residual tritium is likely present beneath much of the southern portion of the former burial ground.	Sr-90, Cs-137 [year 2040]	Tritium [year 2081]	Tritium [year 2051]	N/A	Natural attenuation with ICs (irrigation, shallow and deep excavation restrictions)	Natural attenuation with ICs (irrigation, shallow and deep excavation restrictions)	Natural attenuation with ICs (shallow excavation restriction for Sr-90 and Cs-137); irrigation restriction for tritium.	Natural attenuation with ICs (irrigation, shallow and deep excavation restrictions)	Natural attenuation with ICs (shallow excavation restriction for Sr-90 and Cs-137); irrigation restriction for tritium.	Natural attenuation with ICs (shallow excavation restriction for Sr-90 and Cs-137); irrigation restriction for tritium.	Previously remediated site. Shallow strontium-90/cesium-137 and deep tritium PRG exceedances apply to different areas of the waste site (north versus south, respectively). Although the site specific model forecasts groundwater tritium concentrations will exceed the groundwater PRG until 2051 based on a hypothetical irrigation scenario, tritium in downgradient groundwater at well 199-B8-6 does not currently exceed the tritium PRG of 20,000 pCi/L, and concentrations are decreasing. Alternatives 2 through 7 assume compliance groundwater monitoring for tritium.

Table A-1. Basis for Action, COCs, Estimated Date Decay Achieves PRG, and Alternative Remedial Action Components

Waste Site Identification and Type	Description	Basis for Remedial Action and COCs (Estimated Year When PRG is Achieved[a])				Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Comments
		Shallow Soil >Direct Contact HH PRG	Deep Soil Rad>Direct Contact HH Cleanup Level[b]	Soil >GW/SW Protection SSL[c]	Soil >GW/SW Protection PRG[c]							
118-B-8:4 Subsite	New subsite. Adjacent to B Reactor Museum. Exceedances at RI boreholes C7847 (shallow) and C8239 (deep).	Cs-137, Eu-152, Sr-90 [year 2203]	C-14, Sr-90 [year 32021]	N/A	N/A	Natural attenuation with ICs (shallow and deep excavation restrictions)	Natural attenuation with ICs (shallow and deep excavation restrictions)	RTD to 4.6 m (15 ft) (deep excavation restrictions)	Natural attenuation with ICs (shallow and deep excavation restrictions)	RTD to 4.6 m (15 ft) (deep excavation restrictions)	RTD to 4.6 m (15 ft) (deep excavation restrictions)	Additional administrative and technical considerations for RTD adjacent to fuel storage basin and B Reactor National Historic Landmark, part of the Hanford Unit of the Manhattan Project National Historical Park.
116-B-5 Crib	Received liquid waste from 108-B Building P-10 Project	Eu-152 [year 2021]	N/A	N/A	N/A	Natural attenuation with ICs (shallow excavation restrictions)	Natural attenuation with ICs (shallow excavation restrictions)	Natural attenuation with ICs (shallow excavation restrictions)	Natural attenuation with ICs (shallow excavation restrictions)	Natural attenuation with ICs (shallow excavation restrictions)	Natural attenuation with ICs (shallow excavation restrictions)	Approximate total depth of contamination is 4.6 m (15 ft). No RTD option based on short decay timeframe.
116-B-6A Crib / (116-B-16 Tank	The crib received liquid wastes from equipment decontamination performed in the 111-B facility, as well as from the decontamination of fuel element spacers. The tank was a low-level liquid waste disposal site that was operational during the lifetime of the 111-B Metallurgical Examination Building.	Cs-137, Sr-90 [year 2045]	Sr-90 [year 2095]	N/A	N/A	Natural attenuation with ICs (shallow and deep excavation restrictions)	Natural attenuation with ICs (shallow and deep excavation restrictions)	RTD to 4.6 m (15 ft) (deep excavation restrictions)	Natural attenuation with ICs (shallow and deep excavation restrictions)	RTD to 4.6 m (15 ft) (deep excavation restrictions)	RTD to 4.6 m (15 ft) (deep excavation restrictions)	Previously remediated but contamination remains on sidewalls and beneath excavation floor. Approximate total depth of contamination is 6 m (19.7 ft)

Notes: Blue shading indicates remedial action component.

Waste sites with a common element deep excavation restriction are provided in Table B-2.

a. Estimated year (shown in parentheses) decay achieves PRG or cleanup level is the year cumulative cancer risk decays to less than 1×10^{-4}.

b. An institutional control to restrict excavation will be applied to sites that meet this condition. No further remedial action alternatives were developed for direct contact PRG exceedances for deep soil.

c. The term "SSL" refers to a PRG value calculated for an irrigation land use scenario. The term "PRG" refers to a PRG value calculated for conversation with native vegetation land use.

d. Includes segments of a former radioactive process sewer (waste site 100-C-6:1) and sodium dichromate transfer pipeline (waste site 100-B-28).

e. Presumed exceedances based on process history and data for connecting pipeline segments (previously remediated).

Alt = Alternative
bgs = below ground surface
Co-60 = cobalt-60
COC = contaminant of concern
Cr(VI) = hexavalent chromium
Cs-137 = cesium-137
CSM = conceptual site model
ET = evapotranspiration
Eu-152 = europium-152
Eu-154 = europium-154
GW = groundwater
HH = human health
IC = institutional control
N/A = not applicable
Ni-63 = nickel-63
PRG = preliminary remediation goal
RI = remedial investigation
RTD = removal, treatment (as necessary), and disposal
Sr-90 = strontium-90
SSL = soil screening level
SW = surface water

Table A-2. Groundwater PRZ Source and Groundwater Plume Remedy Components for Remedial Action Alternatives

Groundwater Source/Dissolved Plume	Description	Basis for Remedial Action and Estimated Time Frame to Achieve PRG* with No Further Action	Alternatives						Comments
			Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	
Cr(VI) CSM-PRZ Sources	CSM indicates residual Cr(VI) source present in two areas: Area 1 = vicinity of 100-C-7 and 100-C-7:1; Area 2 = vicinity of 116-B-11.	Assumed source to dissolved Cr(VI) plume that contributes to remedial action timeframe for the plume.	Natural attenuation	Natural attenuation	Natural attenuation	ISR (116-B-11 vicinity), Natural attenuation (100-C-7, 100-C-7:1 vicinity)	ISR (116-B-11 vicinity), Natural attenuation (100-C-7, 100-C-7:1 vicinity)	ISR (116-B-11 vicinity), Natural attenuation (100-C-7, 100-C-7:1 vicinity)	
Cr(VI) Groundwater Dissolved Plume	Dissolved plumes in shallow and deep unconfined zones	Exceeds Cr(VI) PRG based on 10 µg/L state surface water quality standard for 60 years (year 2075) at the shoreline. Exceeds Cr(VI) PRG based on 48 µg/L MTCA groundwater cleanup level for 15 years (year 2030) in the aquifer.	MNA and ICs (groundwater use) for 60 years	Pump 1,515 L/min (400 gal/min) for 40 yr, treat at 100-KW, and reinject at 100-BC	Pump 1,515 L/min (400 gal/min) for 40 yr, treat at 100-KW, and reinject at 100-BC	Pump 1,515 L/min (400 gal/min) for 15 yr, treat at 100-KW, and reinject at 100-BC	Pump 1,515 L/min (400 gal/min) for 15 yr, treat at 100-KW, and reinject at 100-BC	Pump 1,515 L/min (400 gal/min) for 15 yr, treat at 100-KW, and reinject at 100-BC	
Sr-90 CSM-PRZ Sources	CSM indicates residual Sr-90 sources within the Sr-90 plume footprint, overlying the higher concentration portion of the Sr-90 plume.	Source to dissolved Sr-90 plume that contributes to remedial action timeframe for the plume.	Natural attenuation	Natural attenuation	Natural attenuation	Natural attenuation	Natural attenuation	In situ sequestration of Sr-90 using Apatite Jet Injection	For Alternative 7, apatite injection target zone includes Treatment Area 2, a 24,400 m^2 (259,410 ft^2) area overlying the Sr-90 plume to approximately to 12.8 m (42 ft) bgs. Alternative 7 would not reduce Sr-90 remedial time frames in the aquifer
Sr-90 Groundwater Dissolved Plume	Dissolved plume in shallow unconfined zone	Exceeds Sr-90 PRG based on 8 pCi/L DWS for 70 years (year 2085) in the aquifer.	MNA and ICs (groundwater use) for 70 years	Pump 1,515 L/min (400 gal/min) for 40 yr, treat at 100-KW, and reinject at 100-BC; MNA and ICs (groundwater use) for Sr-90 after P&T shutdown	Pump 1,515 L/min (400 gal/min) for 40 yr, treat at 100-KW, and reinject at 100-BC; MNA and ICs (groundwater use) for Sr-90 after P&T shutdown	Pump 1,515 L/min (400 gal/min) for 15 yr, treat at 100-KW, and reinject at 100-BC; MNA and ICs (groundwater use) for Sr-90 after P&T shutdown	Pump 1,515 L/min (400 gal/min) for 15 yr, treat at 100-KW, and reinject at 100-BC; MNA and ICs (groundwater use) for Sr-90 after P&T shutdown	Pump 1,515 L/min (400 gal/min) for 15 yr, treat 100-KW, and reinject at 100-BC; MNA and ICs (groundwater use) for Sr-90 after P&T shutdown	Although some Sr-90 is co-extracted with Cr(VI) P&T, the Sr-90 plume is remediated primarily through natural attenuation (radioactive decay). Sr-90 treatment is not anticipated to be required but would be added if influent concentrations are above 8 pCi/L.
TCE Groundwater Dissolved Plume	Dissolved plume in deep unconfined zone	In 2016, exceeded TCE PRG at one well location (199-B5-11) based on 4 µg/L MTCA groundwater cleanup level. Estimated cleanup timeframe is 25 years (year 2040) in the aquifer.	MNA and ICs (groundwater use) for 25 years	MNA and ICs (groundwater use) for 25 years	MNA and ICs (groundwater use) for 25 years	MNA and ICs (groundwater use) for 25 years	MNA and ICs (groundwater use) for 25 years	MNA and ICs (groundwater use) for 25 years	

Reference: WAC 173-340, "Model Toxics Control Act—Cleanup," *Washington Administrative Code*, Olympia, Washington. Available at: http://apps.leg.wa.gov/WAC/default.aspx?cite=173-340.

Note: Blue shading indicates remedial action component

*Estimated time frame to achieve PRG or cleanup level is for groundwater with contributing source combined. The date/years are based on Cmax.

Alt = Alternative
Cmax = maximum concentration
Cr(VI) = hexavalent chromium
CSM = conceptual site model
DWS = drinking water standard
IC = institutional control
ISR = in situ reduction
MNA = monitored natural attenuation
MTCA = "Model Toxics Control Act—Cleanup"
P&T = pump and treat
PRG = preliminary remediation goal
PRZ = periodically rewetted zone
Sr-90 = strontium-90
TCE = trichloroethene

Appendix B

Waste Site, Strontium-90 and Cr(VI) PRZ Source, and Groundwater Plume Information

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Tables

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Table B-1. Estimated Area and Depth of Contamination for Waste Sites Carried Forward into the Feasibility Study - Identified for Further Action

Site	Area of Contamination (m^2 [ft^2])	Basis/Comment	Depth Range of Contamination (m [ft])	Basis/Comment	Estimated Contaminated Soil Volume (cubic yards)	References
100-B-34 Radioactive Process Sewer	Eastern segments - Effluent sewers: 60 [646]	Area for effluent sewers based on two 15 m (49 ft) pipe segments; assuming 2 m (6.5 ft) wide remediation corridor.	3.3-6.1 [11-20] (overlain by clean fill and export water line). Shallow RTD assumes excavation and removal from 0-4.6 [0-15], including removal of clean soil interval from 0-3.3 [0-11], removal of pipe structure to 5.5 [18], and removal of contaminated interval from 3.3-4.6 [11-15]. Deep RTD ROM assumes excavation and removal from 0-6.1 [0-20], including removal of clean soil interval from 0-3.3 [0-11], removal of pipe structure to 5.5 [18], and removal of contaminated interval from 3.3-6.1 [11-20].	Includes physical pipe structures to an assumed maximum depth of 5.5 [18] plus an additional 0.6 [2] below the pipe structure; overlain by clean fill and export water line). Effluent sewer depths based on remediation depth of adjacent 100-C-6:1 remediation plus a typical "soil box" for 60-in. pipeline. Effluent sewers are 60-in. carbon steel with estimated bottom depth up to 5.5 m [18 ft]. Assumes relocating the export water line prior to RTD (42 in. diameter, top of pipe 1.8 m [6 ft]).	Shallow: 96 Deep: 96 + 119 = 215	WSRF-2004-020/CVP-2003-00022
	Western segment - Dichromate transfer line: 17 [183]	Area for dichromate transfer line based on one remaining 17 m (56 ft) segment; assuming 1 m (3 ft) wide remediation corridor.	1.8-2.7 [6-9] (overlain by clean fill and fire suppression loop). Shallow RTD assumes excavation and removal from 0-2.7 [9], including removal of clean soil interval from 0-1.8 [0-6], and removal of contaminated interval and pipe structure from 1.8-2.7 [6-9]. Assumes no contamination below 2.7 [9].	Includes physical pipe structure to an assumed maximum depth of 2.1 [7] plus an additional 0.6 [2] below the pipe structure; overlain by clean fill and fire suppression line). Dichromate transfer line depth based on line depth plus a typical "soil box" for small-diameter pipeline. Dichromate transfer line is 10 cm (4 in.) cast iron. Assumes relocating the fire suppression loop prior to RTD. RTD (10 in. diameter, top of pipe 1.2 m [4 ft]).	Shallow: 20	WSRF-2004-020/CVP-2003-00022
116-C-1 Trench	Area for Deep RTD: 11,116 [119,652] Area 1 for Jet Injection: 1,025 [11,025] area at the west end of the trench.	Area for RTD: CVP deep zone footprint Area for Apatite Injection: location of maximum contamination (assumed to include area near trench inlet)	6-12 [19.7-39.4] (overlain by clean fill material). Assume 12.8 [42] total depth for RTD and apatite injection based on groundwater depth in CVP.	Upper boundary of contamination based on typical depth of previous remediation; lower boundary based on extending to "Lift 7" of the previous characterization test pit for extent of elevated Sr-90. For cost estimate, assume lower boundary is groundwater depth.	Deep: 98,824	WSRF-98-012/CVP-98-00006
118-B-1 Burial Ground	Area 3: 4,642 [49,966] Area 5: 1,089 [11,722] Areas 1&2 for Deep RTD ROM: 5,284 [56,876] Note, Areas 3 and 5 do no overlap with Areas 1&2. No alternatives include RTD	Area 3 and Area 5 shallow Sr-90 and Cs-137 based on CVP footprints. Deep "Tritium footprint" conservatively approximated as combined CVP footprints of Areas 1 and 2 based on deep characterization results.	Area 3: 2-5 [6.6-16.4] (overlain by clean fill material) Area 5: 3-5.5 [9.8-18] (overlain by clean fill material) Areas 1 & 2 "Tritium footprint": 5-22.5 [16.4-73.8] (overlain by clean fill material)	Area 3 and 5 ranges based on typical depth range for footprint area, plus generically assumed additional 1 m below extent of previous remediation. Areas 1 & 2 "Tritium footprint" range based on typical floor depth in footprint area, extending to typical groundwater table depth.	Deep: 120,875	WSRF-2007-032/CVP-2007-00006
118-B-8:4 Subsite	Area for shallow RTD: 150 [1,615] Area for deep RTD ROM: 1,200 [12,917]	Shallow: 15 m [49.2 ft] corridor around eastern portion of FSB building. Deep: 1,200 m^2 [12,917 ft^2] area incorporating deep boring C8239.	Shallow: 0 - 4.6 [0-15] Deep RTD ROM: 0-25 [0-82]	Shallow: Upper boundary at surface. Lower boundary based on approximate maximum depth of excavation without impact to remaining structural elements. Location is immediately adjacent to B Reactor museum structures. Deep: Assumes contaminated from 0-25 m [0-82 ft] bgs.	Shallow: 897 Deep: 39,229	DOE/RL-2010-96, Chapter 4; Borehole C7847 (shallow) and borehole C8239 (deep) Deep ROM: Approximately 30×10 m (98×33 ft) corridor to incorporate borings; likely similar deep soil contamination under the FSB, which would add another ~900 m^2 (9,688 ft^2) of footprint. The cost for any excavation to 25 m (82 ft) in this area would be removal of the reactor. Costs provided are for those beyond removal of the reactor and associated remaining components, and assume a ~1,200 m^2 (12,917 ft^2) excavation.

Table B-1. Estimated Area and Depth of Contamination for Waste Sites Carried Forward into the Feasibility Study - Identified for Further Action

Site	Area of Contamination (m^2 [ft^2])	Basis/Comment	Depth Range of Contamination (m [ft])	Basis/Comment	Estimated Contaminated Soil Volume (cubic yards)	References
116-B-5 Crib	Area: 69.6 [749] No alternatives include RTD	Crib footprint is 2.4×29 m (7.9×95 ft)	Shallow focused: 1.2-4.6 [4-15], overlain by clean fill material	Boundaries based on sample depths and detections for risk drivers.	Shallow: 305	NPL-111 with attached CVP
116-B-6A Crib	Area for Shallow RTD: 604 [6,501] Area for Deep RTD ROM: 604 [6,501]	CVP excavation area at surface is 604 m^2 [6,501 ft^2]. Excavation floor is 200 m^2 [2,153 ft^2]	Shallow Zone: 0-4.6 [0-15] outside of the 200 m^2 [2,153 ft^2] previously excavated area Deep Zone: 4.6 - 6 [15-19.7] (overlain by clean fill material inside of the 200 m^2 [2,153 ft^2] previously excavated area)	Contamination was detected on excavation sidewalls (shallow decision unit) and excavation floor (deep decision unit). Upper boundary for deep contamination based on typical excavation floor depth. Lower boundary based on maximum excavation floor depth. (Excavation beyond 4.6 m (15 ft) bgs was performed in only a small portion of the footprint; volume for potential contamination beyond 6 m (20 ft) bgs in this small area is adequately bounded by total volume.)	Shallow: 2,416 Deep: 3,619	WSRF-99-055/CVP-99-00011 Estimate assumes contaminated soil volume for shallow RTD = outer area minus inner area times 15 ft = (($6,501 ft^2 – 2,153 ft^2$) *15 ft) / 27 cy/ft = 2,416 cy Estimate assumes contaminated soil volume for deep RTD ROM = outer area to 20 ft minus inner area shallow zone = ($6,501 ft^2$ * 20 ft) – (2,153 ft *15 ft) / 27 cy/ft =3,619 cy
116-B-16 Storage Tank	Included with 116-B-6A	Included with 116-B-6A	Included with 116-B-6A	Included with 116-B-6A		Included with 116-B-6A

References: DOE/RL-2010-96, 2018, *Remedial Investigation/Feasibility Study for the 100-BC-1, 100-BC-2, and 100-BC-5 Operable Units*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

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bgs = below ground surface
Cs-137 = cesium-137
CVP = cleanup verification package
cy = cubic yard
FSB = fuel storage basin
ROM = rough order of magnitude
RTD = removal, treatment (as necessary), and disposal
Sr-90 = strontium-90

Table B-2. Estimated Area and Depth of Contamination for Deep Waste Sites Carried Forward into the Feasibility Study - Identified for Excavation Restriction ICs

Site	FS Category	Area of Contamination (m^2 [ft^2])	Date when Radionuclide COC Concentration Declines to PRG (e.g., ELCR < 10^{-4})	Basis/Comment	Depth Range of Contamination (m [ft])	Basis/Comment
100-B-34 (east)	Site from Table B-1 with Deep Contamination Requiring Deep Excavation Restriction IC in Addition to Other Action(s)	Eastern segments - Effluent sewers: 60 [646]	2055	Area for effluent sewers based on two 15 m (49 ft) pipe segments; assuming 2 m (6.6 ft) wide remediation corridor.	3.3-6.1 [11-20]	Deep RTD ROM assumes excavation and removal from 0-6.1 [0-20], including removal of clean soil interval from 0-3.3 [0-11], removal of pipe structure to 5.5 [18], and removal of contaminated interval from 3.3-6.1 [11-20].
116-C-1	Site from Table B-1 with Deep Contamination Requiring Deep Excavation Restriction IC in Addition to Other Action(s)	11,116 [119,652]	2485	Area for RTD: CVP DZ footprint	6-12 [19.7-39.4] (overlain by clean fill material). Assume 12.8 [42] total depth for RTD	Assume 12.8 [42] total depth for RTD based on groundwater depth

Table B-2. Estimated Area and Depth of Contamination for Deep Waste Sites Carried Forward into the Feasibility Study - Identified for Excavation Restriction ICs

Site	FS Category	Area of Contamination (m^2 [ft^2])	Date when Radionuclide COC Concentration Declines to PRG (e.g., ELCR < 10^{-4})	Basis/Comment	Depth Range of Contamination (m [ft])	Basis/Comment
118-B-**1**	Site from Table B-1 with Deep Contamination Requiring Deep Excavation Restriction IC in Addition to Other Action(s)	5,284 [56,876]	2081	Deep "Tritium footprint" conservatively approximated as combined CVP footprints of Areas 1 and 2 based on deep characterization results.	Areas 1 & 2 "Tritium footprint": 5-22.5 [16.4-73.8] (overlain by clean fill material)	Areas 1 & 2 "Tritium footprint" range based on typical floor depth in footprint area, extending to typical groundwater table depth.
118-B-8:4	Site from Table B-1 with Deep Contamination Requiring Deep Excavation Restriction IC in Addition to Other Action(s)	1,200 [12,917]	32021	Deep ROM: Approximately 30×10 m (98×33 ft) corridor to incorporate borings; likely similar deep soil contamination under the FSB, which would add another ~900 m^2 (9,688 ft^2) of footprint. The cost for any excavation to 25 m (82 ft) in this area would be removal of the reactor. Costs provided are for those beyond removal of the reactor and associated remaining components, and assume a ~1,200 m^2 (12,917 ft^2) excavation.	0-25 m [0-82 ft]	RI/FS Chapter 4; Borehole C7847 (shallow) and borehole C8239 (deep)
116-B-6A Crib	Site from Table B-1 with Deep Contamination Requiring Deep Excavation Restriction IC in Addition to Other Action(s)	604 [6,501] (outer area) 200 m^2 [2,153 ft^2] (inner area)	2095	Outer area = CVP excavation area at surface is 604 m^2 [6,501 ft^2]. Inner Area = Excavation floor is 200 m^2 [2,153 ft^2].	0–6.1 [0-20] outer area 4.6–6.1 [15-20] inner area	Estimate assumes contaminated soil volume for deep RTD ROM = outer area to 0-20 ft minus inner area 0-15 ft = (6,501 ft^2 * 20 ft) – (2,153 ft *15 ft) / 27 cy/ft =3,619 cy
116-B-16 Storage Tank	Site from Table B-1 with Deep Contamination Requiring Deep Excavation Restriction IC in Addition to Other Action(s)	Included with 116-B-6A	Included with 116-B-6A	Included with 116-B-6A	Included with 116-B-6A	Included with 116-B-6A
100-B-5	Deep excavation restrictions only	1,276 [13,735]	2083	CVP DZ footprint	6.5-18 [21.5-59.5] (overlain by clean fill material)	Upper boundary based on generic average (DZ was a V-trench ranging 4.6 - 8.5 m deep). Lower boundary based on Sr-90 data for RI borehole nominally above PRG.
100-B-8:1	Deep excavation restrictions only	3,300 [35,521]	2055	Based on 1/3 of CVP DZ footprint area considering significantly elevated Cs-137 limited to 2/9 sample areas. Note that area is generally the bottom portion of a typical pipe remediation with a long/narrow-type footprint.	6.5-7.5 [21.5-24.8] (overlain by clean fill material)	Upper boundary based on average elevation in area of elevated Cs-137. Assumed 1 additional m of underlying material based on relative magnitude of risk exceedance.
100-B-8:2	Deep excavation restrictions only	18,335 [197,356]	2065	CVP DZ footprint	5-7.5 [16.5-24.8] (overlain by clean fill material)	Upper boundary based on typical DZ depth for the area. Lower boundary based on typical maximum depth in area plus 1 additional m of underlying material.
100-B-14:1	Deep excavation restrictions only	2,000 [21,528]	12,110	Assumed 1/4 of DZ RSVP footprint. Affected overburden is documented as having been backfilled to the DZ, but is not explicit on exact placement. Based on the volume of affected material and stockpile location, use of 1/4 of the DZ footprint is reasonably bounding. Note that area represents the bottom portion of a typical pipe remediation trench with a long/narrow-type footprint.	4.6-7.6 [15.2-25.1] (overlain by clean fill material)	Deep zone range for the 100-B-14:1 remediation.

Table B-2. Estimated Area and Depth of Contamination for Deep Waste Sites Carried Forward into the Feasibility Study - Identified for Excavation Restriction ICs

Site	FS Category	Area of Contamination (m^2 [ft^2])	Date when Radionuclide COC Concentration Declines to PRG (e.g., ELCR < 10^{-4})	Basis/Comment	Depth Range of Contamination (m [ft])	Basis/Comment
100-B-21:4	Deep excavation restrictions only	1,000 [10,764]	2112	1/3 of RSVP footprint based on relative portion of excavation below 4.6 m (15 ft). Note that area represents the bottom portion of a typical pipe remediation trench with a long/narrow-type footprint.	4.6-8.6 [15-28.4] (overlain by clean fill material)	Upper boundary based on the top of the DZ for potential overburden backfill. Lower boundary based on maximum excavation depth plus an additional 1 m (3 ft).
100-C-6:1	Deep excavation restrictions only	Included with 100-B-8:1	Included with 100-B-8:1	Included with 100-B-8:1	Included with 100-B-8:1	Included with 100-B-8:1
100-C-6:2	Deep excavation restrictions only	Included with 100-B-8:2	Included with 100-B-8:2	Included with 100-B-8:2	Included with 100-B-8:2	Included with 100-B-8:2
100-C-6:3	Deep excavation restrictions only	Included with 100-B-8:2	Included with 100-B-8:2	Included with 100-B-8:2	Included with 100-B-8:2	Included with 100-B-8:2
100-C-6:4	Deep excavation restrictions only	Included with 100-B-8:2	Included with 100-B-8:2	Included with 100-B-8:2	Included with 100-B-8:2	Included with 100-B-8:2
116-B-1	Deep excavation restrictions only	1,863 [20,053]	2112	CVP DZ footprint	4.6-9 [15-29.8] (overlain by clean fill material)	Upper boundary based on depth of previous remediation. Lower boundary based on results in the LFI borehole.
116-B-2	Deep excavation restrictions only	459 [49,41]	2112	CVP DZ footprint	4.9-5.9 [16.2-19.5] (overlain by clean fill material)	Upper boundary based on depth of remediation. Lower boundary based on an assumed additional 1 m (3 ft) beyond previous depth due to low mobility of radionuclide risk drivers. LFI data do not show significant contamination at greater depths.
116-B-3	Deep excavation restrictions only	28 [301]	2075	CVP DZ footprint	4.6-5.6 [15-18.5] (overlain by clean fill material)	Upper boundary based on depth of remediation. Lower boundary based on an assumed additional 1 m (3 ft) beyond previous depth due to low mobility of radionuclide risk drivers. LFI data do not show significant contamination at greater depths.
116-B-4	Deep excavation restrictions only	600 [6,458]	2152	Footprint reported for the demonstration project area in site CVP. Elevated residual radionuclide concentrations are limited to samples from this area.	5.5-6.5 [18.2-21.5] (overlain by clean fill material)	Upper boundary based on reported depth of remediation for the demonstration project remediation. Lower boundary based on the assumed additional 1 m (3 ft) of removal due to low mobility associated with radionuclide risk drivers.
116-B-11	Deep excavation restrictions only	14,563 [156,755]	2247	CVP DZ footprint	5-6 [16.5-19.8] (overlain by clean fill material)	Upper boundary based on previous depth of remediation. Lower boundary based on an assumed additional 1 m (3 ft) beyond previous depth due to low mobility of radionuclide risk drivers.
116-B-14	Deep excavation restrictions only	132 [1,421]	2030	CVP DZ footprint	5.5-6.5 [18.2-21.5] (overlain by clean fill material)	Upper boundary based on previous depth of remediation. Lower boundary based on an assumed additional 1 m (3 ft) beyond previous depth due to low mobility of radionuclide risk drivers.
116-C-2A	Deep excavation restrictions only	908 [9,774]	2228	CVP DZ footprint	4.6-9 [15-29.7] (overlain by clean fill material)	Target material is backfilled overburden placed in the DZ. Upper boundary based on top of DZ; lower boundary based on maximum depth of excavation.
116-C-2B	Deep excavation restrictions only	Included with 116-C-2A		Included with 116-C-2A	Included with 116-C-2A	Included with 116-C-2A
116-C-2C	Deep excavation restrictions only	Included with 116-C-2A		Included with 116-C-2A	Included with 116-C-2A	Included with 116-C-2A

Table B-2. Estimated Area and Depth of Contamination for Deep Waste Sites Carried Forward into the Feasibility Study - Identified for Excavation Restriction ICs

Site	FS Category	Area of Contamination (m^2 [ft^2])	Date when Radionuclide COC Concentration Declines to PRG (e.g., ELCR < 10^{-4})	Basis/Comment	Depth Range of Contamination (m [ft])	Basis/Comment
116-C-3	Deep excavation restrictions only	25 [269]	2109	Footprint area associated with western third of northern tank footprint and adjacent area (where elevated result occurred)	7.3-8.3 [24.1-27.4] (overlain by clean fill material)	Upper boundary based on depth of remediation beneath northern tank. Lower boundary based on an assumed additional 1 m (3 ft) beyond previous depth due to low mobility and magnitude of radionuclide risk drivers.
116-C-5	Deep excavation restrictions only	25,695 [276,579]	2137	CVP DZ footprint	4.6-5.6 [15-18.5] (overlain by clean fill material)	Upper boundary based on previous depth of remediation. Lower boundary based on an assumed additional 1 m (3 ft) beyond previous depth due to low mobility of radionuclide risk drivers. Lower boundary bounds depth of previous LFI.
118-B-6	Deep excavation restrictions only	55 [592]	2042	CVP DZ footprint	6-16 [19.8-52.8] (overlain by clean fill material)	Upper boundary based on previous depth of remediation. Lower boundary based on extent of tritium above the HH PRG in the RI borehole.
118-C-1	Deep excavation restrictions only	2,678 [28,826]	8698	One half of CVP footprint area for Sample Areas 1 and 2 (burial trench footprints). Uncertainty as to exact location of backfill of material with elevated C-14; used 50% of footprint area as a conservative bounding estimate for the portion of these sample areas within the DZ.	4.6-5 [15-16.5] (overlain by clean fill material)	Target material is backfilled overburden. Upper boundary based on top of DZ; lower boundary based on maximum depth of excavation.
118-C-3:2	Deep excavation restrictions only	2,475 [26,641]	2254	Based on 55×45 m (180×148 ft) footprint for FSB and surrounding area.	4.6-8 [15-26.4] (overlain by clean fill material)	Depth of remaining FSB structure plus nominal additional underlying soil removal. Contaminated structural FSB elements remain within the cited depth range.

C-14 = carbon-14
COC = contaminant of concern
Cs-137 = cesium-137
CVP = cleanup verification package
DZ = deep zone
ELCR = estimated lifetime cancer risk
FSB = fuel storage basin
HH = human health
IC = institutional control
LFI = limited field investigation
PRG = preliminary remediation goal
RI = remedial investigation
ROM = rough order of magnitude
RSVP = remaining sites verification package
RTD = removal, treatment (as required), and disposal
Sr-90 = strontium-90

Table B-3. Estimated Area and Depth of Contamination at Source Areas Identified for In Situ Treatment

Site		Area of Contamination (m^2 [ft^2])	Basis/Comment	Depth Range of Contamination (m [ft])	Basis/Comment	Number of Injection Points	Basis/Comment	Approach	References
Sr-90 In Situ Stabilization									
Target Area 1	116-C-1 Trench	1,025 [11,025]	Area for Apatite Injection is the assumed location of maximum contamination near trench inlet at west end of trench	Top of contamination: 4.6 [15] (overlain by clean fill material). Bottom of contamination / bottom of PRZ: 12.8 [42]	Upper boundary of contamination based on typical depth of previous remediation; lower boundary based on known extent of elevated Sr-90 and depth to groundwater reported in CVP.	306	Assumes maximum injection radial distance will be 2 m (6 ft) from the injection nozzle.	Boreholes will be installed with a hydraulic drill rig having jet grout injection capabilities. Approximately 2,000 L (528 gal) of phosphate and pre-formed apatite injected per borehole.	WSRF-98-012/CVP-98-00006, SGW-47062.
Target Area 2	Area overlying Sr-90 plume	24,400 [259,410]	Area for apatite Injection is an assume source area based on current CSM for Sr-90	Top of contamination: 4.6 [15] (overlain by clean fill material). Bottom of contamination / bottom of PRZ: 12.8 [42]	Upper boundary of contamination based on typical depth of previous remediation; lower boundary based on CSM for Sr-90 and estimated depth to bottom of PRZ.	7205	Assumes maximum injection radial distance will be 2 m (6 ft) from the injection nozzle.	Boreholes will be installed with a hydraulic drill rig having jet grout injection capabilities. Approximately 2,000 L (528 gal) of phosphate and pre-formed apatite injected per borehole.	
Cr(VI) In Situ Reduction									
CSM PRZ Source	Area overlying Cr(VI) plume near previously remediated waste site 116-B-11	5,200 [59,201]	Area for in situ reduction is an assumed source area based on current CSM for Cr(VI)	Top of contamination: 9 [29.5] (overlain by clean fill material). Bottom of contamination / bottom of PRZ: 12.5 [41]	Upper boundary of contamination based on typical depth of top of PRZ; lower boundary based on CSM for Sr-90 and estimated depth to bottom of PRZ.	24	Assumes radius of injection well influence = 7.6 m [25 ft].	Assumes injections of calcium polysulfide solution through temporary borings. Total Injection volume = 57,700 L (15,240 gal)	

References: SGW-47062, 2010, *Treatability Test Report for Field-Scale Apatite Jet Injection Demonstration for the 100-NR-2 Operable Unit*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/pdf.cfm?accession=1009270920.

WSRF-98-012/CVP-98-00006, 1999, *Cleanup Verification Package for the 116-C-1 Process Effluent Trench*, Rev. 0, Bechtel Hanford, Inc., Richland, Washington. Available at: https://pdw.hanford.gov/arpir/pdf.cfm?accession=D199128695.

Cr(VI) = hexavalent chromium
CSM = conceptual site model
CVP = cleanup verification package
PRZ = periodically rewetted zone
Sr-90 = strontium-90

Table B-4. Estimated Quantities for Groundwater Remedial Action Components

	Alternate 2		Total	Alternate 3		Total	Alternate 4		Total	Alternate 5		Total	Alternate 6		Total	Alternate 7		Total
	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info
Monitored Natural Attenuation																		
Total Remedy Duration (years) [includes post-remedy compliance assumed to be 5 years]		years	75		years	75		years	75		years	75		years	75		years	75
# of Wells (First Year)	32	6	38	32	6	38	32	6	38	32	6	38	32	6	38	32	6	38
Samples/Event (First Year) (Lab analysis for Cr(VI), Sr-90, and VOCs)	32	24	56	32	24	56	32	24	56	32	24	56	32	24	56	32	24	56
Samples/Event for Years 2-5 (4 years total)-annual sampling of 38 wells (lab analysis for Cr(VI), Sr-90, and VOCs)	32	6	152	32	6	152	32	6	152	32	6	152	32	6	152	32	6	152
Samples/Event for Years 6-10 Years (5 years total)-annual sampling of 42 wells (lab analysis for Cr(VI), Sr-90, and VOCs). Four new wells installed year 5.	32	10	210	32	10	210	32	10	210	32	10	210	32	10	210	32	10	210
Samples/Event (Out Years) [Years 11-25] 15 years (sampling 20 wells every 2 years) (Lab analysis for VOCs)	15	5	150	15	5	150	15	5	150	15	5	150	15	5	150	15	5	150
Samples/Event (Out Years) [Years 11-15] 5 years (sampling 20 wells every 2 years) (Lab analysis for Cr(VI))										15	5	50	15	5	50	15	5	50
Samples/Event (Out Years) [Years 11-40] 30 years (sampling 20 wells every 2 years) (Lab analysis for Cr(VI))				15	5	300	15	5	300									
Samples/Event (Out Years) Years 11-60 (50 years total) - sampling 20 wells every 2 years with Lab analysis for Cr(VI)	15	5	500															
Samples/Event (Out Years) Years 11-70 (60 years total) - sampling 20 wells every 2 years with Lab analysis for Sr-90.	15	5	600	15	5	600	15	5	600	15	5	600	15	5	600	15	5	600
Samples/Event Years 1-5 (5 years total) compliance sampling semiannually with Lab analysis for tritium	32	6	380	32	6	380	32	6	380	32	6	380	32	6	380	32	6	380
Samples/Event (Out Years) [Years 26-30] 5 years post-remedy -sampled semiannually (lab analysis for VOCs)	32	10	420	32	10	420	32	10	420	32	10	420	32	10	420	32	10	420
Samples/Event (Out Years) [Years 16-20] 5 years post-remedy -sampled semiannually (lab analysis for Cr(VI))										32	10	420	32	10	420	32	10	420
Samples/Event (Out Years) [Years 61-65] 5 years post-remedy -sampled semiannually (lab analysis for Cr(VI))	32	10	420															
Samples/Event (Out Years) [Years 41-45] 5 years post-remedy -sampled semiannually (lab analysis for Cr(VI))				32	10	420	32	10	420									
Samples/Event (Out Years) [Years 71-75] 5 years post-remedy -sampled semiannually (lab analysis for Sr-90)	32	10	420	32	10	420	32	10	420	32	10	420	32	10	420	32	10	420
New GW Monitoring Wells																		
Phase I (MW) **New**	6	100		6	100		6	100		6	100		6	100		6	100	
Year 5, Phase II Shallow well depth (ft) **new**	4	100		4	100		4	100		4	100		4	100		4	100	
Total drilling (LF)		1000			1000			1,000			1000			1000			1000	

Table B-4. Estimated Quantities for Groundwater Remedial Action Components

	Alternate 2		Total	Alternate 3		Total	Alternate 4		Total	Alternate 5		Total	Alternate 6		Total	Alternate 7		Total
	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info
Groundwater Extraction																		
Number of Wells	0	0		0	6		0	6		0	7		0	7		0	7	
Flow rate per well (average) (gal/min)	0	0		0	67		0	67			57			57			57	
Assumed deep well depth (ft)	0	0			200			200			200			200			200	
Assumed shallow well depth (ft)					100			100			100			100			100	
Drilling footage	0	0			800			800			900			900			900	
Type of Submersible Pump	0	0			4-in., 56-95 gal/min, 101 ft < Head <=220 ft, w/ controls			4 in., 56-95 gal/min, 101 ft < Head <=220 ft, w/ controls			4 in., 56-95 gal/min, 101 ft< Head <=220 ft, w/ controls			4 in., 56-95 gal/min, 101 ft < Head <=220 ft, w/ controls			4 in., 56-95 gal/min, 101 ft < Head <=220 ft, w/ controls	
Casing Diameter, in.					8			8			8			8			8	
3 in. HDPE Transfer Piping, ft (from wells to Transfer Station)					5,000			5,000			5,000			5,000			5,000	
8-in. HDPE Transfer Piping, ft (from Transfer Station to 100-K)					10,000			10,000			10,000			10,000			10,000	
Transfer Station - Outbound																		
Influent Pumping Stations (New)					1			1			1			1			1	
Influent Pumping Station Flow, ea					400			400			400			400			400	
Influent collection tanks					1			1			1			1			1	
Tank Capacity Each, gal					10,000			10,000			10,000			10,000			10,000	
Groundwater Treatment																		
Treatment Building (use existing KW Bldg)				1	0		1	0		1	0		1	0		1	0	
Process Control System (use existing with 50% allowance for refurbishment)				0.5	0		0.5	0		0.5	0		0.5	0		0.5	0	
Influent Tank (use existing)				0	0		0	0		0	0		0	0		0	0	
pH Adjustment (use existing with 50% allowance for refurbishment)				0.5	0		0.5	0		0.5	0		0.5	0		0.5	0	
IX Vessel Feed Pumps (1 primary + 1 backup)				0	4		0	4		0	4		0	4		0	4	
IX Vessels (2 Parallel Trains - 200 gal/min/train)				0	4		0	4		0	4		0	4		0	4	
Effluent Tank (use existing)				1	0		1	0		1	0		1	0		1	0	
Groundwater Injection																		
Number of Injection Wells	0	0		0	4		0	4		0	4		0	4		0	4	
Injection Rate per Well, gal/min	0	0			100			100			100			100			100	
Assumed well depth, ft	0	0			200			200			200			200			200	
Well Casing Diameter, in.					8			8			8			8			8	

Table B-4. Estimated Quantities for Groundwater Remedial Action Components

	Alternate 2		Total	Alternate 3		Total	Alternate 4		Total	Alternate 5		Total	Alternate 6		Total	Alternate 7		Total
	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info	Existing	New	or Info
4 in. HDPE Transfer Piping, ft (from Transfer Station to wells)					4,000			4,000			4,000			4,000			4,000	
8 in. HDPE Transfer Piping, ft (from 100-K to 100-BC Transfer Station)					10,000			10,000			10,000			10,000			10,000	
Transfer Station - Return																		
Effluent Pumping Stations (New), ea					1			1			1			1			1	
Effluent Pumping Station Flow, gal/min					400			400			400			400			400	
Feed Tank(s)					1			1			1			1			1	
Tank Capacity Each, gal					10,000			10,000			10,000			10,000			10,000	
Well and Pump O&M Schedule																		
Extraction Well Pump Replacement, yr					5			5			5			5			5	
Extraction Well Rehab, yr					5			5			5			5			5	
Extraction Well Replacement, yr					25			25			25			25			25	
Injection Well Rehab, yr					2			2			2			2			2	
Injection Well Replacement, yr					15			15			15			15			15	
Monitoring Well Pump Replacement, yr		10			10			10			10			10			10	
Monitoring Well Rehab, yr		10			10			10			10			10			10	
Monitoring Well Replacement, yrs		25			25			25			25			25			25	
Treatment Systems																		
Active P&T Monitoring - years																		
During 1st yr P&T Monitoring - samples/yr per well					4			4			4			4			4	
After 1st yr P&T Monitoring - samples/yr per well					2			2			2			2			2	
Post P&T Monitoring Verification - yr					0			0			0			0			0	
Post P&T Monitoring Verification - samples/yr per well					0			0			0			0			0	
Treatment systems annual online fraction					0.85			0.85			0.85			0.85			0.85	
Process peak design capacity factor					1.2			1.2			1.2			1.2			1.2	
Feet per meter					3.2808			3.2808			3.2808			3.2808			3.2808	
P&T System Refurbishment						25 yrs			25 yrs			15 yr			15 yr			15 yr
New Transfer Station					1 new			1 new			0			0			0	
Refurbish after 25 years					1 refurbish			1 refurbish			N/A			N/A			N/A	
New pipe line, from Transfer Station to K P&T					NA			NA			0			0			0	

Note: Color in table is to distinguish one alternative from another.

N/A = not applicable
Sr-90 = strontium-90
Cr(VI) = hexavalent chromium
P&T = pump and treat
VOC = volatile organic compound
HDPE = high density polyethylene
IX = ion exchange

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