0083994

DOE/ORP-2005-01

INITIAL SINGLE-SHELL TANK SYSTEM PERFORMANCE ASSESSMENT FOR THE HANFORD SITE

DATA PACKAGE

SECTION

3 OF 4

Table 4-18 Contaminants Unique to Tank C-106 Post-Retrieval Sample Results

Bromide	2-Nitropropane	Isobutanol
1, 1, 1-Trichloroethane	2-Propanone (acetone)	m-Cresol (3-Methylphenol)
1, 1, 2, 2-Tetrachloroethane	4-Methyl-2-pentanone (MIBK)	Nitrobenzene
1, 1, 2-Trichloro-1, 2, 2-trifluoroethane	Benzene	N-nitroso-di-n-propylamine
1, 1, 2-Trichloroethane	Carbon disulfide	o-Dichlorobenzene
1, 1, 2-Trichloroethylene	Carbon tetrachloride	o-Nitrophenol
1-1-Dichloroethene	Chlorobenzene	o-Xylene
1, 2-Dichloroethane	Chloroethene(vinyl chloride)	p-Chloro-m-cresol (4-Chloro-3-methylphenol)
1, 4-Dichlorobenzene	Chloroform	Pentachlorophenol
2, 4, 5-Trichlorophenol	Cresylic acid (cresol, mixed isomers)	Phenol
2, 4, 6-Trichlorophenol	Cyclohexanone	Pyridine
2, 4-Dinitrotoluene	Dichloromethane (methylene chloride)	Tetrachloroethylene
2-Butanone (MEK)	Diethyl ether	Toluene
2-Chlorophenol	Ethyl Acetate	trans-1, 3-dichloropropene
2-Ethoxyethanol	Ethylbenzene	Trichlorofluoromethane
2-Methylphenol (o-cresol)	Glycolate	Xylenes

Residual waste inventories for WMA C include post-retrieval analytical sample results for tank C-106 (included in tank row C-103). Tank C-106 was the first tank to undergo retrieval in WMA C and post-retrieval samples were collected from the residual waste. C-106 analytical results were taken from the TWINS database (TWINS 2005) and incorporated into this SST PA. These results included several constituents not considered in HTWOS modeling, most notably organic compounds. Consequently, 53 constituents not included in the HTWOS model estimates have residual inventories estimated for tank C-106 based on post-retrieval analytical sample results. Inventories for these constituents are not included in the HTWOS model estimates for residual wastes in the other WMA C tanks.

For fate and transport calculations, the additional constituents were assigned K_d values based on the best available reported values, typically derived from published organic carbon partition coefficients (K_{oc}). For most of these constituents, little information exists on how they interact with Hanford Site soils. These constituents were conservatively modeled with infinite environmental half-lives. Of the 53 additional constituents analyzed in tank C-106, the contaminants that reached the fenceline in concentrations less than effective zero are listed in Table 4-18. Of the 48 contaminants listed in Table 4-18, only glycolate is predicted to reach the fenceline in concentrations above effective zero (1×10^{-5} mg/L) for the residual waste component. Glycolate is estimated to have a peak concentration of 1.20×10^{-4} mg/L in year 10481. (Acetate, formate, tellurium, and tungsten are projected to have fenceline concentrations above effective zero because of tank C-106 residual inventory.) In other WMAs, the HTWOS calculated inventory for these four contaminants resulted in fenceline concentrations that were effectively zero for the 10,000-year simulation period. As waste from additional tanks is

retrieved, residual waste inventories for each tank will be updated with analytical results from post-retrieval samples.

Table 4-19 lists the contaminants with fenceline concentrations above the effective zero; the dominant source term and the tank row inventory that contributes to the peak concentration estimate are also indicated in the table.

Table 4-19. Estimated Concentrations of Contaminants from All Waste Components Appearing at the Waste Management Area C Fenceline

Radionuclides [a]				
Analyte Name	**Peak Concentration pCi/L**	**Dominant Source Term**	**Peak Year**	**Row with Peak Concentration**
Tritium	2.41E+02	Past releases	2044	C-102
Carbon-14	4.27E+01	Past releases	2051	C-102
Technetium-99	5.65E+02	Past releases	2051	C-102
Iodine-129	3.09E-02	Past releases	9621	C-102
Nonradionuclides [b]				
Analyte Name	**Peak Concentration mg/L**	**Dominant Source Term**	**Peak Year**	**Row with Peak Concentration**
Acetate	1.45E-04	Tank residuals	10481	C-103
Ammonia	5.38E-03	Past releases	2051	C-101
Bismuth	2.31E-03	Tank residuals	10481	C-101
Cerium	5.35E-05	Tank residuals	10481	C-101
Chloride	5.12E-02	Past releases	2051	C-101
Chromium	1.35E-02	Past releases	2051	C-102
Fluoride	8.37E-03	Past releases	2051	C-101
Formate	1.45E-04	Tank residuals	10481	C-103
Hydroxide	4.21E-02	Tank residuals	10481	C-102
Lanthanum	2.13E-05	Tank residuals	10481	C-102
n-Butyl alcohol	2.24E-03	Past releases	2051	C-101
Neodymium	4.91E-05	Tank residuals	10481	C-103
Nitrate	2.71E+00	Past releases	2051	C-101
Nitrite	1.02E+00	Past releases	2051	C-102
Oxalate	1.64E-03	Tank residuals	10481	C-103
Phosphate	1.01E-01	Past releases	2051	C-101
Praseodymium	2.23E-05	Tank residuals	10481	C-103
Rhodium	1.13E-05	Tank residuals	10481	C-103
Sodium	2.37E+00	Past releases	2051	C-102
Sulfate	1.95E-01	Past releases	2051	C-101
Tellurium	1.21E-05	Tank residuals	10481	C-103
Tungsten	2.34E-05	Tank residuals	10481	C-101

[a] The following radionuclides reached the fenceline during the modeling period, but had concentrations below the effective zero (1.0E-02 pCi/L): cobalt-60, tin-126, samarium-151, radium-226 + D, uranium-232, uranium-233, uranium-234, uranium-235 + D, uranium-236, and uranium-238 + D.

[b] The following nonradionuclides reached the fenceline during the modeling period, but had concentrations below the effective zero defined in (1.0E-05 mg/L): aluminum, cobalt, manganese, rubidium, sulfide, tantalum, uranium, and yttrium.

4.7.3 Results for Waste Management Area C Waste Components

For the indicator contaminants described in Section 4.2.1, the past releases component is the primary contributing source to fenceline concentrations in WMA C. The past releases component consists of both SST leaks and UPRs. Modeling of both source terms was the same except for the initial depth assignment (130 ft bgs for SST past leaks in the 200 East Area, 150 ft bgs for SST past leaks in the 200 West Area, and 30 ft bgs for UPRs). There are eight total SST past leaks in the WMA, with at least one past leak in each row except tank rows C-103 and CR vault. There are four UPRs in the WMA (Field and Jones 2005), one occurring in tank row C-101 and the other three grouped in tank row CR vault. Except for nitrate, tank row C-102 is predicted to result in the highest fenceline peak concentrations for all of the mobile and semi-mobile indicator contaminants considered in this section. The estimated peak nitrate concentration is associated with tank row C-101, resulting from a slightly higher nitrate inventory associated with past tank leaks from tanks C-101 and C-110 compared to the past leak inventory for row C-102. Uranium is not projected to occur at the fenceline above the effective zero concentration.

Semi-mobile and non-mobile contaminants from tank residuals are not projected to reach the fenceline in the 10,000-year simulation time frame, using retrieval volume and inventory estimates provided by Kirkbride et al. (2005). Different rows in the WMA contribute peak fenceline concentrations from tank residuals for the mobile indicator contaminants considered in this chapter.

Table 4-20 shows peak fenceline concentrations for radionuclides by row, and Table 4-21 shows peak fenceline concentrations for nonradionuclides by row. Both tables show concentrations from past releases and tank residuals source terms relative to the peak contributing tank row. Since ancillary equipment residuals are modeled as tank residuals, the tank residuals portion of the tables include ancillary equipment that reside within a tank row. Although the peak concentrations from different source components occur at different times, Tables 4-20 and 4-21 show that, for any given contaminant, the peak concentration resulting from past releases is between two and five orders of magnitude greater than that resulting from tank residuals.

Plugged and blocked pipelines do not fall within any one tank row and were therefore evaluated separately. Plugged and blocked pipelines were modeled as a shallow release in the same manner as UPRs (i.e., initial depth of 30 ft bgs). Modeling results indicate that the plugged and blocked pipelines contribute concentrations that are all effectively zero except for nitrate, which exhibits a peak concentration of 8.06×10^{-5} mg/L in year 5711. The overall impact from the pipelines is negligible.

Figures 4-28 through 4-33 illustrate the BTCs for each of the six indicator contaminants discussed in this section. Each plot in the figure is a separate source component, with the bottom plot containing the previous five plots superimposed on each other to show the maximum impact. Blank plots indicate cases where the concentration for a source component does not exceed the effective zero for any tank row over the 10,000-year simulation period. In those cases, the tank row with the greatest inventory is included. Again, a linear scale (y-axis) is used for the individual source component plots, but in order to include the entire range of data, the maximum impact plot is shown using a logarithmic scale. Each plot represents the BTC for the tank row contributing the peak concentration estimate for that source component. Also given in

each of the plots is the time of the peak and the inventory for each of the like source terms in the row. The tank row containing the largest inventory is shown even though the peak concentration falls below the effective zero.

4.7.4 Discussion of Results and Conclusions for Waste Management Area C

Estimated long-term groundwater impacts from three contaminant source components (i.e., past releases inventory, tank residuals inventory, and ancillary equipment residuals inventory) in WMA C were modeled. Except for nitrate and uranium, results indicate that contamination at depth from the past releases in tank row C-102 is the dominant contributor to fenceline concentration for all indicator contaminants in the early part of the simulation period. Past releases from tank row C-101 provide the peak fenceline concentration for nitrate, while uranium is not projected to have a concentration above effective zero during the 10,000-year simulation. Past releases are by far the greatest contributor to projected fenceline contaminant concentrations, typically two to three orders of magnitude greater than residual waste contributions.

Retrieval of tanks to the HFFACO prescribed volume and inventories estimated by Kirkbride et al. (2005) results in an impact from tank residuals that is two to three orders of magnitude below those of past releases. Note that, for the tank residuals and for all indicator contaminants, only the tank row with the maximum impact is shown; the other 100-Series tank rows are usually within a factor of 3 or lower of the row with peak concentration, with tank rows C-201 and CR vault typically being an order of magnitude lower (Tables 4-20 and 4-21). The notable exception is hexavalent chromium, for which tank row C-201 contributes the highest fenceline concentration from tank residuals.

Due to existing vadose zone contamination and the maximum operational recharge occurring during that period, contaminants with high mobility (K_d less than 0.2 mL/g) exhibit concentration peaks that occur early in the simulation and prior to emplacement of the Modified RCRA Subtitle C Barrier. Contaminants with lower mobility (K_d = 0.2 mL/g or greater) exhibit increasing concentrations toward the end of the simulation period, dominated by the contamination at depth source component. Contaminants with low mobility (K_d = 0.6 mL/g) are not projected to have fenceline concentrations above effective zero during the 10,000-year simulation.

Table 4-20. Waste Management Area C Tank Row Peak Radionuclide Concentrations [a]

Technetium-99				
	Past Releases Component, Peak Year: 2051		**Tank Residuals Component, Peak Year: 10461**	
Tank Row	**Peak Concentration pCi/L**	**Concentration Relative to Row C-102**	**Peak Concentration pCi/L**	**Concentration Relative to Row C-103**
C-101	5.02E+02	88.85%	2.47E+00	42.15%
C-102	5.65E+02	100.00%	2.46E+00	41.98%
C-103 [b]	NA	NA	5.86E+00	100%
C-201	7.03E+01	12.44%	1.25E-01	2.13%
CR vault	1.62E+02	28.67%	1.84E-01	3.14%
Iodine-129				
	Past Releases Component, Max. Year: 9621		**Tank Residuals Component, Max. Year: 12032**	
Tank Row	**Peak Concentration pCi/L**	**Concentration Relative to Row C-102**	**Max. Concentration pCi/L [c]**	**Concentration Relative to Row with Peak Concentration**
C-101	0.00E+00	0.00%	0.00E+00	NA
C-102	3.09E-02	100.00%	0.00E+00	NA
C-103	NA	NA	0.00E+00	NA
C-201	0.00E+00	0.00%	0.00E+00	NA
CR vault	0.00E+00	0.00%	0.00E+00	NA

[a] Maximum values are shaded.

[b] Tank row C-103 contains tank residuals from C-301 catch tank.

[c] Iodine-129 concentrations from the tank residuals component were not above effective zero (1.00E-02 pCi/L) for any row in the waste management area.

NA = not applicable

Table 4-21. Waste Management Area C Tank Row Peak Nonradionuclide Concentrations [a]

Hexavalent Chromium				
Tank Row	**Past Releases Component, Peak Year: 2051**		**Tank Residuals Component, Peak Year: 10481**	
	Peak Concentration mg/L	**Concentration Relative to Row C-102**	**Peak Concentration mg/L**	**Concentration Relative to Row C-201**
C-101	6.02E-03	44.59%	1.15E-04	67.25%
C-102	1.35E-02	100.00%	6.77E-05	39.59%
C-103	NA	NA	5.66E-05	33.10%
C-201	5.11E-03	37.85%	1.71E-04	100.00%
CR vault	2.53E-03	18.74%	0.00E+00	NA
Nitrate				
Tank Row	**Past Releases Component, Peak Year: 2051**		**Tank Residuals Component, Peak Year: 10481**	
	Peak Concentration mg/L	**Concentration Relative to Row C-101**	**Peak Concentration mg/L**	**Concentration Relative to Row C-101**
C-101	2.71E+00	100.00%	5.37E-03	100.00%
C-102	2.39E+00	88.19%	2.03E-03	37.80%
C-103	NA	NA	1.88E-03	35.01%
C-201	6.35E-01	23.43%	1.46E-03	27.19%
CR vault	2.02E-01	7.45%	1.82E-04	3.39%
Nitrite				
Tank Row	**Past Releases Component, Peak Year: 2051**		**Tank Residuals Component, Peak Year: 10481**	
	Peak Concentration mg/L	**Concentration Relative to Row C-102**	**Peak Concentration mg/L**	**Concentration Relative to Row C-103**
C-101	1.85E-01	18.14%	1.41E-03	89.91%
C-102	1.02E+00	100.00%	9.50E-04	60.51%
C-103	NA	NA	1.57E-03	100.00%
C-201	1.72E-01	16.86%	3.50E-04	22.29%
CR vault	9.44E-02	9.25%	7.21E-05	4.59%
Uranium				
Uranium concentrations from the past leak and tank residuals components were not above effective zero (1.00E-05 mg/L) for any row in the waste management area.				

[a] Maximum values are shaded.

NA = not applicable

Figure 4-28. Waste Management Area C Technetium-99 Breakthrough Curves by Waste Source Component

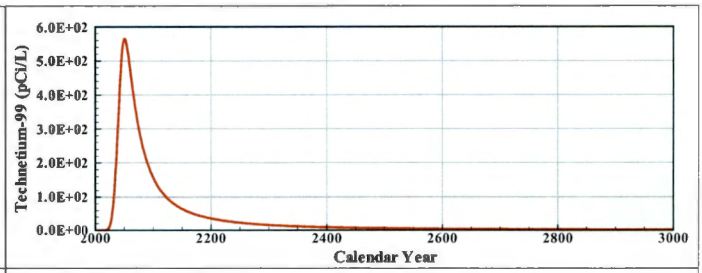
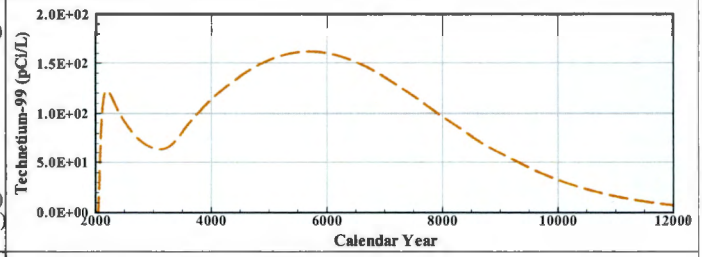
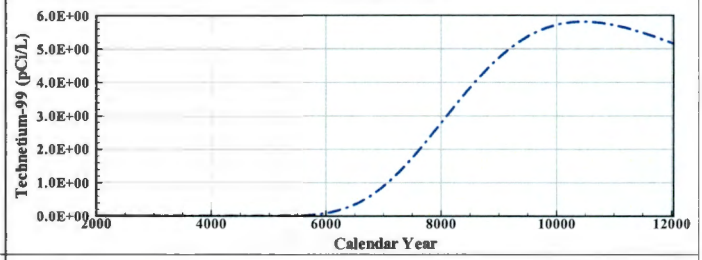
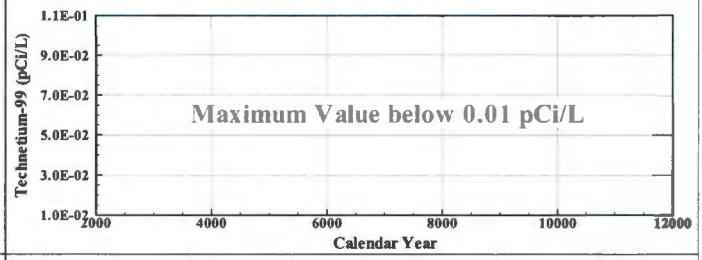
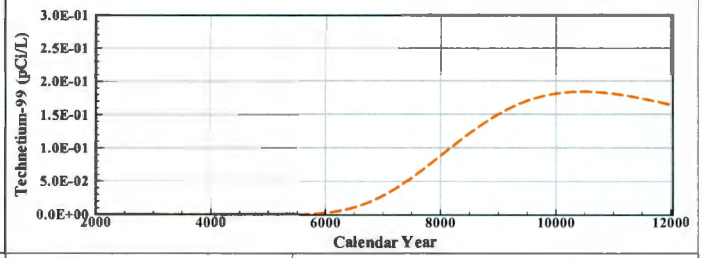
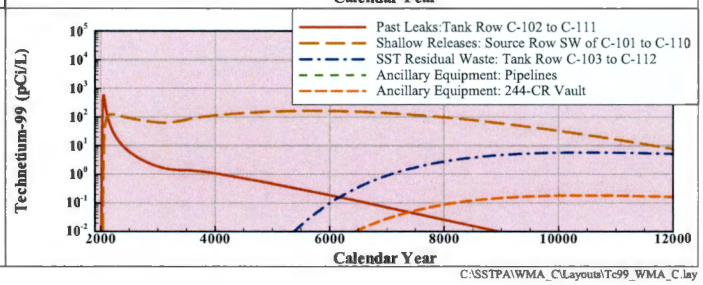
Technetium-99 **K_d = 0.0 mL/g**		
Past Releases	**Past Leaks from Tanks Tank Row C-102 to C-111** ^{99}Tc Inventory (Ci) C-102 = 0.00E+0 C-105 = 2.26E-1 C-108 = 0.00E+0 C-111 = 5.38E-2 Sum = 2.80E-1 Peak = 5.65E+2 pCi/L Occurs in Year 2051	
	UPR Row is ~ 160 ft SW of Tank Row C-101 to C-110 UPR-E-200-E-81 = 2.74E-2 UPR-E-200-E-82 = 1.42E+0 UPR-E-200-E-86 = 4.92E+0 Sum = 6.36E+0 1st Peak = 1.22E+2 pCi/L (2196) 2nd Peak = 1.62E+2 pCi/L (5701)	
Residual Waste	**Tank Residuals Tank Row C-103 to C-112** ^{99}Tc Inventory (Ci) C-103 = 7.17E-2 C-106 = 1.65E-1 C-109 = 4.96E-1 C-112 = 7.23E-1 C-301 = 1.25E-2 SUM = 1.47E+0 Peak = 5.86E+0 pCi/L Occurs in Year 10461	
	Ancillary Equipment Pipeline Residuals ^{99}Tc Inventory (Ci) WMA C Pipelines = 3.58E-5 Maximum < 1.00E-2 pCi/L at End of Simulation	
	Ancillary Equipment MUST ^{99}Tc Inventory (Ci) 244 CR Vault= 4.60E-2 Peak = 1.84E-1 pCi/L Occurs in Year 10461	
Maximum Impact Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.		

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Figure 4-29. Waste Management Area C Iodine-129 Breakthrough Curves by Waste Source Component

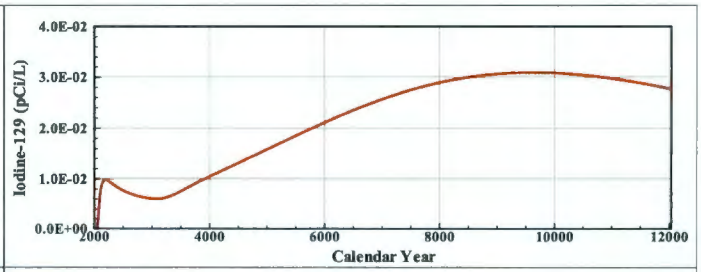
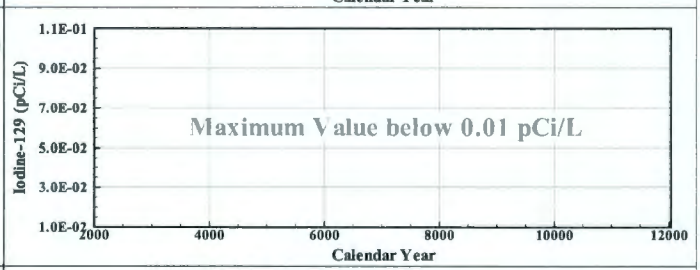
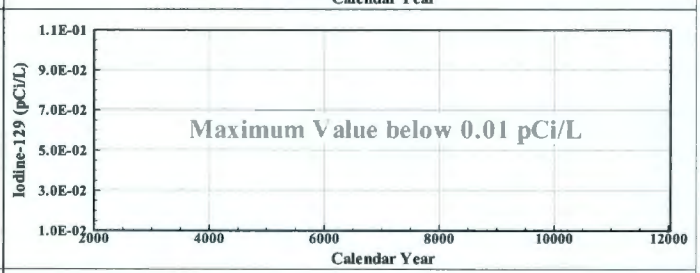
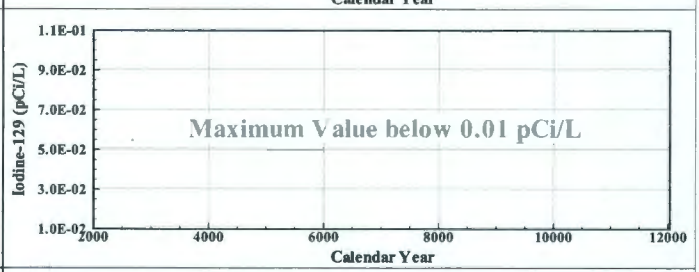
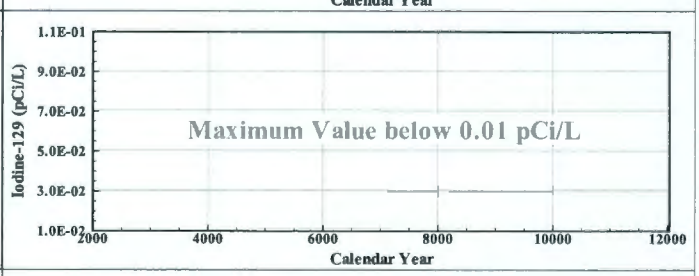
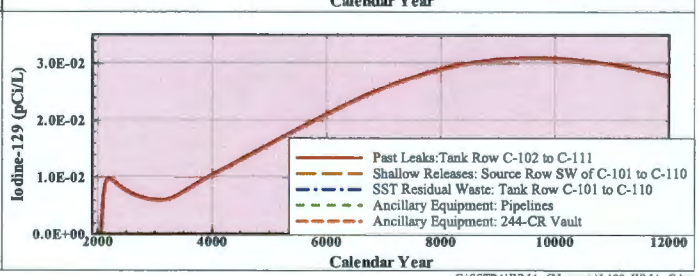
Iodine-129 **K_d = 0.2 mL/g**	**Past Leaks from Tanks Tank Row C-102 to C-111** ^{129}I Inventory (Ci) C-102 = 0.00E+0 C-105 = 8.85E-5 C-107 = 0.00E+0 C-111 = 2.64E-3 Sum = 2.73E-3 Peak = 3.09E-2 pCi/L Occurs in Year 9621	
Past Releases	UPR Row is ~ 160 ft SW of Tank Row C-101 to C-110 UPR-E-200-E-81 = 2.38E-2 UPR-E-200-E-82 = 8.39E-4 UPR-E-200-E-86 = 2.61E-3 Sum = 2.73E-2 Maximum < 1.00E-2 pCi/L at End of Simulation	
Residual Waste	**Tank Residuals SST Tank Row C-101 to C-110** ^{129}I Inventory (Ci) C-101 = 1.68E-3 C-104 = 4.23E-3 C-107 = 2.72E-3 C-110 = 1.18E-6 SUM = 8.64E-3 Maximum < 1.00E-2 pCi/L at End of Simulation	
	Ancillary Equipment Pipeline Residuals ^{129}I Inventory (Ci) WMA C Pipelines = 3.03E-7 Maximum < 1.00E-2 pCi/L at End of Simulation	
	Ancillary Equipment MUST ^{129}I Inventory (Ci) 244 CR Vault= 2.18E-4 Maximum < 1.00E-2 pCi/L at End of Simulation	
Maximum Impact Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.		

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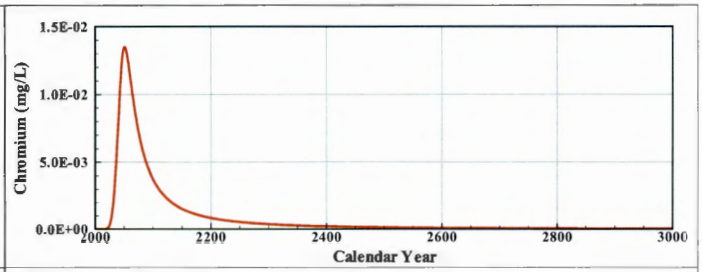
Figure 4-30. Waste Management Area C Hexavalent Chromium Breakthrough Curves by Waste Source Component

Chromium
K_d = 0.0 mL/g

Past Releases

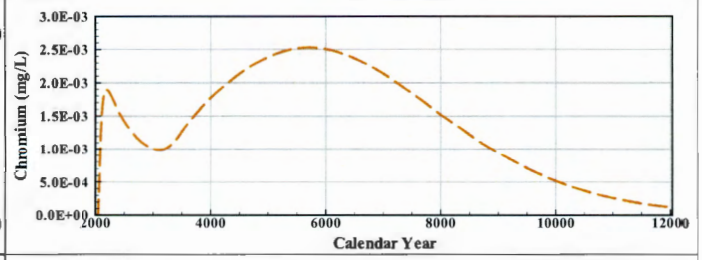
Past Leaks from Tanks
Tank Row
C-102 to C-111
Chromium Inventory (kg)
C-102 = 0.00E+0
C-105 = 1.42E+0
C-108 = 0.00E+0
C-111 = 5.27E+0
Sum = 6.69E+0
Peak = 1.35E-2 mg/L
Occurs in Year 2051



UPR Row is ~ 160 ft SW of Tank Row C-101 to C-110

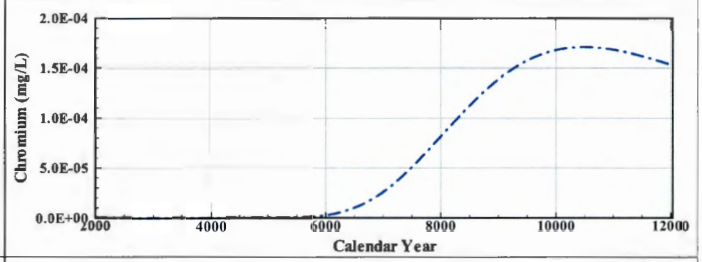
UPR-E-200-E-81 = 2.17E+1
UPR-E-200-E-82 = 1.62E+1
UPR-E-200-E-86 = 6.04E+1
Sum = 9.83E+1

1st Peak = 1.89E-3 mg/L (2196)
2nd Peak = 2.53E-3 mg/L (5711)



Residual Waste

Tank Residuals
SST Tank Row
C-201 to C-204
Chromium Inventory (kg)
C-201 = 8.66E+0
C-202 = 6.32E+0
C-203 = 1.69E+1
C-204 = 9.86E+0
SUM = 4.18E+1
Peak = 1.71E-4 mg/L
Occurs in Year 10481

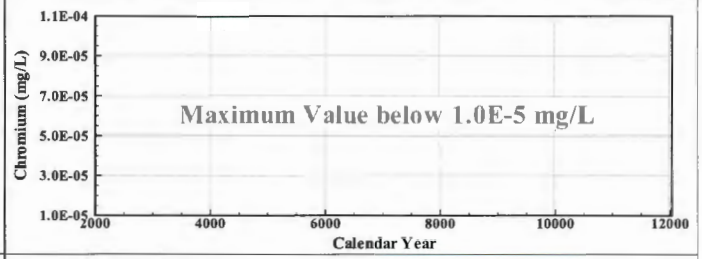


Ancillary Equipment
Pipeline Residuals

Chromium Inventory (kg)

WMA C Pipelines = 1.05E-2

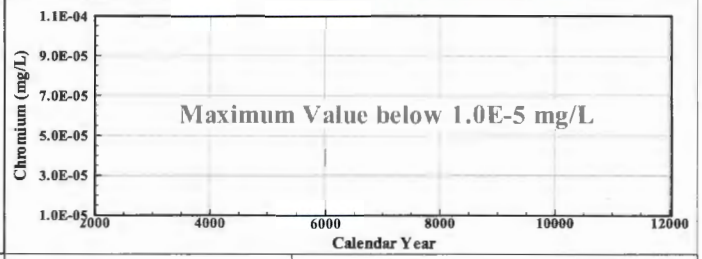
Maximum < 1.00E-5 mg/L
at End of Simulation



Ancillary Equipment
MUST

Chromium Inventory (kg)
244 CR Vault = 1.68E+0

Maximum < 1.00E-5 mg/L
at End of Simulation



Maximum Impact

Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.

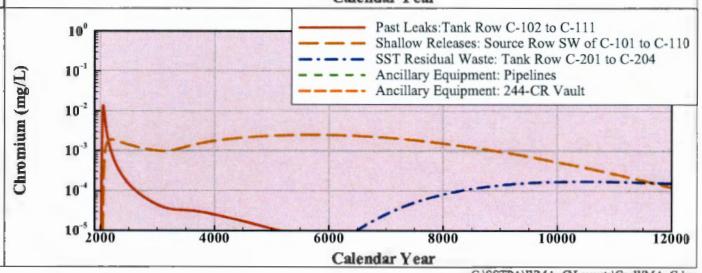


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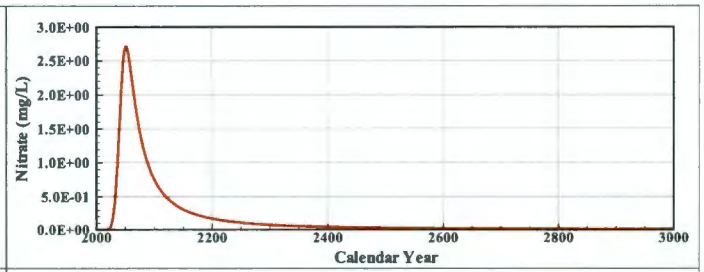
Figure 4-31. Waste Management Area C Nitrate Breakthrough Curves by Waste Source Component

Nitrate
K_d = 0.0 mL/g

Past Releases

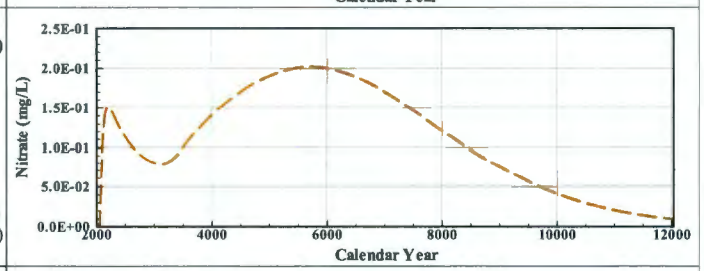
Past Leaks from Tanks
Tank Row
C-101 to C-110
Nitrate Inventory (kg)
C-101 = 5.03E+1
C-104 = 0.00E+0
C-107 = 0.00E+0
C-110 = 1.30E+3
Sum = 1.35E+3
Peak = 2.71E+0 mg/L
Occurs in Year 2051



UPR Row is ~ 160 ft SW of Tank Row C-101 to C-110

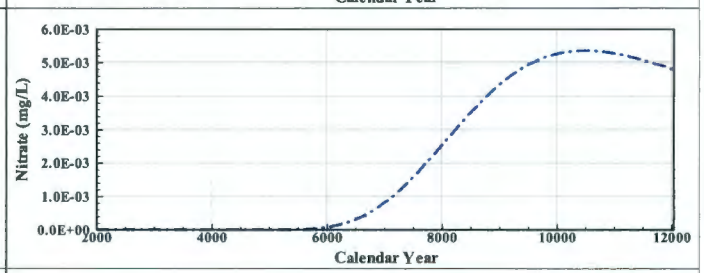
UPR-E-200-E-81 = 5.81E+3
UPR-E-200-E-82 = 7.64E+2
UPR-E-200-E-86 = 1.27E+3
Sum = 7.84E+3

1st Peak = 1.51E-1 mg/L (2196)
2nd Peak = 2.02E-1 mg/L (5711)



Residual Waste

Tank Residuals
SST Tank Row
C-101 to C-110
Nitrate Inventory (kg)
C-101 = 3.37E+2
C-104 = 7.40E+1
C-107 = 3.34E+2
C-110 = 5.62E+2
SUM = 1.31E+3
Peak = 5.37E-3 mg/L
Occurs in Year 10481

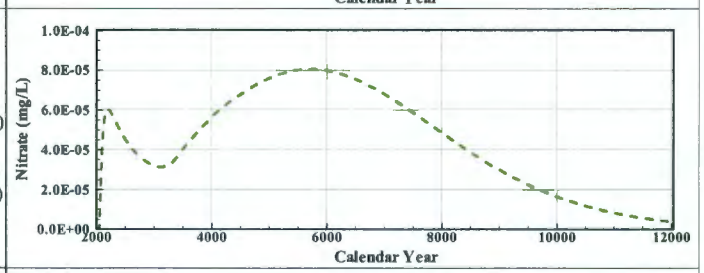


Ancillary Equipment
Pipeline Residuals

Nitrate Inventory (kg)

WMA C Pipelines = 3.13E+0

1st Peak = 6.00E-5 mg/L (2196)
2nd Peak = 8.06E-5 mg/L (5711)

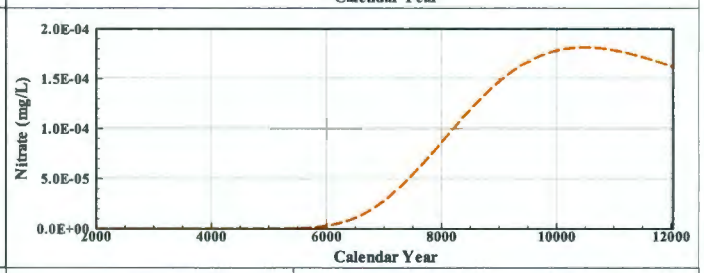


Ancillary Equipment
MUST

Nitrate Inventory (kg)

244 CR Vault= 4.42E+1

Peak = 1.82E-4 mg/L
Occurs in Year 10481



Maximum Impact

Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.

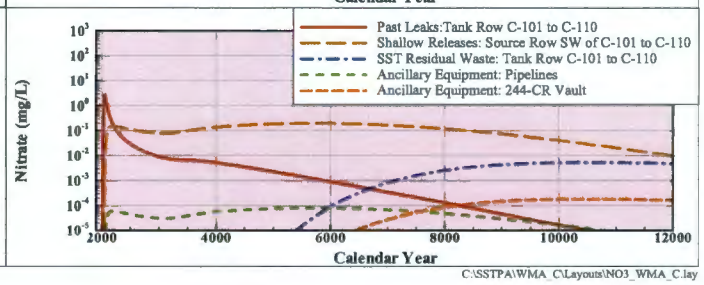


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Figure 4-32. Waste Management Area C Nitrite Breakthrough Curves by Waste Source Component

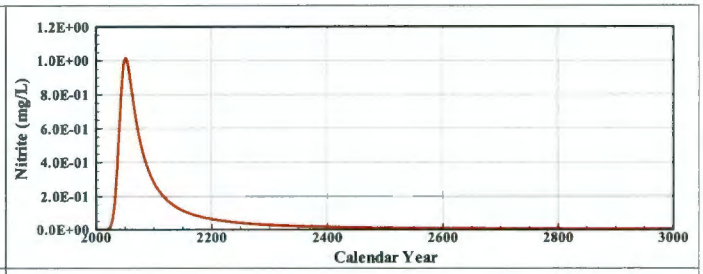
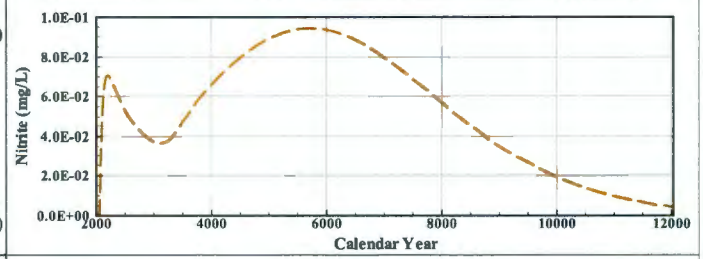
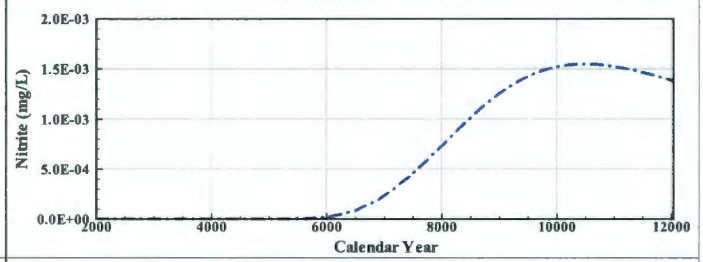
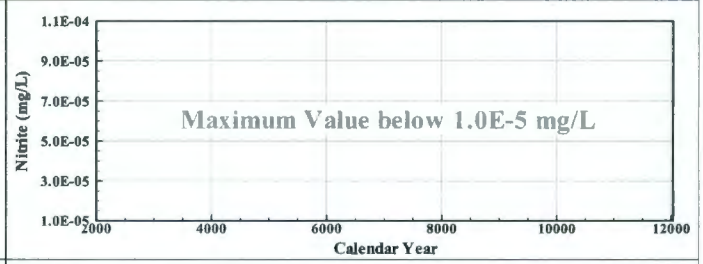
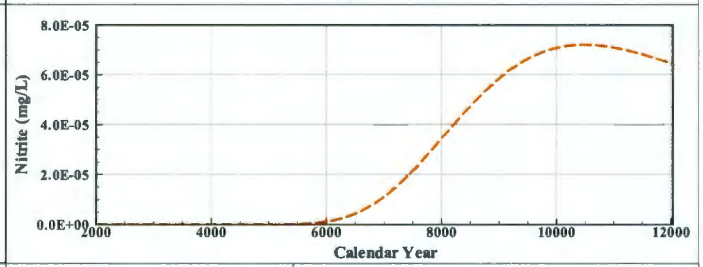
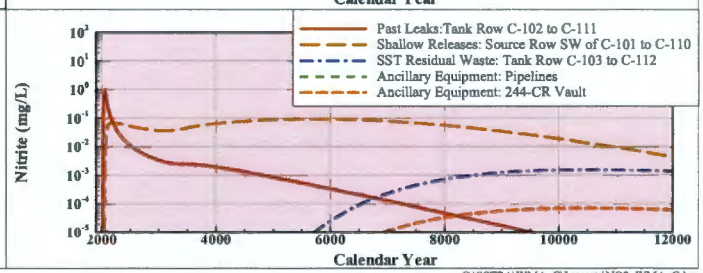
Nitrite **K_d = 0.0 mL/g**		
Past Releases	**Past Leaks from Tanks** **Tank Row** **C-102 to C-111** Nitrite Inventory (kg) C-102 = 0.00E+0 C-105 = 3.77E+1 C-108 = 0.00E+0 C-111 = 4.66E+2 Sum = 5.03E+2 Peak = 1.02E+0 mg/L Occurs in Year 2051	
	UPR Row is ~ 160 ft SW of Tank Row C-101 to C-110 UPR-E-200-E-81 = 1.78E+3 UPR-E-200-E-82 = 3.93E+2 UPR-E-200-E-86 = 1.49E+3 Sum = 3.67E+3 1st Peak = 7.06E-2 mg/L (2196) 2nd Peak = 9.44E-2 mg/L (5711)	
Residual Waste	**Tank Residuals SST** **Tank Row C-103 to C-112** Nitrite Inventory (kg) C-103 = 5.94E+1 C-106 = 4.14E+1 C-109 = 1.03E+2 C-112 = 1.74E+2 C-302 = 4.77E+0 SUM = 3.82E+2 Peak = 1.57E-3 mg/L Occurs in Year 10481	
	Ancillary Equipment **Pipeline Residuals** Nitrite Inventory (kg) WMA C Pipelines = 7.13E-2 Maximum < 1.00E-5 mg/L at End of Simulation	
	Ancillary Equipment **MUST** Nitrite Inventory (kg) 244 CR Vault= 1.76E+1 Peak = 7.21E-5 mg/L Occurs in Year 10481	
Maximum Impact Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.		

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Figure 4-33. Waste Management Area C Uranium Breakthrough Curves by Waste Source Component

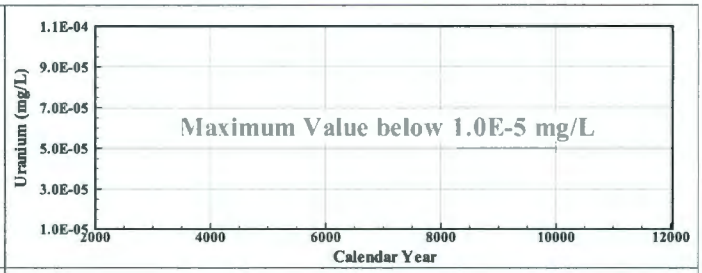
Uranium
K_d = 0.6 mL/g

Past Releases

Past Leaks from Tanks Tank Row C-102 to C-111

Uranium Inventory (kg)
C-102 = 0.00E+0
C-105 = 9.86E-2
C-108 = 0.00E+0
C-111 = 6.01E-1
Sum = 7.00E-1

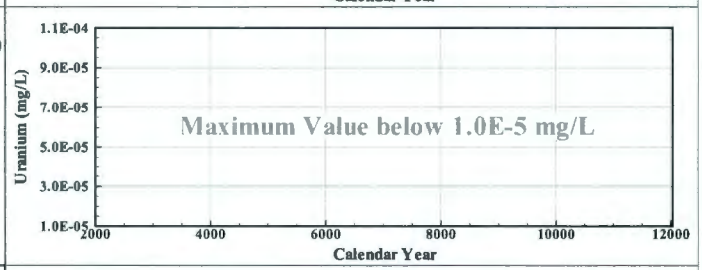
Maximum < 1.00E-5 mg/L at End of Simulation



UPR Row is ~ 160 ft SW of Tank Row C-101 to C-110

Uranium Inventory (kg)
UPR-E-200-E-81 = 4.22E+0
UPR-E-200-E-82 = 3.04E-1
UPR-E-200-E-86 = 2.11E+0
Sum = 6.63E+0

Maximum < 1.00E-5 mg/L at End of Simulation

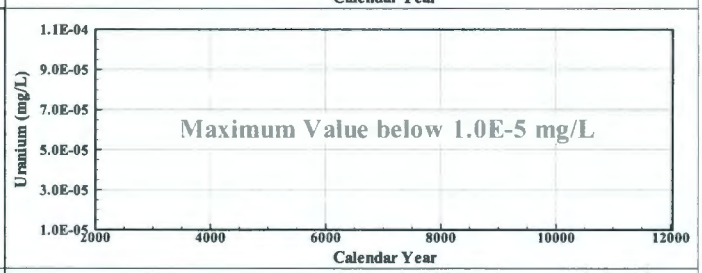


Residual Waste

Tank Residuals SST Tank Row C-103 to C-112

Uranium Inventory (kg)
C-103 = 4.55E+1
C-106 = 2.70E+0
C-109 = 1.46E+2
C-112 = 6.71E+2
SUM = 8.65E+2

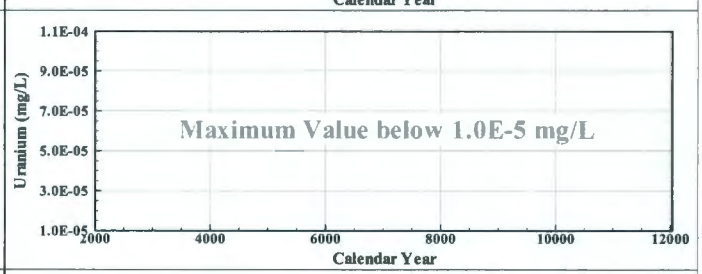
Maximum < 1.00E-5 mg/L at End of Simulation



Ancillary Equipment Pipeline Residuals

Uranium Inventory (kg)
WMA C Pipelines = 4.35E-4

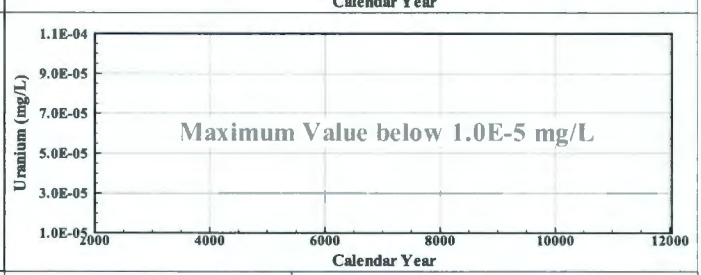
Maximum < 1.00E-5 mg/L at End of Simulation



Ancillary Equipment MUST

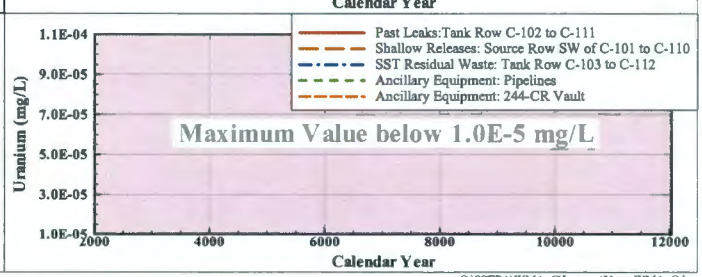
Uranium Inventory (kg)
244 CR Vault= 4.10E+1

Maximum < 1.00E-5 mg/L at End of Simulation



Maximum Impact

Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.



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4.8 LONG-TERM CONTAMINANT CONCENTRATIONS FOR WASTE MANAGEMENT AREA B-BX-BY

This section presents the results of contaminant transport modeling for the indicator contaminants selected for WMA B-BX-BY. The numerical calculation point for this analysis is the WMA B-BX-BY fenceline. Impacts of individual source components (past releases, tank residuals, and ancillary equipment residuals) to the system are described.

WMA B-BX-BY has 36 100-Series tanks and four 200-Series tanks aligned in 7 rows that are effectively parallel with the groundwater flow (Figure 2-69). There are 12 100-Series tanks (530,000 gal) in both B and BX tank farms. BY tank farm has 12 100-Series tanks (758,000 gal). Additionally, B tank farm has four 200-Series tanks (55,000 gal). Reference case contaminant estimates were developed for each row based on the information in Chapter 3.0. Impacts to groundwater from individual waste components were then evaluated on a row-by-row basis. This section presents the concentration results for the indicator contaminants identified in Section 4.2.1 by the highest contributing row for each source component.

Significant groundwater contamination driven by tank past leaks is predicted to reach the WMA B-BX-BY fenceline.

Contamination from tank residuals has minor groundwater concentration impacts late in the simulation.

WMA B-BX-BY is the only WMA in the SST system predicted to have uranium concentrations at the WMA fenceline at the end of the model time frame.

The contaminant transport model developed for WMA C is used as a template for WMA B-BX-BY.

As noted in Section 3.2.2.1, contaminant transport models were developed for WMA C and WMA S-SX and are used as the templates for analyses for the 200 East Area and 200 West Area WMAs, respectively. The contaminant transport model designed for WMA C was coupled with WMA B-BX-BY inventories to produce the results presented in this section. Subsequent versions of the SST PA will include WMA-specific contaminant transport models.

4.8.1 Previous Modeling Efforts for Waste Management Area B-BX-BY

The B-BX-TY FIR (Knepp 2002b) modeled long-term groundwater concentrations for a variety of contaminants from existing vadose contamination related to past releases. The Knepp (2002b) analysis did not address groundwater impacts related to residual waste in tanks and ancillary equipment. Peak concentrations for the indicator contaminants presented in this section and in Knepp (2002b) differ, and are caused primarily by differences in assumptions between Knepp (2002b) and this SST PA. The differences of the SST PA with respect to Knepp (2002b) parameter inputs and modeling assumptions include:

- Barrier emplacement in year 2040 in the FIR rather than year 2032 in the SST PA
- A higher degraded barrier recharge rate
- A simulation period of 1,000 years rather than of 10,000 years
- Assignment of existing vadose zone inventory to discrete depths within the vadose zone rather than to a single discrete depth assignment, as in the SST PA.

4.8.2 Waste Management Area B-BX-BY Fenceline Results

Twenty-six contaminants in WMA B-BX-BY had fenceline concentrations above the effective zero within the 10,000-year simulation period. Table 4-22 defines the tank rows in WMA B-BX-BY and summarizes waste sources included in each row. The designation for each tank row is the lowest numbered tank in the sequence (e.g., B-101 identifies the row consisting of tanks B-101, B-104, B-107, and B-110). Such a designation is used throughout Section 4.8. Three rows include SSTs from both the B and BX tank farms, because the tanks in those rows lie effectively along the same pathline. MUSTs and UPRs (from ancillary equipment) were assigned to the tank row nearest to their locations. Plugged and blocked pipelines for WMA B-BX-BY are not listed in Table 4-23 because they do not coincide with a single tank row and were therefore modeled as a separate source. Table 4-23 lists the contaminants with concentrations above the effective zero indicating the dominant source term and the tank row providing the inventory responsible for the peak concentration.

4.8.3 Results for Waste Management Area B-BX-BY Waste Components

The past releases component is the primary contributing source component to fenceline concentrations in WMA B-BX-BY for all the indicator contaminants described in Section 4.2.1. The past releases component consists of both SST past leaks and UPRs. Modeling of both source terms was the same except for the initial depth assignment (130 ft bgs for SST past leaks in the 200 East Area, 150 ft bgs for SST past leaks in the 200 West Area, and 30 ft bgs for UPRs). There are 12 total SST past leaks in the WMA and each tank row contains one or more past tank leaks. There are nine total UPRs in the WMA and four of the seven tank rows contain one or more of the UPRs. Tank row B-103 to BX-111 is projected to contribute to the highest past releases component concentration for technetium-99, chromium, nitrate, and uranium; the tank row includes the tank BX-102 leak, which is the highest volume tank leak in the WMA. Tank row B-101 is projected to contribute the highest past releases component concentration for iodine and nitrite; the tank row includes six of the nine UPRs in the WMA.

Unlike the past releases component, no single tank row dominates the results from tank residuals for the indicator contaminants discussed in the following sections. The tank residuals component consists of residuals in SSTs and ancillary equipment (i.e., MUSTs). The MUST residuals were incorporated into tank residual calculations for each row because the SST and MUST residuals were modeled in the same manner (i.e., diffusion-limited release). The ancillary equipment residuals component in WMA B-BX-BY consists of plugged and blocked pipelines in the BX tank farm and four MUSTs (241-B-301 and 241-B-302A catch tanks, 241-BX DCRT, 244-BXR vault). The 241-B-301 catch tank and 244-BXR vault were assigned to tank row B-101, the 241-BX DCRT was assigned to tank row B-102, and the 241-B-301 catch tank was assigned to tank row B-103. The pipelines and MUSTs provide negligible contributions to the overall concentrations for each of the indicator contaminants considered in this section.

Table 4-22. Waste Management Area B-BX-BY Tank Rows and Waste Components Included in Modeling

Tank Row	Residual Waste		Past Releases	
	Tanks	Ancillary Equipment	Tank Leaks	Past Shallow Releases
B-101	241-B-101 241-B-104 241-B-107 241-B-110	244-BXR vault 241-BX-302A	241-B-107 past leak 241-B-110 past leak	UPR-200-E-6 UPR-200-E-73 UPR-200-E-75 UPR-200-E-109 UPR-200-E-74 UPR-200-E-38
B-102	241-B-102 241-B-105 241-B-108 241-B-111 241-BX-101 241-BX-104 241-BX-107 241-BX-110	244-BX double-contained receiver tank	241-BX-101 past leak	UPR-200-E-108
B-103	241-B-103 241-B-106 241-B-109 241-B-112 241-BX-102 241-BX-105 241-BX-108 241-BX-111	241-B-301 catch tank	241-B-112 past leak 241-BX-102 past leak 241-BX-108 past leak	None
B-201	241-B-201 241-B-202 241-B-203 241-B-204 241-BX-103 241-BX-106 241-BX-109 241-BX-112	None	241-B-201 past leak 241-B-203 past leak 241-B-204 past leak	None
BY-101	241-BY-101 241-BY-104 241-BY-107 241-BY-110	None	241-BY-107 past leak	UPR-200-E-105
BY-102	241-BY-102 241-BY-105 241-BY-108 241-BY-111	None	241-BY-108 past leak	None
BY-103	241-BY-103 241-BY-106 241-BY-109 241-BY-112	None	241-BY-103 past leak	UPR-200-E-110

Table 4-23. Estimated Concentrations of Contaminants from All Waste Components Appearing at the Waste Management Area B-BX-BY Fenceline

Radionuclides [a]				
Analyte Name	**Peak Concentration pCi/L**	**Dominant Source Term**	**Peak Year**	**Row with Peak Concentration**
Tritium	6.50E+02	Past releases	2044	B-103
Carbon-14	3.27E+02	Past releases	2051	B-103
Cobalt-60	2.65E-02	Past releases	2052	B-101
Technetium-99	9.03E+03	Past releases	2051	B-103
Iodine-129	9.82E-02	Past releases	9621	B-101
Uranium-234	1.25E+00	Past releases	12032	B-103
Uranium-235 + D	5.83E-02	Past releases	12032	B-103
Uranium-236	1.10E-02	Past releases	12032	B-103
Uranium-238 + D	1.31E+00	Past releases	12032	B-103
Nonradionuclides [b]				
Analyte Name	**Peak Concentration mg/L**	**Dominant Source Term**	**Peak Year**	**Row with Peak Concentration**
Ammonia	1.43E-02	Past releases	2051	B-103
Bismuth	4.39E-02	Past releases	2051	B-103
Cerium	1.96E-05	Tank residuals	10481	B-102
Chloride	1.62E-01	Past releases	2051	B-103
Chromium	1.70E-01	Past releases	2051	B-103
Fluoride	4.62E-02	Past releases	2051	B-201
Hydroxide	6.67E-02	Tank residuals	10481	B-102
Lanthanum	2.16E-04	Tank residuals	10481	B-201
n-Butyl Alcohol	1.55E-02	Past releases	2051	BY-101
Neodymium	1.58E-05	Tank residuals	10481	BY-102
Nitrate	1.01E+01	Past releases	2051	B-103
Nitrite	2.02E+00	Past releases	2051	B-101
Oxalate	1.69E-02	Tank residuals	10481	BY-103
Phosphate	8.35E+00	Past releases	2051	B-103
Sodium	3.69E+01	Past releases	2051	B-103
Sulfate	1.16E+01	Past releases	2051	B-103
Uranium	3.94E-03	Past releases	12032	B-103

[a] The following radionuclides reached the fenceline during the modeling period, but had concentrations below the effective zero (1.0E-02 pCi/L): tin-126, samarium-151, radium-226 + D, uranium-232, and uranium-233.

[b] The following nonradionuclides reached the fenceline during the modeling period, but had concentrations below the effective zero (1.0E-05 mg/L): aluminum, cobalt, manganese, rhodium, tellurium, tungsten, and yttrium.

Table 4-24 shows peak fenceline concentrations for radionuclides by row, and Table 4-25 shows peak fenceline concentrations for nonradionuclides by row. Both tables show concentrations from past releases and tank residuals source terms relative to the peak contributing tank row. The values shown for the past releases component include both past tank leaks and UPRs that fall within a tank row. Since ancillary equipment residuals are modeled as tank residuals, the tank residuals portion of the tables include ancillary equipment that reside within a tank row. Although the peak concentrations from different source components occur at different times, Tables 4-24 and 4-25 show that, for any given contaminant, the peak concentration resulting from past releases is generally two to three orders of magnitude greater than the peak concentration resulting from tank residuals.

Plugged and blocked pipelines in WMA B-BX-BY occur only within the BX tank farm. The plugged and blocked pipelines do not fall within any one tank row and were therefore evaluated as a separate row. Plugged and blocked pipelines were modeled as a shallow release in the same manner as UPRs (i.e., initial depth of 30 ft bgs). Modeling results indicate the peak concentrations from the WMA B-BX-BY plugged and blocked pipeline residuals component are below the effective zero concentration for each of the six indicator contaminants discussed in this section.

Table 4-24. Waste Management Area B-BX-BY Tank Row Peak Radionuclide Concentrations [a]

Technetium-99				
	Past Releases Component, Peak Year: 2051		**Tank Residuals Component, Peak Year: 10461**	
Tank Row	**Peak Concentration pCi/L**	**Concentration Relative to Row B-103**	**Peak Concentration pCi/L**	**Concentration Relative to Row BY-103**
B-101 [b]	1.67E+03	18.49%	1.61E+00	2.46%
B-102 [c]	4.99E+02	5.53%	1.06E+01	16.21%
B-103 [d]	9.03E+03	100.00%	1.37E+01	20.95%
B-201	0.00E+00	NA	9.51E-01	1.45%
BY-101	1.81E+03	20.04%	4.91E+01	75.08%
BY-102	6.04E+02	6.69%	1.57E+01	24.01%
BY-103	6.04E+02	6.69%	6.54E+01	100.00%
Iodine-129				
	Past Releases Component, Max. Year: 9621		**Tank Residuals Component, Peak Year: 12032**	
Tank Row	**Peak Concentration pCi/L**	**Concentration Relative to Row B-101**	**Peak Concentration pCi/L**	**Concentration Relative to Row BY-101**
B-101 [b]	9.82E-02	100.00%	0.00E+00	NA
B-102 [c]	0.00E+00	NA	0.00E+00	NA
B-103 [d]	2.84E-02	28.92%	0.00E+00	NA
B-201	0.00E+00	NA	0.00E+00	NA
BY-101	1.45E-02	14.77%	0.00E+00	NA
BY-102	0.00E+00	NA	0.00E+00	NA
BY-103	0.00E+00	NA	0.00E+00	NA

[a] Maximum values are shaded.
[b] Tank row B-101 includes residuals from BXR vault and BX-302A catch tank.
[c] Tank row B-102 includes residuals from 244-BX double-contained receiver tank.
[d] Tank row B-103 includes residuals from B-301 catch tank.
NA = not applicable

1

Table 4-25. Waste Management Area B-BX-BY Tank Row Peak Nonradionuclide Concentrations [a] (2 pages)

Hexavalent Chromium				
	Past Releases Component, Peak Year: 2051		**Tank Residuals Component, Peak Year: 10481**	
Tank Row	**Peak Concentration mg/L**	**Concentration Relative to Row B-103 to BX-111**	**Peak Concentration mg/L**	**Concentration Relative to Row BY-103 to BY-112**
B-101 [b]	3.00E-02	17.65%	3.85E-04	14.26%
B-102 [c]	3.03E-03	1.78%	1.27E-03	47.04%
B-103 [d]	1.70E-01	100.00%	9.11E-04	33.74%
B-201	3.97E-03	2.34%	4.32E-04	16.00%
BY-101	2.64E-02	15.53%	1.30E-03	48.15%
BY-102	8.80E-03	5.18%	4.17E-04	15.44%
BY-103	8.80E-03	5.18%	2.70E-03	100.00%
Nitrate				
	Past Releases Component, Peak Year: 2051		**Tank Residuals Component, Peak Year: 10481**	
Tank Row	**Peak Concentration mg/L**	**Concentration Relative to Row B-103-BX-111**	**Peak Concentration mg/L**	**Concentration Relative to Row B-101-B-110**
B-101 [b]	5.43E+00	53.76%	1.92E-02	100.00%
B-102 [c]	1.46E+00	14.46%	1.18E-02	61.46%
B-103 [d]	1.01E+01	100.00%	1.54E-02	80.21%
B-201	7.90E-01	7.82%	6.62E-03	34.48%
BY-101	1.98E+00	19.60%	1.31E-02	68.23%
BY-102	6.59E-01	6.52%	1.13E-02	58.85%
BY-103	6.60E-01	6.53%	8.96E-03	46.67%
Nitrite				
	Past Releases Component, Peak Year: 2051		**Tank Residuals Component, Peak Year: 10481**	
Tank Row	**Peak Concentration mg/L**	**Concentration Relative to Row B-103-B-110**	**Peak Concentration mg/L**	**Concentration Relative to Row B-102-BX-110**
B-101 [b]	2.01E+00	100.00%	9.97E-04	40.04%
B-102 [c]	2.20E-01	10.89%	2.49E-03	100.00%
B-103 [d]	1.83E+00	90.59%	1.15E-03	46.18%
B-201	2.09E-03	0.10%	1.40E-03	56.22%
BY-101	1.07E+00	52.97%	1.59E-03	63.86%
BY-102	3.58E-01	17.72%	8.80E-04	35.34%
BY-103	3.58E-01	17.72%	1.11E-03	44.58%

Table 4-25. Waste Management Area B-BX-BY Tank Row Peak Nonradionuclide Concentrations [a] (2 pages)

Uranium				
	Past Releases Component, Max. Year: 12032		**Tank Residuals Component**	
Tank Row	**Peak Concentration mg/L**	**Concentration Relative to Row B-103-BX-111**	**Peak Concentration mg/L**	**Concentration Relative to Row with Peak Concentration**
B-101 [b]	0.00E+00	NA	0.00E+00	NA
B-102 [c]	0.00E+00	NA	0.00E+00	NA
B-103 [d]	3.94E-03	100.00%	0.00E+00	NA
B-201	0.00E+00	NA	0.00E+00	NA
BY-101	0.00E+00	NA	0.00E+00	NA
BY-102	0.00E+00	NA	0.00E+00	NA
BY-103	0.00E+00	NA	0.00E+00	NA

[a] Maximum values are shaded.
[b] Tank row B-101 includes residuals from BXR vault and BX-302A catch tank.
[c] Tank row B-102 includes residuals from 244-BX double-contained receiver tank.
[d] Tank row B-103 includes residuals from B-301 catch tank.
NA = not applicable

Figures 4-34 through 4-39 illustrate the BTCs for each of the six indicator contaminants discussed in this section. Each of the first five plots in the figure is from a separate source component, with the bottom plot containing the previous five plots superimposed on each other to show the maximum impact. Blank plots indicate cases where the concentration for a source component does not exceed the effective zero for any tank row over the 10,000-year simulation period. In those cases, the tank row with the greatest inventory is indicated. Again, a linear scale (y-axis) is used for the individual source component plots, but in order to include the entire range of data, the maximum impact plot is shown using a logarithmic scale. Each plot represents the BTC from the tank row contributing the highest concentration for that source component. When two source terms of the same source component occur in a tank row (i.e., SST leaks and shallow releases or SST residuals and MUST residuals), both curves are shown to facilitate comparison of the relative magnitudes of concentration provided by each source term. For example, the past shallow releases plot for technetium-99 (Figure 4-34) shows the BTC for UPRs in tank row B-101, which is the row with peak concentration for UPRs. However, that figure also shows the BTC for past tank leaks from row B-101 even though the row with peak concentration for past tank leak contribution is tank row B-103. The BTC for tank leaks from tank row B-101 is provided to show the contribution to fenceline concentration from past shallow releases relative to fenceline concentration from other past releases in that tank row.

4.8.4 Discussion of Results and Conclusions for Waste Management Area B-BX-BY

Estimated long-term groundwater impacts from three contaminant source components (i.e., past releases inventory, tank residuals inventory, and ancillary equipment residuals inventory) in WMA B-BX-BY were modeled. Results of the analysis indicate that the past releases component is the primary contributing source component to peak fenceline

concentrations in WMA B-BX-BY. Peak contaminant concentrations resulting from contamination at depth are generally one to two orders of magnitude higher than the corresponding peak concentrations from the tank residuals component regardless of contaminant mobility. For the past releases component, tank row B-103 is projected to contribute to the highest fenceline concentration for technetium-99, chromium, nitrate, and uranium. Tank row B-101 is projected to contribute to the highest past releases component concentration for iodine and nitrite.

Tank retrieval to the HFFACO prescribed volume and inventories estimated by Kirkbride et al. (2005) results in a tank residual impact two to three orders of magnitude below that of past releases. No single tank row dominates the BTCs for the tank residuals component.

For highly mobile (K_d = 0 mL/g) contaminants, the past releases component is the dominant contributor to the reference case composite BTC for the early part of the simulation and for the entire simulation period for less-mobile ($K_d \leq 0.6$ mL/g) contaminants. For the mobile contaminants, the tank residuals component dominates the reference case composite BTC toward the end of the simulation period. Ancillary equipment has a negligible effect on the total tank residuals component, with only four of the six indicator contaminants discussed in this section projected to have concentrations above effective zero. Fenceline concentrations for the less mobile contaminants in tank residuals do not exceed the effective zero within the 10,000-year simulation period.

Due to existing vadose zone contamination and the maximum operational recharge occurring during that period, contaminants with high mobility (K_d less than 0.2 mL/g) exhibit concentration peaks that occur early in the simulation and prior to emplacement of the Modified RCRA Subtitle C Barrier. Contaminants with lower mobility (K_d 0.2 mL/g or greater) exhibit increasing concentrations at the end of the simulation period, dominated by the contamination at depth source component. Changes in recharge caused by the emplacement and failure of the Modified RCRA Subtitle C Barrier have dramatic impacts on the shape of the BTC for highly mobile contaminants.

Figure 4-34. Waste Management Area B-BX-BY Technetium-99 Breakthrough Curves by Waste Source Component

Technetium-99
K_d = 0.0 mL/g

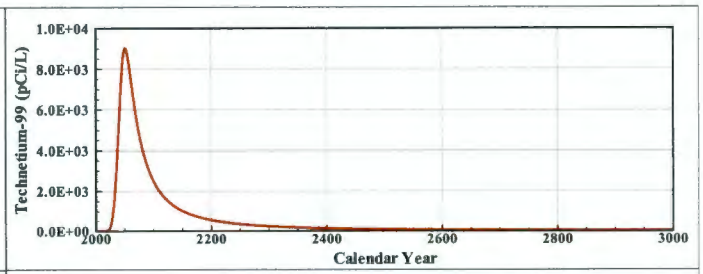
Past Releases

Past Tank Leaks on Same Pathline Tank Row B-103 to BX-111

^{99}Tc Inventory (Ci)

B-103 = 0.00E+0 | BX-102 = 2.28E+0
B-106 = 0.00E+0 | BX-105 = 0.00E+0
B-109 = 0.00E+0 | BX-108 = 1.18E+0
B-112 = 1.02E+0 | BX-111 = 0.00E+0
Sum = 4.48

Peak = 9.03E+3 pCi/L
Occurs in Year 2051

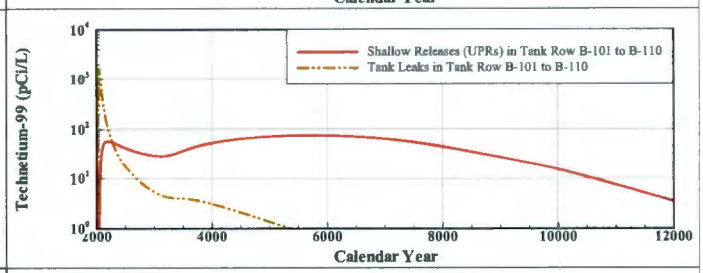


Past Shallow Releases on Same Pathline Tank Row B-101 to B-110

^{99}Tc Inventory (Ci)

UPR-200-	Tank Leak in Row
E-6 = 7.78E-4	B-101 = 0.00E+0
E-38 = 2.94E+0	B-104 = 0.00E+0
E-73 = 2.01E-3	B-107 = 2.38E-1
E-74 = 1.88E-1	B-110 = 5.42E-1
E-75 = 7.77E-4	
E-109 = 2.12E-3	

UPR + Tank Leak Sum = 3.77
First Peak = 1.66E+3 pCi/L in 2051
Second Peak = 7.49E+1 pCi/L in 5701



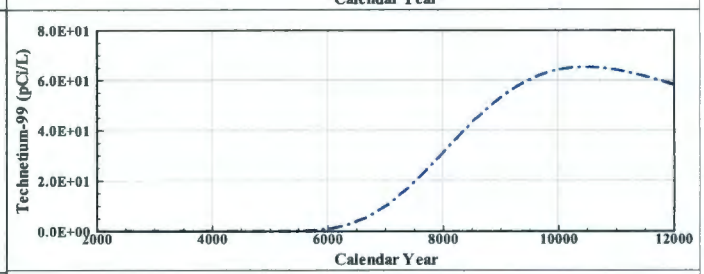
Residual Waste

SST Tank Residuals in Tank Row BY-103 to BY-112

^{99}Tc Inventory (Ci)

BY-103 = 2.34E+0
BY-106 = 1.19E+1
BY-109 = 1.43E+0
BY-112 = 6.90E-1
Sum = 1.64E+1

Peak = 6.54E+1 pCi/L
Occurs in Year 10461

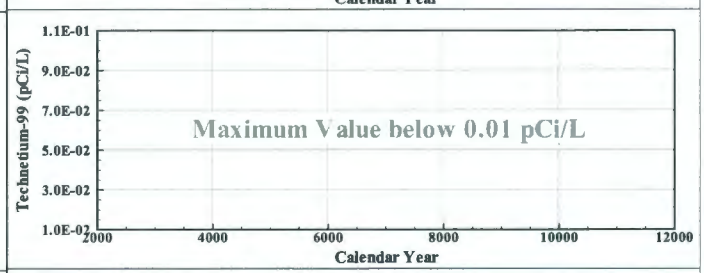


Ancillary Equipment Pipeline Residuals

^{99}Tc Inventory (Ci)

BX Pipelines = 1.28E-7

Maximum < 1.00E-2 pCi/L
at End of Simulation



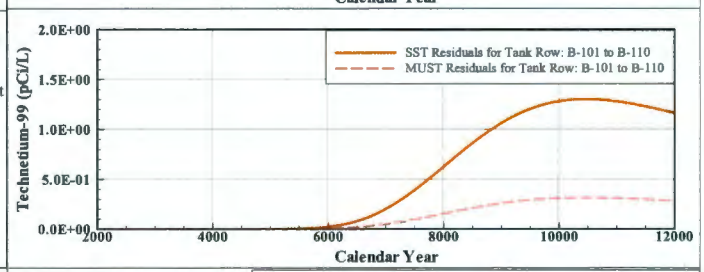
Ancillary Equipment Residuals in Same Pathline Tank Row B-101 to B-110

^{99}Tc Inventory (Ci)

SST Residuals	MUST and BXR Vault
B-101 = 1.22E-2	B-302 A = 7.5E-3
B-104 = 3.52E-2	BXR Vault = 7.03E-2
B-107 = 1.17E-1	
B-110 = 1.62E-1	

Sum SST Resid. + Anc. Equip. = 4.04E-1

SST Peak = 1.3E+0 pCi/L in 10461
MUST Peak = 3.1E-1 pCi/L in 10461



Maximum Impact

Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.

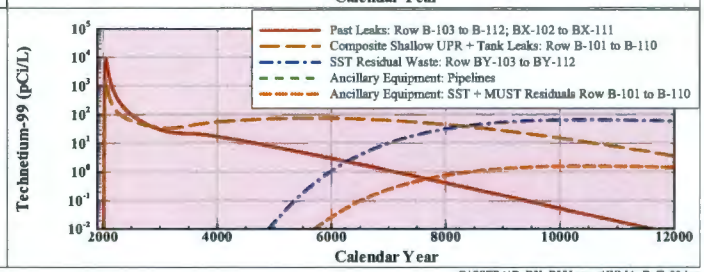


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Figure 4-35. Waste Management Area B-BX-BY Iodine-129 Breakthrough Curves by Waste Source Component

Iodine-129
K_d = 0.2 mL/g

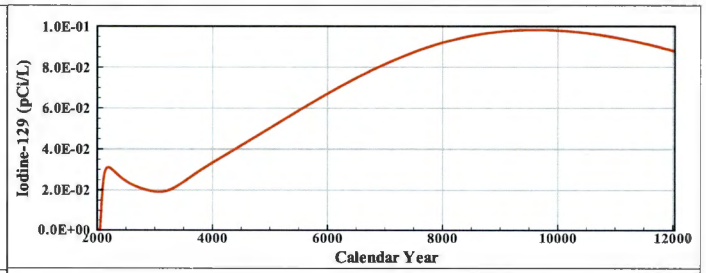
Past Releases

Past Tank Leaks on Same Pathline Tank Row B-101 to B-110

^{129}Iodine Inventory (Ci)

B-101 = 0.00E+0
B-104 = 0.00E+0
B-107 = 8.24E-3
B-110 = 4.09E-4
Sum = 8.65E-03

Peak = 9.82E-2 pCi/L
Occurs in Year 9621

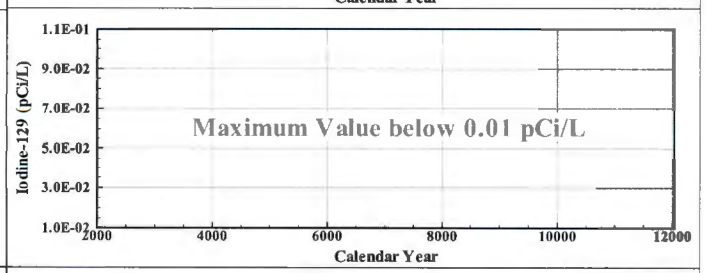


Past Shallow Releases on Same Pathline Tank Row B-101 to B-110

^{129}I Inventory (Ci)

Tank Leak in Row
E-6 = 6.81E-06
E-38 = 1.74E-03
E-73 = 2.28E-06
E-74 = 1.88E-11
E-75 = 6.79E-06
E-109 = 2.72E-06
Sum = 1.76E-3

Maximum < 1.00E-2 pCi/L
at End of Simulation



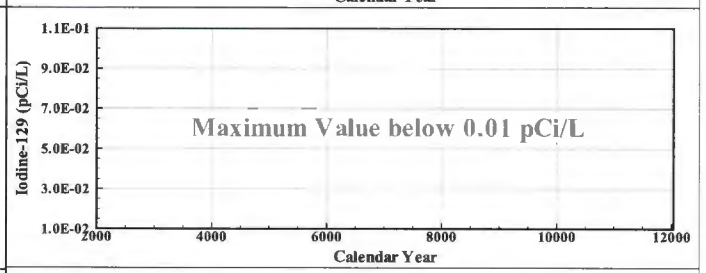
Residual Waste

SST Tank Residuals in Tank Row BY-101 to BY-110

^{129}I Inventory (Ci)

BY-101 = 9.37E-3
BY-104 = 1.72E-2
BY-107 = 1.13E-3
BY-110 = 1.23E-2
SUM = 3.99E-2

Maximum < 1.00E-2 pCi/L
at End of Simulation

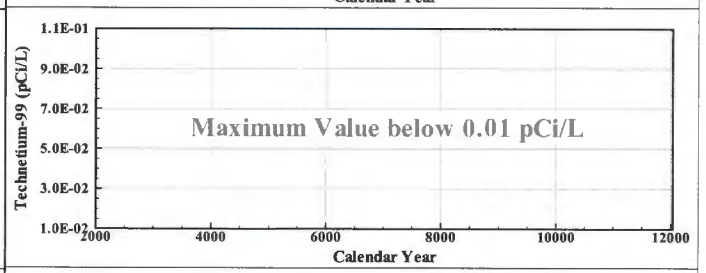


Ancillary Equipment Pipeline Residuals

^{129}I Inventory (Ci)

BX Pipelines = 2.10E-6

Maximum < 1.00E-2 pCi/L
at End of Simulation



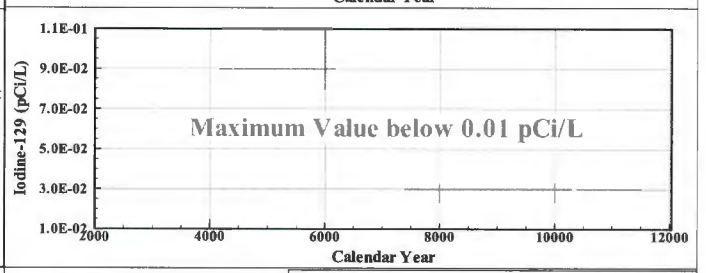
Ancillary Equipment Residuals in Same Pathline Tank Row B-101 to B-110

^{129}I Inventory (Ci)

SST Residuals	MUST and BXR Vault
B-101 = 3.07E-6	B-302 A = 1.86E-5
B-104 = 1.57E-6	BXR Vault = 1.74E-4
B-107 = 8.43E-5	
B-110 = 5.28E-6	

Sum SST Resid. + Anc. Equip. = 2.87E-4

Maximum < 1.00E-2 pCi/L
at End of Simulation



Maximum Impact

Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.

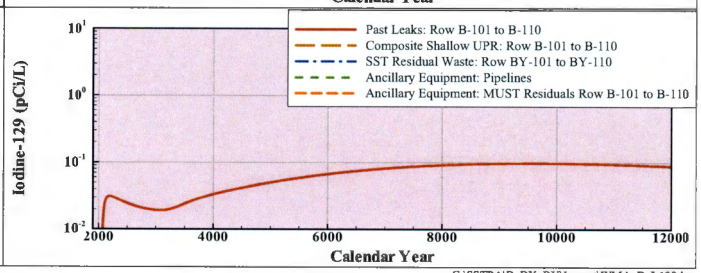


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Figure 4-36. Waste Management Area B-BX-BY Hexavalent Chromium Breakthrough Curves by Waste Source Component

Chromium K_d = 0.0 mL/g

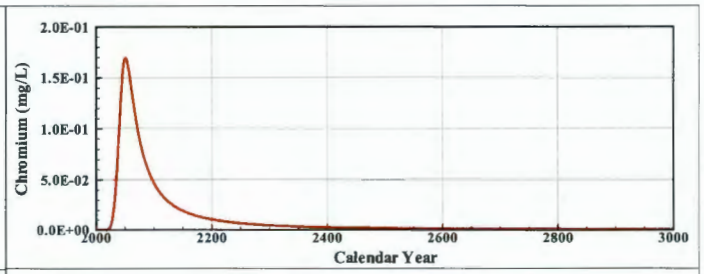
Past Releases

Past Tank Leaks on Same Pathline Tank Row B-103 to BX-111

Chromium Inventory (kg)

B-103 = 0.00E+0 | BX-102 = 6.04E+1
B-106 = 0.00E+0 | BX-105 = 0.00E+0
B-109 = 0.00E+0 | BX-108 = 1.37E+1
B-112 = 9.89E+0 | BX-111 = 0.00E+0
Sum = 8.40E+01

Peak = 1.70E-1 mg/L
Occurs in Year 2051



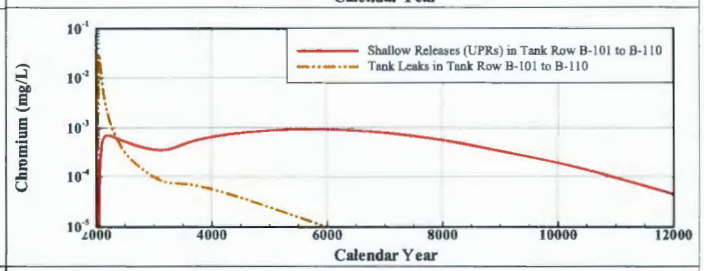
Past Shallow Releases on Same Pathline Tank Row B-101 to B-110

Chromium Inventory (kg)

UPR-200-	Tank Leak in Row
E-6 = 1.38E+0	B-101 = 0.00E+0
E-38 = 3.36E+1	B-104 = 0.00E+0
E-73 = 3.20E-2	B-107 = 9.29E+0
E-74 = 1.60E-2	B-110 = 5.56E+0
E-75 = 1.38E+0	
E-109 = 9.42E-2	

UPR + Tank Leak Sum = 5.14E+1

First Peak = 2.99E-2 mg/L in 2051
Second Peak = 9.41E-4 mg/L in 5711



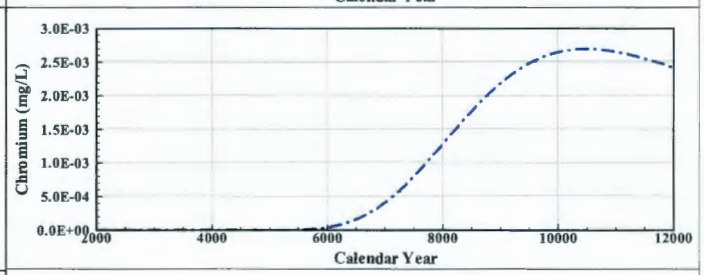
Residual Waste

SST Tank Residuals in Tank Row BY-103 to BY-112

Chromium Inventory (kg)

BY-103 = 5.85E+1
BY-106 = 1.63E+2
BY-109 = 3.24E+1
BY-112 = 4.04E+2
SUM = 6.58E+2

Peak = 2.70E-3 mg/L
Occurs in Year 10481

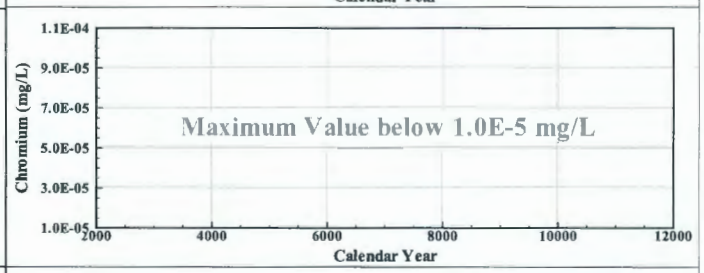


Ancillary Equipment Pipeline Residuals

Chromium Inventory (kg)

BX Pipelines = 4.25E-3

Maximum < 1.00E-5 mg/L
at End of Simulation



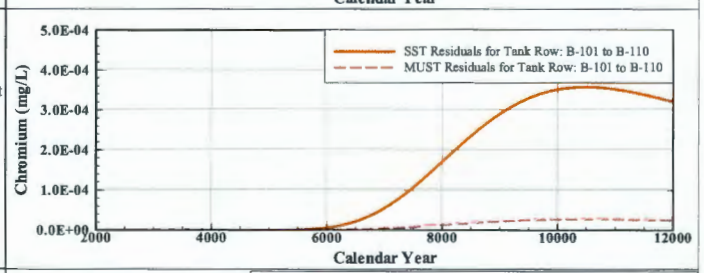
Ancillary Equipment Residuals in Same Pathline Tank Row B-101 to B-110

Chromium Inventory (kg)

SST Residuals	MUST and BXR Vault
B-101 = 1.86E+1	B-302 A = 6.37E-1
B-104 = 3.24E+1	BXR Vault = 5.98E+0
B-107 = 6.48E+0	
B-110 = 2.96E+1	

Sum SST Resid. + Anc. Equip. = 9.37E+1

SST Peak = 3.58E-4 mg/L in 10481
MUST Peak = 2.72E-5 mg/L in 10481



Maximum Impact

Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.

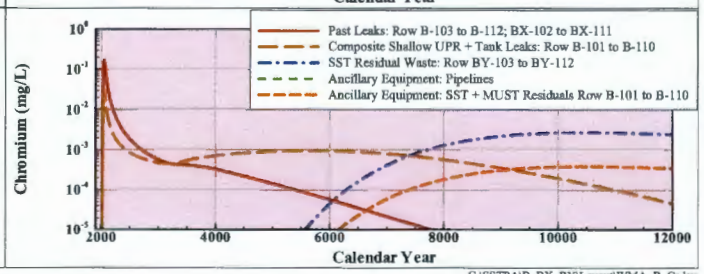


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Figure 4-37. Waste Management Area B-BX-BY Nitrate Breakthrough Curves by Waste Source Component

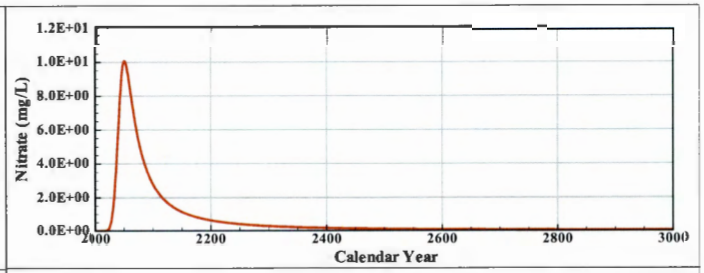
Nitrate
K_d = 0.0 mL/g

Past Releases

Past Tank Leaks on Same Pathline Tank Row B-103 to BX-111

Nitrate Inventory (kg)
B-103 = 0.00E+0 | BX-102 = 3.40E+2
B-106 = 0.00E+0 | BX-105 = 0.00E+0
B-109 = 0.00E+0 | BX-108 = 4.13E+2
B-112 = 2.35E+3 | BX-111 = 0.00E+0
Sum = 2.52E+03

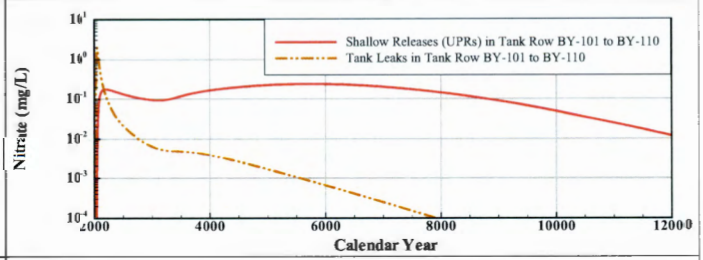
Peak = 1.01E+1 mg/L
Occurs in Year 2051



Past Shallow Releases on Same Pathline Tank Row BY-101 to BY-110

Nitrate Inventory (kg)
Tank Leak in Row | UPR-200-
BY-101 = 0.00E+0 | E-7 = 9.34E+3
BY-104 = 0.00E+0
BY-107 = 9.80E+2
BY-110 = 0.00E+0
UPR + Tank Leak Sum = 1.03E+3

First Peak = 1.98E+0 mg/L in 2051
Second Peak = 2.40E-1 mg/L in 5711

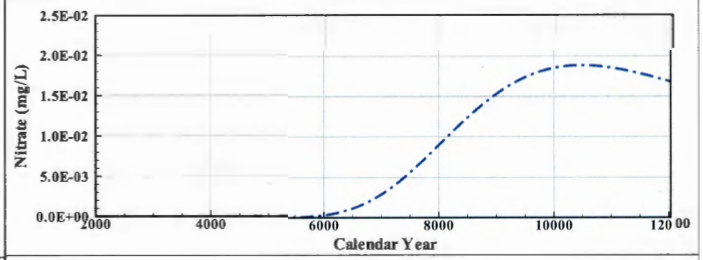


Residual Waste

SST Tank Residuals in Tank Row B-101 to B-110

Nitrate Inventory (kg)
B-101 = 3.42E+2
B-104 = 1.04E+3
B-107 = 1.25E+3
B-110 = 1.97E+3
SUM = 4.61E+3

Peak = 1.89E-2 mg/L
Occurs in Year 10481

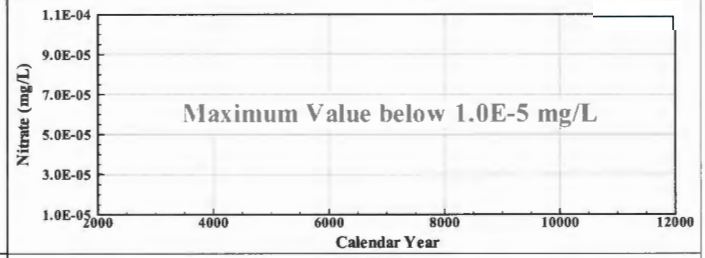


Ancillary Equipment Pipeline Residuals

Nitrate Inventory (kg)

BX Pipelines = 2.55E-1

Maximum < 1.00E-5 mg/L
at End of Simulation

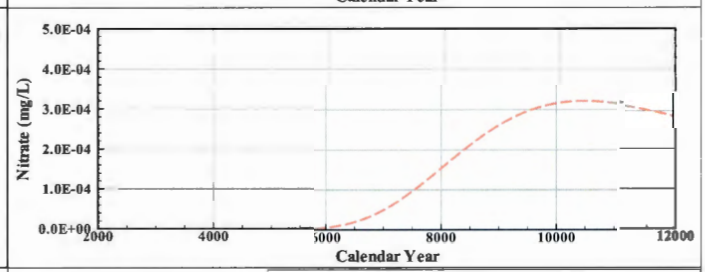


Ancillary Equipment Residuals in Same Pathline Tank Row B-101 to B-110

Nitrate (kg)

MUST and BXR Vault
B-302 A = 7.56E+0
BXR Vault = 7.09E+1
Sum = 7.84E+1

MUST Peak = 3.22E-4 mg/L in 10481



Maximum Impact

Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.

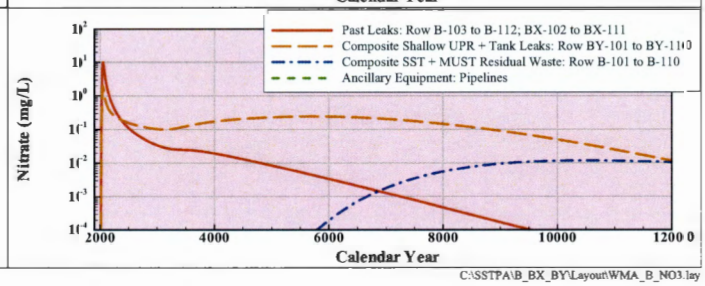


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Figure 4-38. Waste Management Area B-BX-BY Nitrite Breakthrough Curves by Waste Source Component

Nitrite
K_d = 0.0 mL/g

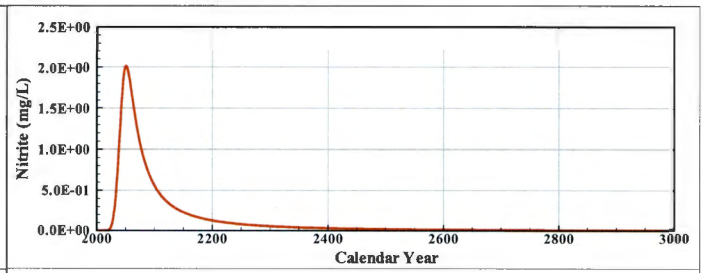
Past Releases

Past Tank Leaks on Same Pathline Tank Row B-101 to B-110

Nitrite Inventory (kg)

B-101 = 0.00E+0
B-104 = 0.00E+0
B-107 = 8.07E+2
B-110 = 1.92E+2
Sum = 9.99E+2

Peak = 2.01E+1 mg/L
Occurs in Year 2051

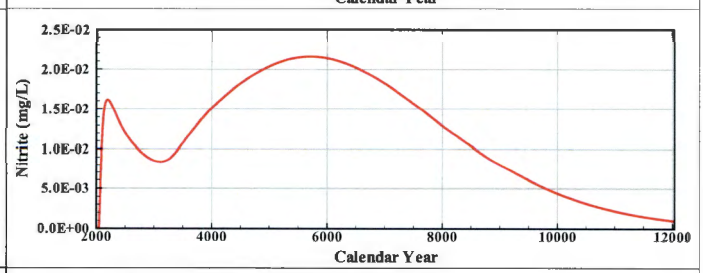


Past Shallow Releases on Same Pathline Tank Row B-101 to B-110

Nitrite Inventory (kg)

E-6 = 8.93E+0
E-38 = 8.16E+2
E-73 = 1.83E-1
E-74 = 4.25E-2
E-75 = 8.92E+0
E-109 = 4.16E+0
Sum = 8.38E+2

First Peak = 1.62E-2 mg/L in 2196
Second Peak = 2.16E-2 mg/L in 5711



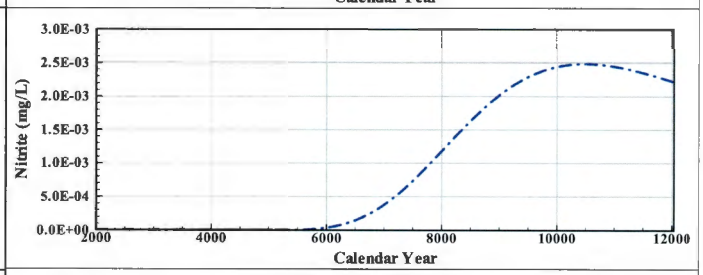
Residual Waste

SST Tank Residuals in Tank Row B-102 to BX-110

Nitrite Inventory (kg)

B-102 = 1.48E+1 | BX-101 = 6.20E+0
B-105 = 2.00E+1 | BX-104 = 6.04E+1
B-108 = 1.74E+1 | BX-107 = 2.34E+1
B-111 = 4.24E+2 | BX-110 = 3.66E+1
244-BX-DCR = 2.29
SUM = 6.05E+2

Peak = 2.49E-3 mg/L
Occurs in Year 10481

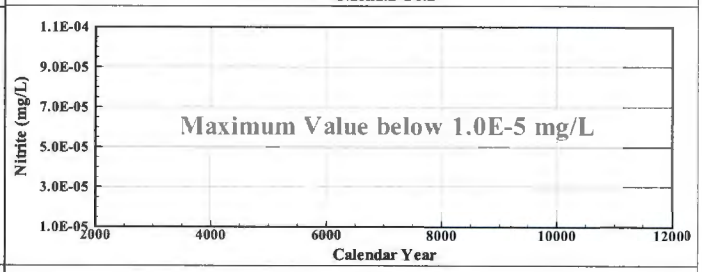


Ancillary Equipment Pipeline Residuals

Nitrite Inventory (kg)

BX Pipelines = 2.76E-2

Maximum < 1.00E-5 mg/L
at End of Simulation

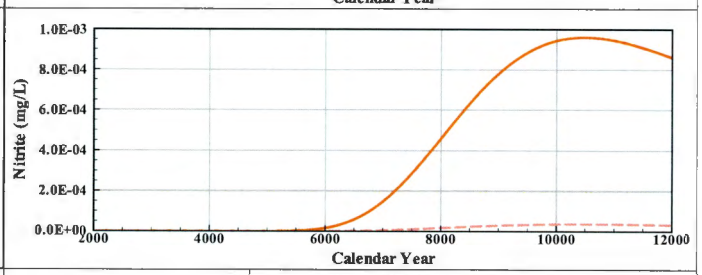


Ancillary Equipment Residuals in Same Pathline Tank Row B-101 to B-110

Nitrite (kg)

SST Residuals | MUST and BXR Vault
B-101 = 9.44E+1 | B-302 A = 8.63E-1
B-104 = 9.63E+0 | BXR Vault = 8.09E+0
B-107 = 2.63E+1
B-110 = 1.04E+2
Sum SST Resid. + Anc. Equip. = 2.51E+2

SST Peak = 9.6E-3 mg/L
MUST Peak = 3.67E-5 mg/L
Occurs in Year 10481



Maximum Impact

Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.

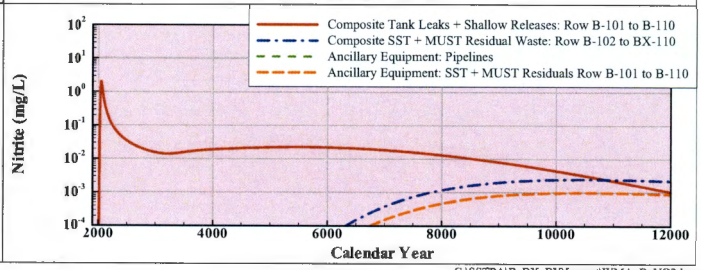


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Figure 4-39. Waste Management Area B-BX-BY Uranium Breakthrough Curves by Waste Source Component

Uranium
K_d = 0.6 mL/g

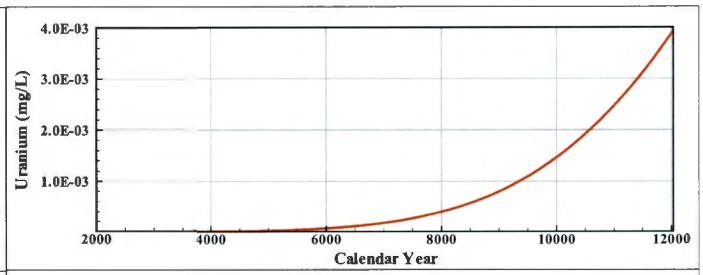
Past Releases

Past Tank Leaks on Same Pathline Tank Row B-103 to BX-111

Uranium Inventory (kg)

B-103 = 0.00E+0 | BX-102 = 1.01E+4
B-106 = 0.00E+0 | BX-105 = 0.00E+0
B-109 = 0.00E+0 | BX-108 = 2.87E-1
B-112 = 2.17E-1 | BX-111 = 0.00E+0
Sum = 1.01E+4

Peak = 3.94E-3 mg/L
Occurs in Year 12032

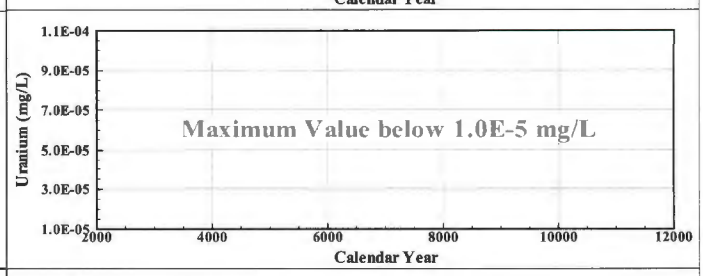


Past Shallow Releases on Same Pathline Tank Row B-101 to B-110

Uranium Inventory (kg)

Tank Leak in Row | UPR-200-
BY-101 = 0.00E+0 | E-105 = 2.70E+0
BY-104 = 0.00E+0
BY-107 = 1.41E-1
BY-110 = 0.00E+0
UPR + Tank Leak Sum = 2.84E+0

Maximum < 1.00E-5 mg/L
at End of Simulation



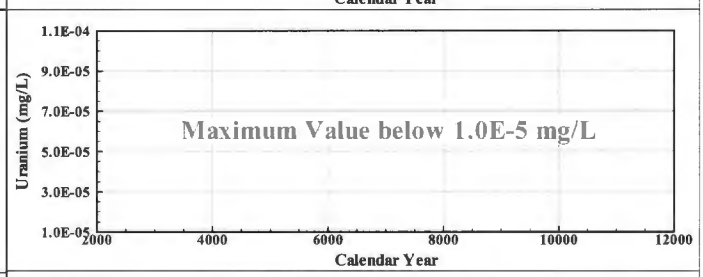
Residual Waste

SST Tank Residuals in Tank Row B-103 to BX-111

Uranium Inventory (kg)

B-103 = 2.70E+2 | BX-102 = 1.62E+1
B-106 = 4.45E+2 | BX-105 = 5.79E+2
B-109 = 2.23E+2 | BX-108 = 2.61E+2
B-112 = 8.75E+0 | BX-111 = 1.88E+1
SUM = 1.82E+3

Maximum < 1.00E-5 mg/L
at End of Simulation

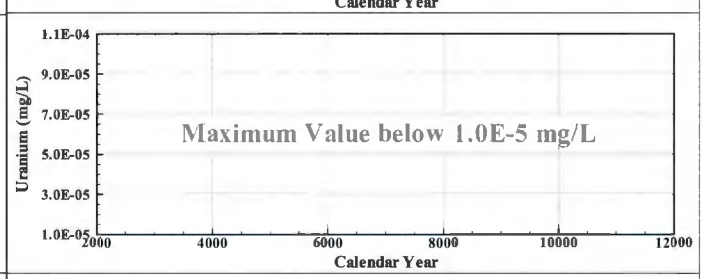


Ancillary Equipment Pipeline Residuals

Uranium Inventory (kg)

BX Pipelines = 4.25E-3

Maximum < 1.00E-5 mg/L
at End of Simulation

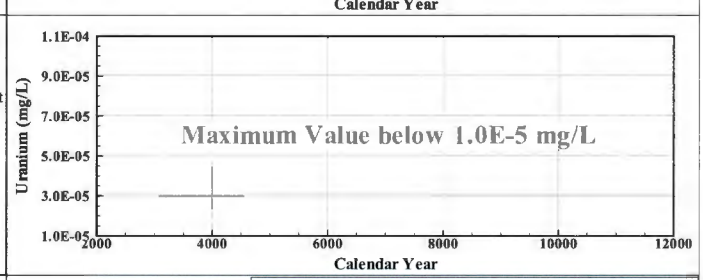


Ancillary Equipment Residuals in Same Pathline Tank Row B-101 to B-110

Uranium Inventory (kg)

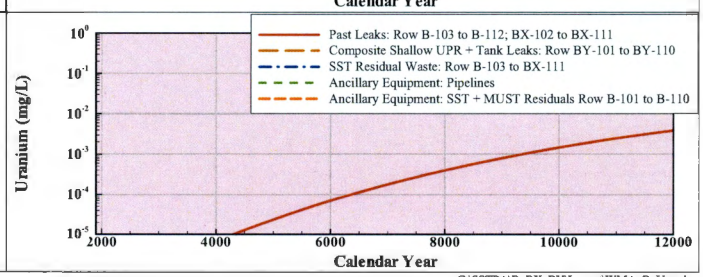
SST Residuals | MUST and BXR Vault
B-101 = 1.86E+1 | B-302 A = 6.37E-1
B-104 = 3.24E+1 | BXR Vault = 5.98E+0
B-107 = 6.48E+0
B-110 = 2.96E+1
Sum SST Resid. + Anc. Equip. = 9.37E+1

Maximum < 1.00E-5 mg/L
at End of Simulation



Maximum Impact

Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.



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4.9 LONG-TERM CONTAMINANT CONCENTRATIONS FOR WASTE MANAGEMENT AREA A-AX

This section presents the results of contaminant transport modeling for the indicator contaminants for WMA A-AX. The numerical calculation point for this analysis is the WMA A-AX fenceline. Impacts of individual source components (past releases, tank residuals, and ancillary equipment residuals) are identified.

> Significant groundwater contamination driven by tank past leaks is predicted to reach the WMA A-AX fenceline.
>
> Contamination from tank residuals has minor groundwater concentration impacts late in the simulation.
>
> The contaminant transport model developed for WMA C is used as a template for WMA A-AX.

WMA A-AX has ten primary 100-Series tanks (1,000,000 gal): six tanks arranged in two rows of three effectively parallel to groundwater flow direction (A farm) and four tanks arranged in two rows of two (AX farm) (Figure 2-79). Reference case inventory estimates were developed for each row based on the information in Chapter 3.0. Impacts to groundwater from individual waste components were then evaluated on a row-by-row basis. This section presents the modeling results for the indicator contaminants identified in Section 4.2.1 by the highest contributing row for each source component.

As noted in Section 3.2.2.1, contaminant transport models were developed for WMA C and WMA S-SX and are used as the templates for analyses for the 200 East Area and 200 West Area WMAs, respectively. The contaminant transport model designed for WMA C was coupled with WMA A-AX inventories to produce the results presented in this section. Subsequent versions of the SST PA will include WMA-specific contaminant transport models.

4.9.1 Previous Modeling Efforts for Waste Management Area A-AX

No previous site-specific modeling has been performed for WMA A-AX.

4.9.2 Waste Management Area A-AX Fenceline Results

Twenty contaminants in WMA A-AX had fenceline concentrations above the effective zero within the 10,000-year simulation period. Table 4-26 defines the tank rows in WMA A-AX and summarizes included waste sources in each row. The designation for each tank row is the lowest numbered tank in the sequence (e.g., A-101 identifies the row consisting of tanks A-101, A-102, and A-103). Such a designation is used throughout Section 4.9. After an extensive literature search, Lambert (2005) concluded that there were no plugged and blocked pipelines in WMA A-AX. Table 4-27 lists the contaminants with fenceline concentrations above the effective zero, indicating the dominant source term and the tank row providing the inventory responsible for the peak concentration.

4.9.3 Results for Waste Management Area A-AX Waste Components

For all of the indicator contaminants described in Section 4.2.1, the past releases component is the primary contributing component to fenceline concentrations in WMA A-AX. The past releases component consists of both SST past leaks and UPRs. Modeling of both source terms was the same except for the initial depth assignment (130 ft bgs for SST past leaks in the 200 East Area, 150 ft bgs for SST past leaks in the 200 West Area, and 30 ft bgs for UPRs). There are four total SST past leaks in the WMA. In A tank farm, there are leaks from three tanks, at least one in each row. In AX tank farm, there is only one tank past leak. There are no UPRs in WMA A-AX (Field and Jones 2005). Tank row A-101 is projected to contribute the highest past releases component concentrations for all the indicator contaminants considered for WMA A-AX.

For mobile contaminants, tank retrieval to HFFACO prescribed volume and inventory estimates provided in Kirkbride et al. (2005) results in tank row A-101 contributing the peak estimated fenceline concentration from tank residuals. Semi-mobile and less-mobile contaminants are not projected to have fenceline concentrations above effective zero during the simulation time frame, using the same inventories. The tank residuals component consists of residuals in SSTs and ancillary equipment (i.e., MUSTs). The MUST residuals were incorporated into tank residual calculations for each row because the SST and MUST residuals were modeled in the same manner (i.e., diffusion-limited release). The ancillary equipment residuals component in WMA A-AX consists of the 241-A-350 catch tank and 241-A-417 catch tank in row A-104, and tank AX-152 in tank row AX-101. These ancillary equipment sources provide negligible contributions to the overall concentrations for each of the indicator contaminants considered in this chapter.

Table 4-26. Waste Management Area A-AX Tank Rows and Waste Components Included in Modeling

Tank Row	Residual Waste		Past Releases	
	Tanks	Ancillary Equipment	Tank Leaks	Past Shallow Releases
A-101	241-A-101 241-A-102 241-A-103	None	241-A-103 leak	None
A-104	241-A-104 241-A-105 241-A-106	241-A-350 catch tank 241-A-417 catch tank	241-A-104 leak 241-A-105 leak	None
AX-101	241-AX-101 241-AX-103	None	None	None
AX-102	241-AX-102 241-AX-104	None	241-AX-102 leak	None

Table 4-27. Estimated Concentrations of Contaminants from All Waste Components Appearing at the Waste Management Area A-AX Fenceline

Radionuclides [a]				
Analyte Name	**Peak Concentration pCi/L**	**Dominant Source Term**	**Peak Year**	**Row with Peak Concentration**
Carbon-14	3.54E+02	Past releases	2051	A-101
Cobalt-60	1.45E-02	Past releases	2052	A-101
Technetium-99	1.03E+04	Past releases	2051	A-101
Iodine-129	6.00E-02	Past releases	9621	A-101
Nonradionuclides [b]				
Analyte Name	**Peak Concentration mg/L**	**Dominant Source Term**	**Peak Year**	**Row with Peak Concentration**
Ammonia	6.54E-02	Past releases	2051	A-101
Bismuth	1.67E-03	Past releases	2051	A-101
Cerium	5.13E-05	Tank residuals	10481	AX-101
Chloride	4.30E-01	Past releases	2051	A-101
Chromium	1.21E-01	Past releases	2051	A-101
Fluoride	7.71E-02	Past releases	2051	A-101
Hydroxide	3.00E-02	Tank residuals	10481	A-104
Lanthanum	9.59E-05	Tank residuals	10481	A-104
n-Butyl alcohol	6.86E-02	Past releases	2051	A-101
Neodymium	5.13E-05	Tank residuals	10481	AX-101
Nitrate	9.11E+00	Past releases	2051	A-101
Nitrite	5.22E+00	Past releases	2051	A-101
Oxalate	1.08E-02	Tank residuals	10481	A-101
Phosphate	2.48E-01	Past releases	2051	A-101
Sodium	1.30E+01	Past releases	2051	A-101
Sulfate	5.00E-01	Past releases	2051	A-101

[a] The following radionuclides reached the fenceline during the modeling period, but had concentrations below the effective zero (1.0E-02 pCi/L): tritium, tin-126, samarium-151, radium-226 + D, uranium-232, uranium-233, uranium-234, uranium-235 + D, uranium-236, and uranium-238 + D.

[b] The following nonradionuclides reached the fenceline during the modeling period, but had concentrations below the effective zero (1.0E-05 mg/L): aluminum, cobalt, manganese, and uranium.

Table 4-28 shows peak fenceline concentrations for radionuclides by row, and Table 4-29 shows peak fenceline concentrations for nonradionuclides by row. Both tables show concentrations from past releases and tank residuals source terms relative to the peak contributing tank row. Since ancillary equipment residuals are modeled as tank residuals, the tank residuals portion of the tables include ancillary equipment that reside within a tank row. Although the peak concentrations from different source components occur at different times, Tables 4-28 and 4-29 show that, for any given contaminant, the peak concentration resulting from past leaks is between two and five orders of magnitude greater than the peak concentration resulting from tank residuals. There are no known blocked or plugged ancillary pipelines in WMA A-AX.

Table 4-28. Waste Management Area A-AX Tank Row Peak Radionuclide Concentrations [a]

Technetium-99				
Tank Row	**Past Releases Component, Peak Year: 2051**		**Tank Residuals Component, Peak Year: 10461**	
	Peak Concentration pCi/L	**Concentration Relative to Row A-101**	**Peak Concentration pCi/L**	**Concentration Relative to Row A-101**
A-101	1.03E+04	100.00%	2.00E+01	100.00%
A-104	2.14E+03	20.78%	1.86E+00	9.30%
AX-101	NA [b]	NA	2.64E+00	13.20%
AX-102	1.62E+03	15.73%	4.64E+00	23.20%
Iodine-129				
Tank Row	**Past Releases Component, Max. Year: 9621**		**Tank Residuals Component, Time of Maximum Concentration: 12032**	
	Peak Concentration pCi/L	**Concentration Relative to Row A-101**	**Max. Concentration pCi/L [c]**	**Concentration Relative to Row with Peak Concentration**
A-101	6.00E-02	100.00%	0.00E+00	NA
A-104	0.00E+00	NA	0.00E+00	NA
AX-101	NA	NA	0.00E+00	NA
AX-102	0.00E+00	NA	0.00E+00	NA

[a] Maximum values are shaded.

[b] No past releases occur in tank row AX-101.

[c] Iodine-129 concentrations from the tank residuals component were not above effective zero (1.00E-02 pCi/L) for any row in the waste management area.

NA = not applicable

Table 4-29. Waste Management Area A-AX Tank Row Peak Nonradionuclide Concentrations [a]

Hexavalent Chromium				
	Past Releases Component, Peak Year: 2051		**Tank Residuals Component, Peak Year: 10481**	
Tank Row	**Peak Concentration mg/L**	**Concentration Relative to Row A-101**	**Peak Concentration mg/L**	**Concentration Relative to Row A-101**
A-101	1.21E-01	100.00%	4.32E-03	100.00%
A-104	1.68E-02	13.88%	4.68E-04	10.83%
AX-101	NA [b]	NA	3.61E-03	83.56%
AX-102	2.99E-03	2.47%	1.06E-04	2.45%
Nitrate				
	Past Releases Component, Peak Year: 2051		**Tank Residuals Component, Peak Year: 10481**	
Tank Row	**Peak Concentration mg/L**	**Concentration Relative to Row A-101**	**Peak Concentration mg/L**	**Concentration Relative to Row A-101**
A-101	9.11E+00	100.00%	4.10E-03	100.00%
A-104	3.53E-01	3.87%	1.08E-03	26.34%
AX-101	NA	NA	2.89E-03	70.49%
AX-102	3.93E-01	4.31%	2.42E-03	59.02%
Nitrite				
	Past Releases Component, Peak Year: 2051		**Tank Residuals Component, Peak Year: 10481**	
Tank Row	**Peak Concentration mg/L**	**Concentration Relative to Row A-101**	**Peak Concentration mg/L**	**Concentration Relative to Row A-101**
A-101	5.22E+00	100.00%	2.65E-03	100.00%
A-104	5.08E-01	9.73%	6.88E-04	25.96%
AX-101	NA	NA	1.82E-03	68.68%
AX-102	4.21E-02	0.81%	4.59E-04	17.32%
Uranium				
Uranium concentrations from the past leak and tank residuals components were not above effective zero (1.00E-05 mg/L) for any row in the waste management area.				

[a] Maximum values are shaded.

[b] No past releases occur in tank row AX-101.

NA = not applicable

Figures 4-40 through 4-45 provide the BTCs for each of the six indicator contaminants discussed in this section. Each of the first five plots in the figure is from a separate source component, with the bottom plot containing the previous plots superimposed on each other to illustrate the maximum impact. Blank plots indicate cases where the concentration for a source component does not exceed the effective zero for any tank row over the 10,000-year simulation period. In those cases, the tank row with the greatest inventory is indicated. Again, a linear scale (y-axis) is used for the individual source component plots, but in order to include the entire range of data, the maximum impact plot is shown using a logarithmic scale. Each plot represents the BTC from the tank row contributing the highest concentration for that source component. Also given in each of the plots is the time of the peak and the inventory for each of the like source terms in the row. The tank row containing the largest inventory is shown even though the peak concentration is below the effective zero.

4.9.4 Discussion of Results and Conclusions for Waste Management Area A-AX

Estimated long-term groundwater impacts from three contaminant source components (i.e., past releases inventory, tank residuals inventory, and ancillary equipment residuals inventory) in WMA A-AX were modeled. For all of the contaminants, results of the analysis indicate that the past releases component is the primary contributing source component to fenceline concentrations in WMA A-AX. The past releases component consists of past tank leaks identified in three of the four tank rows. No shallow releases (i.e., UPRs) are known to exist within WMA A-AX. Tank row A-101 is projected to contribute to the highest past leak component concentration, by nearly an order of magnitude, for five of the indicator contaminants. Uranium concentrations from the past releases component are not projected to occur above effective zero. The primary source for high concentrations predicted for this tank row is the A-103 past tank leak and associated leak inventory.

Tank retrieval to the HFFACO prescribed volume and inventories estimated by Kirkbride et al. (2005) results in tank residual impacts that are two to three orders of magnitude below those of past releases. Tank row A-101 is predicted to contribute to the highest residual waste component concentration for four of the six indicator contaminants. Iodine-129 and uranium from the tank residual component are not predicted to have fenceline groundwater concentrations above effective zero due to their lower mobility within the vadose zone (i.e., higher K_d values).

Ancillary equipment contribution to the WMA A-AX fenceline concentration estimate is negligible due to its small residual waste inventory estimate.

Due to existing vadose zone contamination and the maximum operational recharge occurring during that period, contaminants with high mobility (K_d less than 0.2 mL/g) exhibit concentration peaks that occur early in the simulation and prior to emplacement of the Modified RCRA Subtitle C Barrier. Semi-mobile contaminants (K_d = 0.2 mL/g) exhibit increasing concentrations toward the end of the simulation period, dominated by the contamination at depth source component. Contaminants with low mobility (K_d = 0.6 mL/g) are not projected to reach the fenceline during the simulation time frame.

Figure 4-40. Waste Management Area A-AX Technetium-99 Breakthrough Curves by Waste Source Component

Technetium-99
K_d = 0.0 mL/g

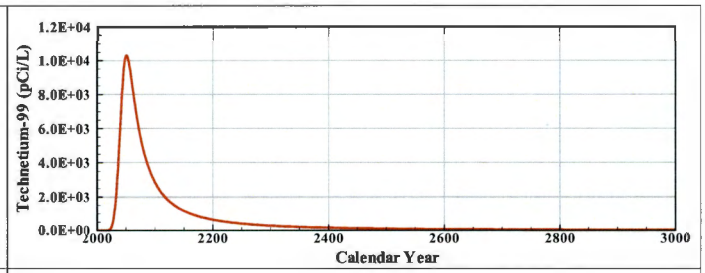
Past Releases

Past Leaks from Tanks Tank Row A-101 to A-103

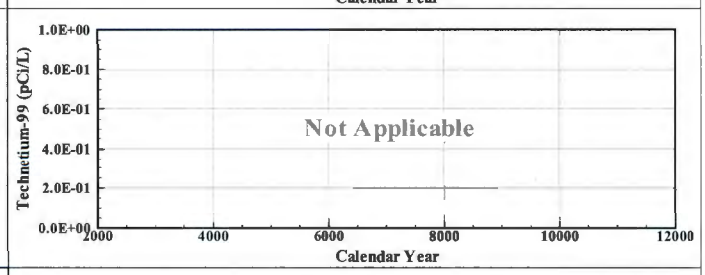
^{99}Tc Inventory (Ci)

A-101 = 0.00E+0
A-102 = 0.00E+0
A-103 = 5.11E+0
Sum = 5.11E+0

Peak = 1.03E+4 pCi/L
Occurs in Year 2051



No Shallow Releases within WMA A-AX



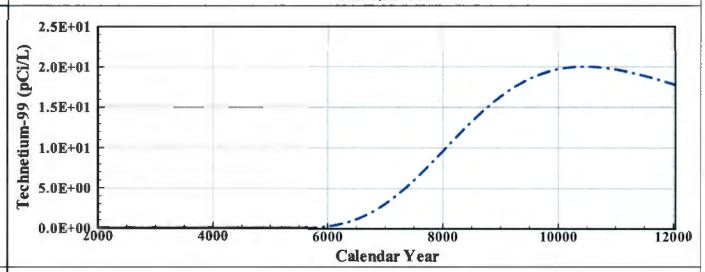
Residual Waste

Tank Residuals SST Tank Row A-101 to A-103

^{99}Tc Inventory (Ci)

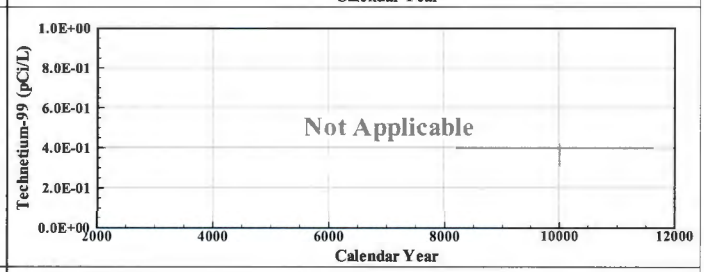
A-101 = 2.88E-1
A-102 = 3.39E+0
A-103 = 1.34E+0
SUM = 5.02E+0

Peak = 2.00E+1 pCi/L
Occurs in Year 10461



Ancillary Equipment Pipeline Residuals

No Blocked or Plugged Pipelines within WMA A-AX

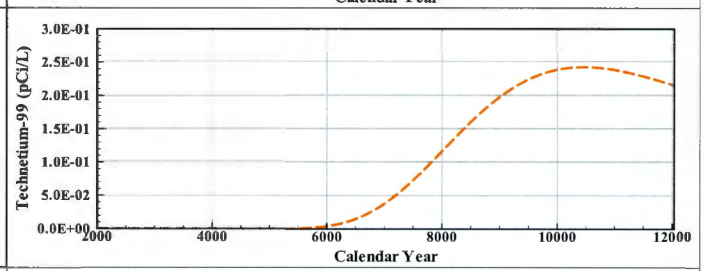


Ancillary Equipment MUST

^{99}Tc Inventory (Ci)

A-417 = 6.05E-2

Peak = 2.24E-1 pCi/L
Occurs in Year 10461



Maximum Impact

Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.

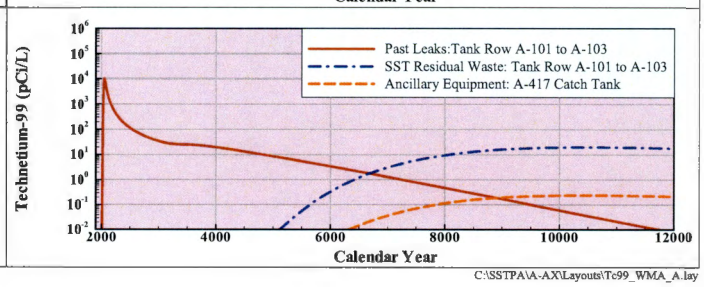


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Figure 4-41. Waste Management Area A-AX Iodine-129 Breakthrough Curves by Waste Source Component

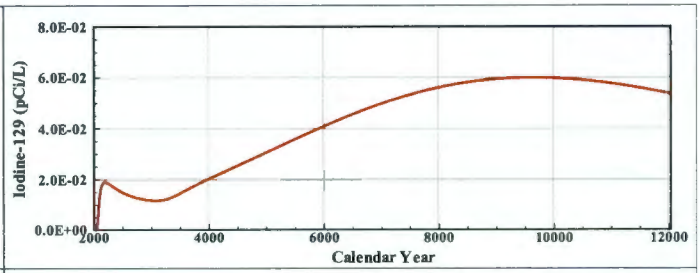
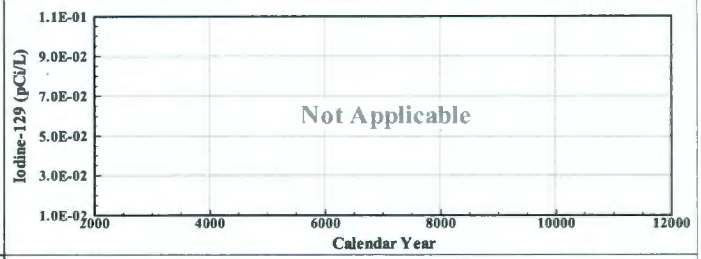
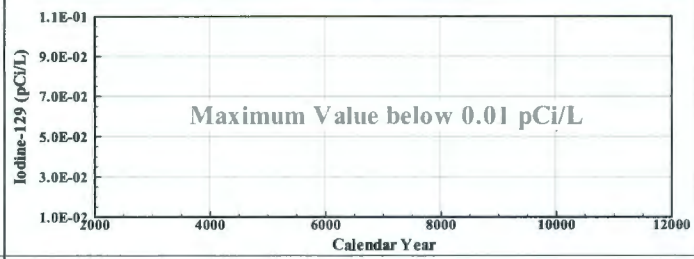
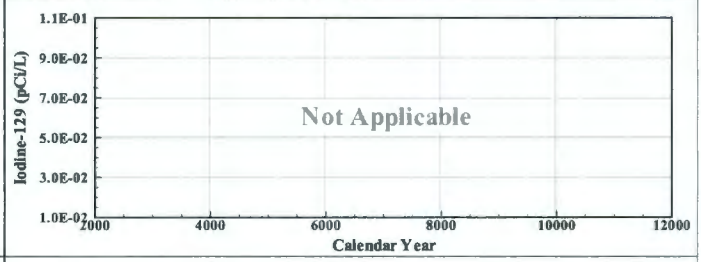
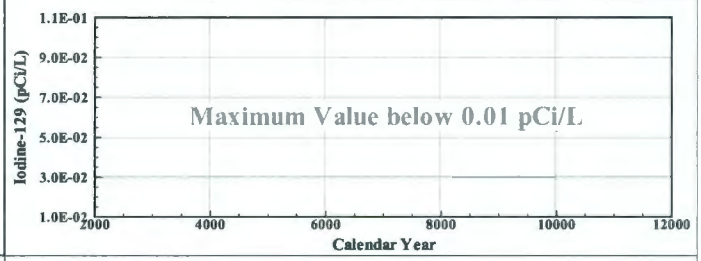
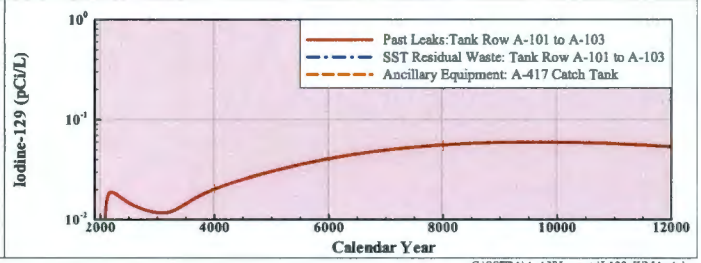
Iodine-129 **K_d = 0.2 mL/g**		
Past Releases	**Past Leaks from Tanks Tank Row A-101 to A-103** ^{129}I Inventory (Ci) A-101 = 0.00E+0 A-102 = 0.00E+0 A-103 = 5.29E-3 Sum = 5.29E-3 Peak = 6.00E-2 pCi/L Occurs in Year 9621	
	No Shallow Releases within WMA A-AX	
Residual Waste	**Tank Residuals SST Tank Row A-101 to A-103** ^{129}I Inventory (Ci) A-101 = 2.93E-4 A-102 = 3.70E-4 A-103 = 5.05E-4 SUM = 1.17E-3 Maximum < 1.0E-02 pCi/L by End of Simulation	
	Ancillary Equipment Pipeline Residuals No Blocked or Plugged Pipelines within WMA A-AX	
	Ancillary Equipment MUST ^{129}I Inventory (Ci) A-417 = 1.55E-5 Maximum < 1.0E-02 pCi/L by End of Simulation	
Maximum Impact Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.		

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Figure 4-42. Waste Management Area A-AX Hexavalent Chromium Breakthrough Curves by Waste Source Component

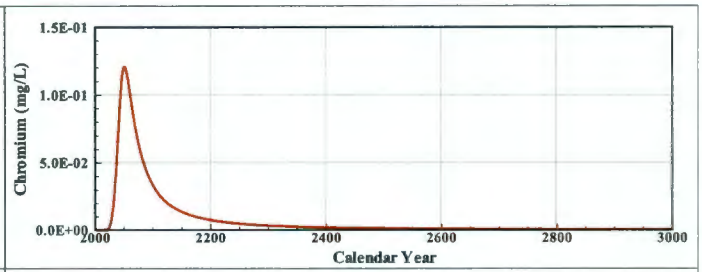
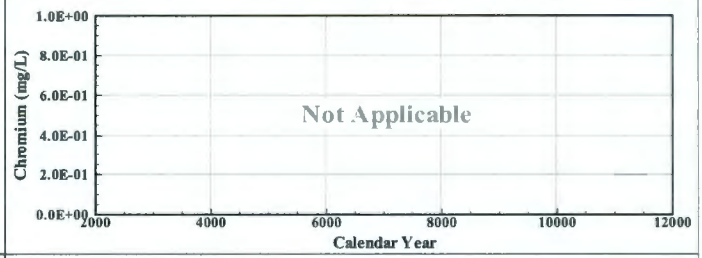
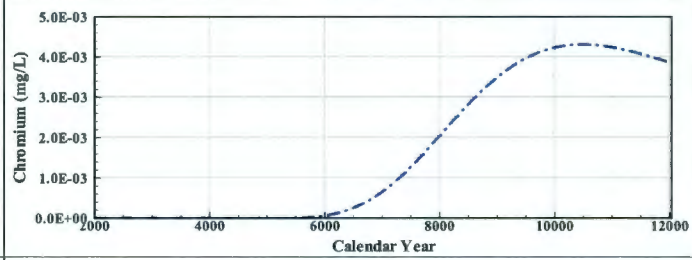
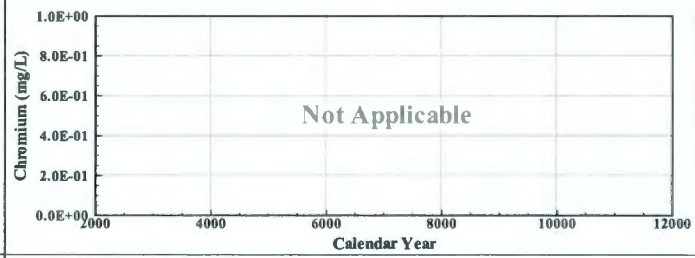
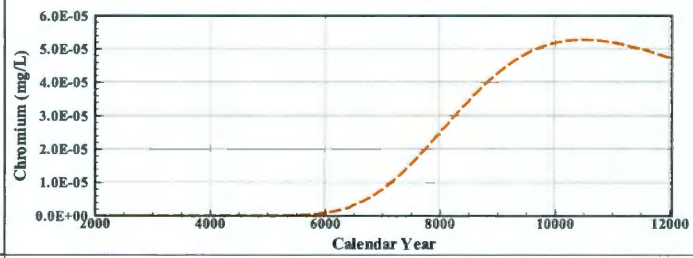
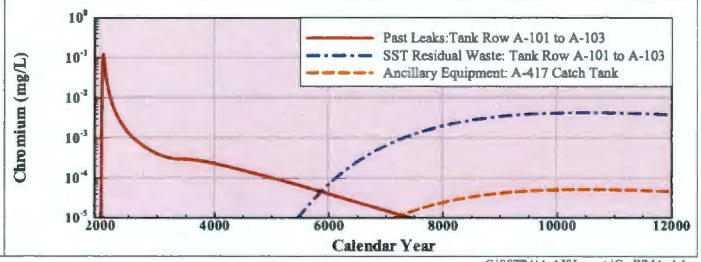
Chromium K_d **= 0.0 mL/g**	**Past Leaks from Tanks Tank Row A-101 to A-103** Chromium (kg) A-101 = 0.00E+0 A-102 = 0.00E+0 A-103 = 5.99E+1 Sum = 5.99E+1 Peak = 1.21E-1 mg/L Occurs in Year 2051	
Past Releases	No Shallow Releases within WMA A-AX	
Residual Waste	**Tank Residuals SST Tank Row A-101 to A-103** Chromium (kg) A-101 = 6.52E+2 A-102 = 2.92E+2 A-103 = 1.08E+2 SUM = 1.05E+3 Peak = 4.32E-3 mg/L Occurs in Year 10481	
	Ancillary Equipment Pipeline Residuals No Blocked or Plugged Pipelines within WMA A-AX	
	Ancillary Equipment MUST Chromium (kg) A-417 = 1.29E+1 Peak = 5.28E-5 mg/L Occurs in Year 10481	
Maximum Impact Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.		

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Figure 4-43. Waste Management Area A-AX Nitrate Breakthrough Curves by Waste Source Component

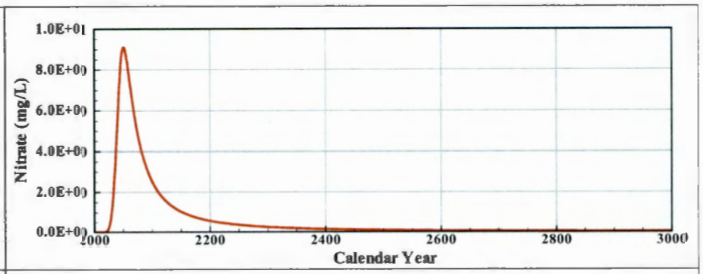
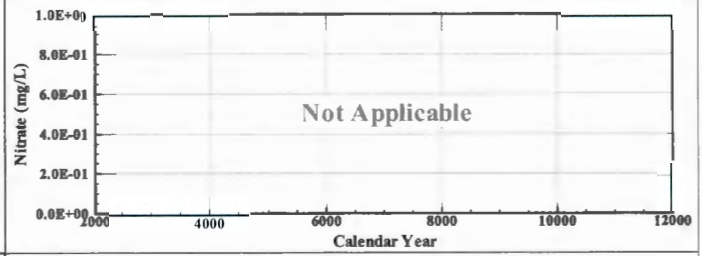
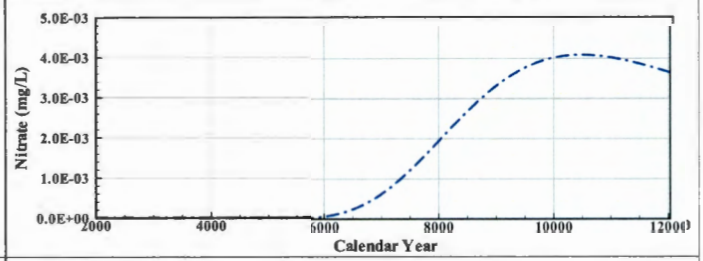
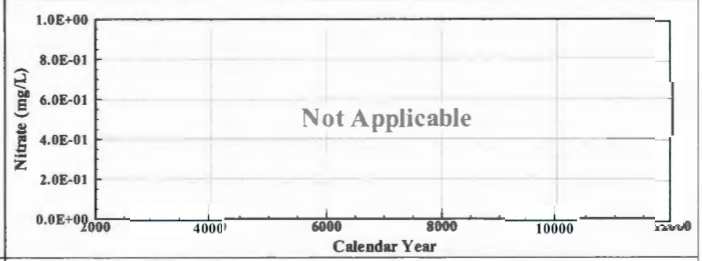
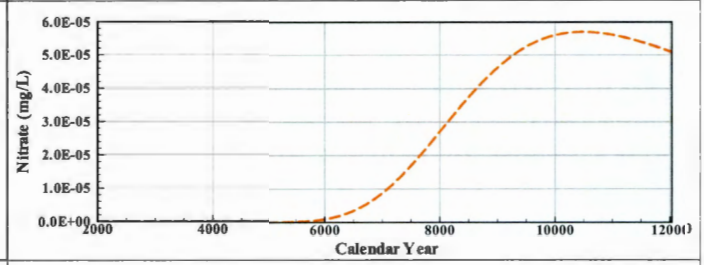
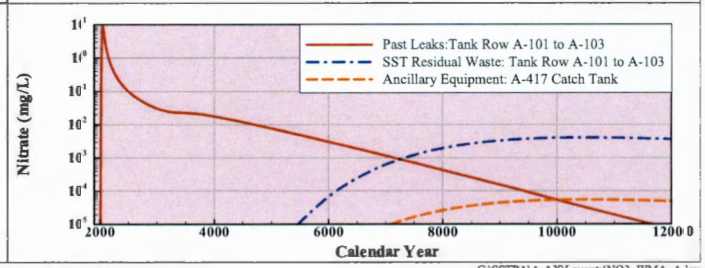
Nitrate **K_d = 0.0 mL/g**	**Past Leaks from Tanks** **Tank Row** **A-101 to A-103** Nitrate (kg) A-101 = 0.00E+0 A-102 = 0.00E+0 A-103 = 4.52E+3 Sum = 4.52E+3 Peak = 9.11E-0 mg/L Occurs in Year 2051	
Past Releases	No Shallow Releases within WMA A-AX	
Residual Waste	**Tank Residuals** **SST Tank Row** **A-101 to A-103** Nitrate (kg) A-101 = 3.08E+2 A-102 = 3.74E+2 A-103 = 3.16E+2 SUM = 9.98E+2 Peak = 4.10E-3 mg/L Occurs in Year 10481	
	Ancillary Equipment **Pipeline Residuals** No Blocked or Plugged Pipelines within WMA A-AX	
	Ancillary Equipment **MUST** Nitrate (kg) A-417 = 1.39E+1 Peak = 5.71E-5 mg/L Occurs in Year 10481	
Maximum Impact Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.		

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Figure 4-44. Waste Management Area A-AX Nitrite Breakthrough Curves by Waste Source Component

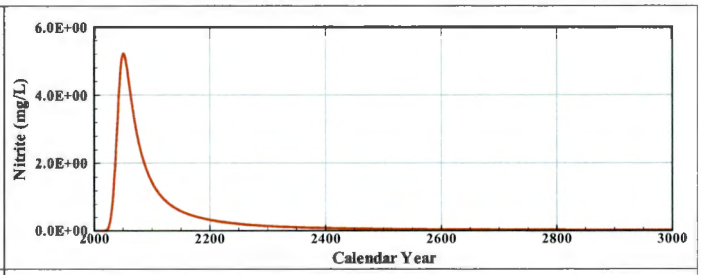
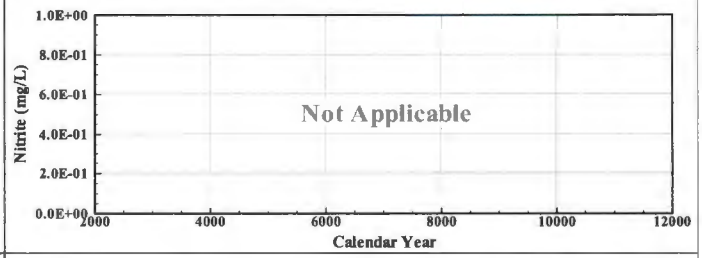
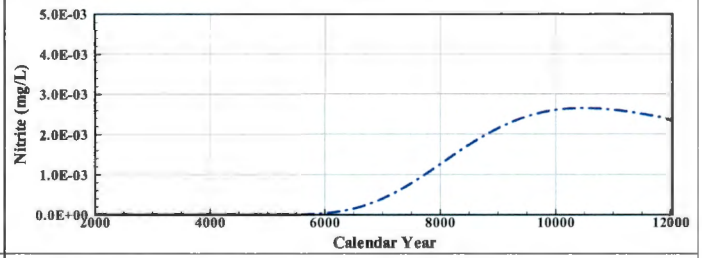
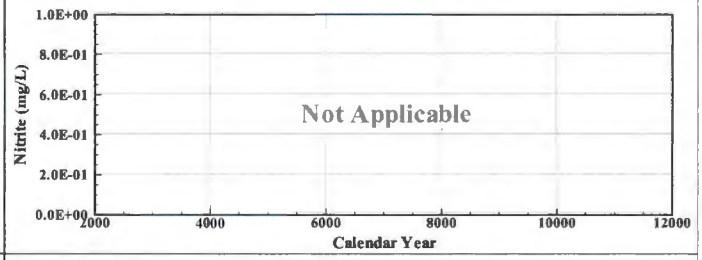
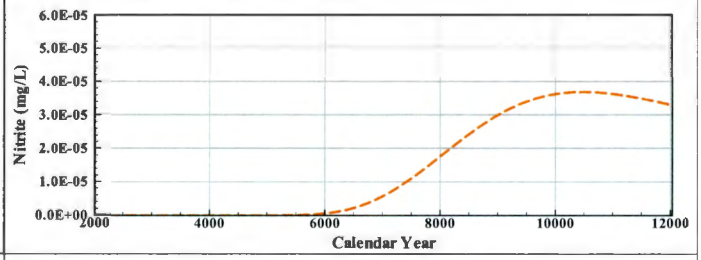
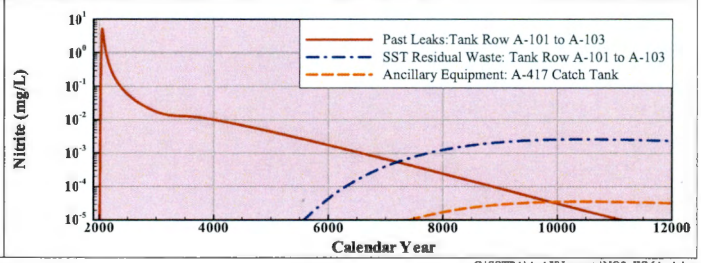
Nitrite **K_d = 0.0 mL/g**		
Past Releases	**Past Leaks from Tanks Tank Row A-101 to A-103** Nitrite (kg) A-101 = 0.00E+0 A-102 = 0.00E+0 A-103 = 2.59E+3 Sum = 2.59E+3 Peak = 5.22E+0 mg/L Occurs in Year 2051	
	No Shallow Releases within WMA A-AX	
Residual Waste	**Tank Residuals SST Tank Row A-101 to A-103** Nitrite (kg) A-101 = 1.67E+2 A-102 = 2.56E+2 A-103 = 2.22E+2 SUM = 6.45E+2 Peak = 2.65E-3 mg/L Occurs in Year 10481	
	Ancillary Equipment Pipeline Residuals No Blocked or Plugged Pipelines within WMA A-AX	
	Ancillary Equipment MUST Nitrite (kg) A-417 = 8.97E+0 Peak = 3.68E-5 mg/L Occurs in Year 10481	
Maximum Impact Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.		

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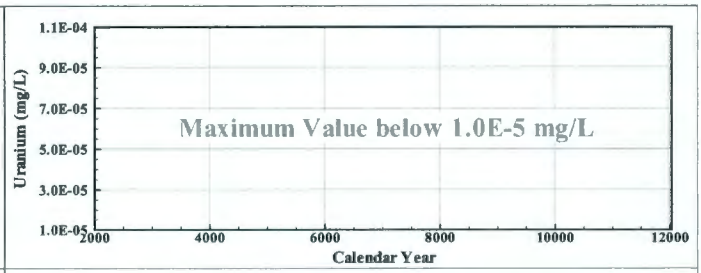
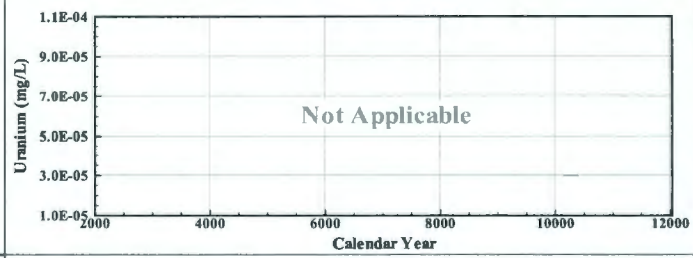
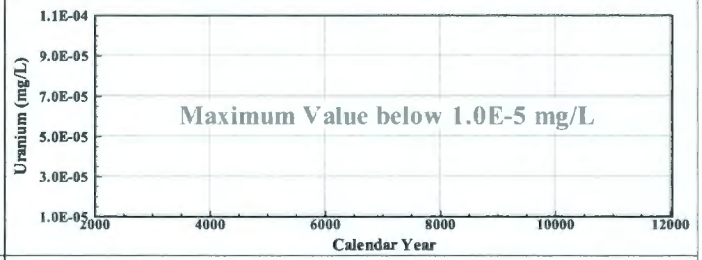
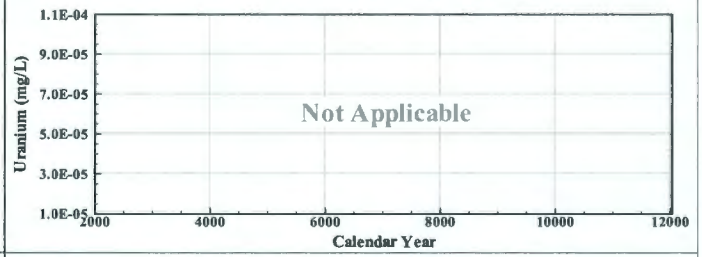
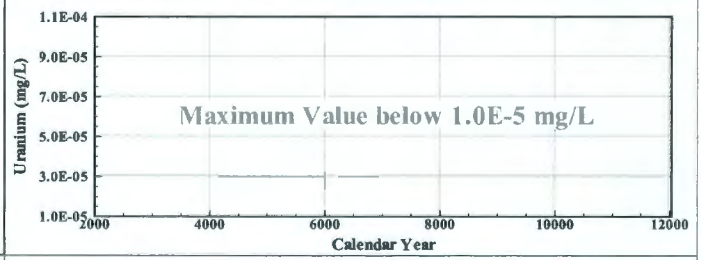
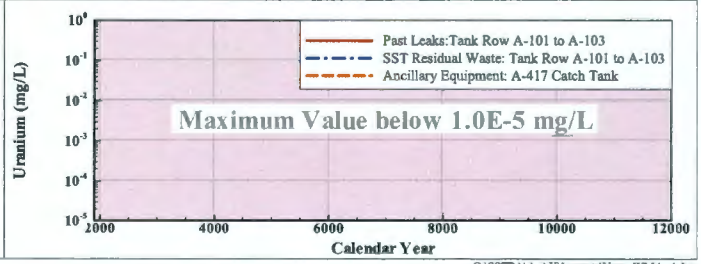
Figure 4-45. Waste Management Area A-AX Uranium Breakthrough Curves by Waste Source Component

Uranium **K_d = 0.6 mL/g**	**Past Leaks from Tanks** **Tank Row** **A-101 to A-103** Uranium (kg) A-101 = 0.00E+0 A-102 = 0.00E+0 A-103 = 6.45E-1 Sum = 6.45E-1 Maximum < 1.0E-05 mg/L by End of Simulation	
Past Releases	No Shallow Releases within WMA A-AX	
Residual Waste	**Tank Residuals** **SST Tank Row** **A-101 to A-103** Uranium (kg) A-101 = 1.84E+2 A-102 = 1.19E+3 A-103 = 1.07E+2 SUM = 1.48E+3 Maximum < 1.0E-05 mg/L by End of Simulation	
	Ancillary Equipment **Pipeline Residuals** No Blocked or Plugged Pipelines within WMA A-AX	
	Ancillary Equipment **MUST** Uranium (kg) A-417 = 1.71E+1 Maximum < 1.0E-05 mg/L by End of Simulation	
Maximum Impact Note: Shaded background indicates a change from a linear Y-Axis to a Log Y-Axis. This change in axis scale is necessary show all curves over the range of data in the same plot.		

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4.10 SUMMARY OF GROUNDWATER IMPACTS FOR THE REFERENCE CASE

Long-term groundwater modeling analysis projected the estimated groundwater concentrations for the following waste components: past releases (including past tank leaks and other UPRs), tank residuals, and ancillary equipment residuals (including plugged and blocked pipelines and MUSTs). The analysis was performed for each WMA in the SST system for a period of 10,000 years. Groundwater pathway modeling results focused on six indicator contaminants, which were selected for their range of mobility and as general water quality indicators. These six indicator contaminants and their mobilities are:

- Technetium-99 (mobile)
- Hexavalent chromium (mobile)
- Nitrite (mobile)
- Nitrate (mobile)
- Iodine-129 (semi-mobile)
- Uranium (less-mobile).

For each WMA discussed in this chapter, the past releases source component is the dominant contributor to the fenceline concentrations of mobile and semi-mobile indicator contaminants discussed in Sections 4.3 through 4.9. The past releases source term dominates due to larger inventories, greater availability to infiltrating moisture, and closer proximity (130 ft bgs for SST past leaks in the 200 East Area, 150 ft bgs for SST past leaks in the 200 West Area, and 30 ft bgs for UPRs) to the unconfined aquifer at the beginning of the simulation period. The short transport distance within the vadose zone allows mobile and semi-mobile contaminants, influenced by high pre-barrier recharge rates, to reach the unconfined aquifer early in the simulation time frame. Inventories in the tank residual source component have a longer travel distance to the unconfined aquifer and are influenced by lower, post-barrier recharge rates for the majority of their travel times. Accordingly, only the mobile contaminants in this source component are projected to have concentrations above the effective zero in all WMAs. Ancillary equipment source component contributions are orders of magnitude less than past release contributions early in the simulation time frame, when mobile past release contaminants and mobile plugged and blocked pipe contaminants arrive at the unconfined aquifer. Ancillary equipment source component contributions are less than those of the tank residuals component in the last half of the simulation time frame when contaminants from MUSTs and SSTs reach the unconfined aquifer.

For the reference case, specific results for the six indicator contaminants within the SST system are as follows:

- Technetium-99 is projected to have concentrations above the effective zero from all source terms in all WMAs except for the residuals from plugged and blocked pipelines in WMAs B-BX-BY and C. In all WMAs, the past releases source component provides the highest contaminant concentration.
- Hexavalent chromium is projected to have concentrations above the effective zero from all source terms in all WMAs except for the residuals from plugged and blocked pipelines in WMA B-BX-BY and WMA C. In all WMAs, the past releases source component provides the highest contaminant concentration.

- Nitrite is projected to have concentrations above the effective zero from all source terms in all WMAs except for the residuals from plugged and blocked pipelines in WMA B-BX-BY and WMA C. In all WMAs, the past releases source component provides the highest contaminant concentration.
- Nitrate is projected to have concentrations above effective zero from all source terms in all WMAs except for the residuals from plugged and blocked pipelines in WMA B-BX-BY. In all WMAs, the past releases source component provides the highest contaminant concentration.
- Iodine-129 is only projected to have concentrations above the effective zero from past leaks in all WMAs. No other source component provides iodine-129 concentration above effective zero in the SST system.
- Uranium is projected to occur above the effective zero only in WMA B-BX-BY for the past releases source component. This is because the largest less-mobile contaminant inventory in the SST system occurs in tank row B-103 and was placed in close proximity (130 ft bgs for SST past leaks in the 200 East Area, 150 ft bgs for SST past leaks in the 200 West Area, and 30 ft bgs for UPRs) to the unconfined aquifer at the start of the simulation period.

Table 4-30 contains the peak fenceline concentrations for the six indicator contaminants discussed in this chapter for each WMA. All of the concentrations shown in Table 4-30 are a result of inventories from the past releases component.

Table 4-30. Reference Case Peak Fenceline Concentrations for Selected Contaminants Within the Single-Shell Tank System [a]

WMA	Contaminant Fenceline Concentration					
	Tc-99 pCi/L	I-129 pCi/L	Cr^{+6} mg/L	NO_2 mg/L	NO_3 mg/L	Uranium mg/L
A-AX	1.03E+04	6.00E-02	1.21E-01	5.22E+00	9.11E+00	0.00E+00
B-BX-BY	9.03E+03	9.82E-02	1.70E-01	2.02E+00	1.01E+01	3.94E-03
C	5.65E+02	3.09E-02	1.35E-02	1.02E+00	2.71E+00	0.00E+00
S-SX	1.92E+05	9.18E-01	5.22E+00	1.89E+02	3.93E+02	0.00E+00
T	3.44E+05	7.02E-01	4.64E+00	1.23E+02	2.72E+02	0.00E+00
TX-TY	4.03E+04	1.37E-01	7.96E-01	2.31E+01	3.49E+02	0.00E+00
U	1.95E+04	6.75E-02	7.00E-01	1.15E+01	3.94E+01	0.00E+00

[a] Maximum concentrations are shaded.

The highest technetium-99 fenceline concentration in the SST system occurs in WMA T and is the result of the 1973 T-106 tank leak (Wood et al. 2001). The 115,000 gal T-106 leak is the largest and most thoroughly documented single-shell tank leak at the Hanford Site. The large technetium-99 inventory associated with this leak and its close proximity to the water table at the beginning of the simulation results in the peak fenceline concentration.

WMA S-SX has the highest fenceline concentration for iodine-129, hexavalent chromium, nitrite, and nitrate; these high concentrations are caused by inventory estimates associated with SX-107, SX-108, and SX-109 tank leaks, which together contributed 52,000 gal of leaked tank supernate (Field and Jones 2005). The large contaminant inventories and their close proximity to the water table at the beginning of the simulation result in the peak concentrations exhibited at WMA S-SX.

WMA B-BX-BY is the only WMA in the SST system projected to have a fenceline concentration of uranium within the 10,000-year simulation time frame. Typically, uranium is not projected to exhibit concentrations greater than effective zero because of its low mobility (K_d = 0.6 mL/g). Uranium inventories from past leaks in other WMAs do not have sufficient inventory at depth to result in appreciable concentrations. The past tank leak inventory from tank BX-102 contains $1.01 \times 10^{+4}$ kg of uranium, the largest uranium past release inventory in the entire SST system, at over 50 times more than the next highest past release uranium inventory (tank U-104 past tank leak, $1.79 \times 10^{+2}$ kg). Knepp (2002b) attributes this large inventory mostly to a tank overfill event in 1951. Such a large inventory in proximity to the water table ensures that enough uranium will transport to the water table to result in a fenceline concentration greater than effective zero, despite the low mobility of uranium.

For the reference case, WMA S-SX and WMA T, both 200 West Area WMAs, dominate the peak concentration projections within the SST system for all the indicator contaminants considered for this chapter except uranium. 200 East Area WMAs generally exhibit lower projected fenceline concentrations for all indicator contaminants discussed in this chapter except uranium. For the WMAs in the 200 East Area, peak fenceline concentrations for technetium-99 and nitrate occur in WMA A-AX, and peak fenceline concentrations for iodine-129, hexavalent chromium, nitrate, and uranium occur in WMA B-BX-BY. Fenceline concentrations for all indicator contaminants except uranium are within an order of magnitude between WMA A-AX and WMA B-BX-BY.

4.11 SUMMARY OF RESULTS OF SENSITIVITY AND "WHAT IF" ANALYSES

Sensitivity and "what if" analyses evaluate changes in estimated groundwater impacts that result from changes in modeling input parameter estimates, either individually or some cumulatively. Parameter value ranges used in these analyses were selected to reflect the inherent variability of site-specific conditions. In general, sensitivity analyses refer to changes in parameter estimates to address variability in the reference case model parameters. The sensitivity analyses evaluate the effects on the fenceline groundwater concentrations of modifying the parameter in question to the high or low value in the possible range. The "what if" analyses refer to changes in assumptions regarding events that may or may not happen in the future, which, in turn, cause changes in modeling input parameters. The results of these analyses indicate what changes in parameters may cause the largest variability in the results, and how much changes in certain parameters, which are variable by their nature or dependent on future events, may cause the results to vary.

Sensitivity and "what if" analyses evaluate changes in estimated groundwater impacts to determine which parameters that are variable by their nature have the largest impacts on the results.

Primary sources of variability in parameter values are natural system heterogeneities, long-term engineered barrier performance and human actions. Unlike classic uncertainty analyses, these variability analyses estimate a range of future impacts without assigning a likelihood of occurrence to a particular result other than a qualitative expectation that the actual outcome should tend toward the reference case estimate. This approach to variability was selected for several reasons:

- Most performance objectives are deterministic.
- In general, there is a sufficient understanding of "how the system works."
- Existing databases support and provide a reasonable quantification of the range of parameters, but not necessarily the probability distribution of the parameters.
- In general, the results indicate that the determination of performance adequacy is obvious over the range of future impacts estimated by the variability analysis.

The sensitivity and "what if" analyses quantify the ranges of plausible estimated groundwater contamination outcomes due to single parameter site-specific variability, and determine the relative importance between parameters. With respect to the defense in depth concept, the analyses quantify impacts of cumulative parameter variability on groundwater contamination estimates to evaluate the impacts of barrier degradation on total system performance. Ranges of plausible future groundwater contamination levels can be estimated that are derived from disposal system (natural and engineered components) variability. These estimates can provide a reliable determination of system performance adequacy with regard to performance criteria involving the use of contaminated groundwater. These analysis results are an effective tool for making closure action decisions and determining necessary future data collection activities that support SST WMA closure.

To estimate the sensitivity of the fenceline concentration estimate to the variability of a particular parameter, a sensitivity and "what if" case result is compared to the relevant reference case result. This is done by calculating ratios of the two maximum value estimates. If the ratio is less than 1, then the specific change in parameter or assumption produces a lower peak or maximum concentration than the reference case parameters and assumptions. If the ratio is greater than 1, then the change produces a greater peak or maximum concentration than the reference case. If the ratio is equal to 1, then the change produces no change in peak or maximum concentration from the reference case. From these comparisons, several key observations and conclusions were drawn:

- The most influential parameters (i.e., those that caused the greatest variation in maximum concentrations relative to the reference case value) differed depending on the contaminant (e.g., mobile, semi-mobile or less-mobile) and waste type (tank residual waste or past releases).
  - For mobile contaminants ($K_d = 0$ mL/g) in tank residual waste, the most significant parameter is recharge rate after barrier emplacement and either the loss of institutional control (300 years after closure) or after the design life of the barrier (500 years after closure).

  - For mobile contaminants in past releases, the most significant parameter is the recharge rate during the operational period.
  - For semi-mobile contaminants (K_d = 0.2 mL/g) in past releases, the most significant parameters are the sorption coefficient and recharge rates, either pre- or post-barrier placement depending on the K_d value.
- Changes in the vadose zone and unconfined aquifer hydrogeologic properties produced similar effects on maximum value variability, regardless of contaminant and waste type.
- Within the range of parameter values estimated to reflect plausible variability in geologic features and engineered system components of the defense in depth elements, maximum values increased or decreased by factors less than 10.
- Maximum value increases or decreases because of cumulative parameter variability (i.e., parameter value changes acting simultaneously to change maximum value estimates) changed by factors of less than 10 for mobile contaminants, and by factors of less than 50 for semi-mobile contaminants.
- The impacts of single defense in depth barrier underperformance on overall system performance for most barriers increased maximum values by about a factor of 10.

The parameters that caused the greatest variation in the results differed depending on the contaminant mobility and waste type. For mobile contaminants in tank residual waste, the most significant parameter is recharge rate after barrier emplacement. For mobile contaminants in past releases, the most significant parameter is the recharge rate during the operational period. For semi-mobile contaminants in past releases, the most significant parameters are the sorption coefficient (K_d value) and recharge rates.

Sections 4.11.1 through 4.11.3 present the sensitivity and "what if" case results in three categories: 1) changes in recharge, 2) changes in source term characteristics (e.g., inventory, release mechanism, initial location, vadose zone retardation), and 3) changes in hydrologic parameters. The recharge sensitivity and "what if" simulation cases examine the impacts of changes in recharge rate estimates during both pre- and post-barrier performance periods. The recharge category addresses those elements of the defense in depth associated with the surface barrier function. The contaminant source term characteristics cases examine the impacts of changes in the contaminant source inventory and release. The source term characteristics category addresses those elements of the defense in depth associated with the grouted tank structure function. The hydrologic cases examine the impacts of changes in the mobility of the contaminants, the location of the past release source, and the hydrologic parameters and assumptions. The hydrology category addresses those elements of the defense in depth associated with the vadose zone function.

These analyses provided comparisons to the WMAs C and S-SX reference case results. These results covered the effects of 200 West Area versus 200 East Area hydrogeology on estimated groundwater impacts. Second, sensitivity analyses were made only for reference case results for source term contaminant inventory releases associated with past leaks and tank residuals. The "what if" comparison cases included those sources, as well as retrieval leaks,

which were not included in the reference case analysis. Finally, comparisons were made for reference case results involving three specific contaminants, technetium-99, iodine-129, and uranium. These contaminants encompass the range of contaminant mobility considered in the reference case analyses. Following the presentation of the results for each category of analyses in the two WMAs is a results integration summary that relates the individual results to the impact on the defense in depth barrier effected by the sensitivity and "what if" change in parameters.

The "what if" analysis also includes some cases that are postulated only to demonstrate the impacts of known phenomena (e.g., what is the effect of not assuming anisotropy in hydraulic conductivity for the vadose zone geologic units). A detailed description of the selected alternative conditions and cases and reasons for selecting these particular cases is provided in Section 3.5.

Section 4.11.4 presents comparisons of individual parameter variability effects on groundwater contaminant levels as a function of contaminant and waste type combination. The comparisons consider the entire parameter set. The primary contaminant and waste type combinations considered were those that yielded non-negligible contamination levels in the unconfined aquifer in the reference cases. These included mobile contaminants in tank residual wastes, and mobile and semi-mobile contaminants in past releases. Some high recharge rate sensitivity and "what if" cases resulted in non-negligible groundwater contamination levels for contaminant and waste type combinations that yielded in the reference case, at most, negligible groundwater contamination levels within the simulation period. These are also discussed briefly.

Section 4.11.5 presents estimates of cumulative parameter variability effects on groundwater contaminant levels for the contaminant and waste type combinations. Cumulative parameter variability assumes that the variability of multiple parameter values are simultaneously influencing contaminant migration and maximum value estimates. Cumulative variability factors may be used to estimate plausible ranges of maximum values around reference case values.

Section 4.11.6 evaluates the impacts of single barrier underperformance on total system performance. Cumulative variability factors (referred to in these analyses as cumulative underperformance factors) were estimated to gauge potential increases in maximum values because of barrier underperformance. Barrier performance for tank residuals and past releases were considered. For tank residuals, this analysis addresses the robustness of the multiple barrier system (surface barrier, grouted tank structure, and vadose zone) derived to implement the defense in depth philosophy. For past releases, this analysis evaluates the ability of the total system to mitigate groundwater impacts if one of two barriers (surface barrier or vadose zone) underperforms.

Single barrier underperformance degrades overall system performance by a factor of about 10.

4.11.1 Recharge

In the context of the defense in depth strategy, the recharge category of sensitivity and "what if" analysis cases primarily addresses the protection of groundwater provided by the surface barrier. The results of the sensitivity and "what if" analyses indicate that the key elements of this defense element are the:

- Post-design recharge rate
- Timing of barrier placement
- Estimate of recharge occurring during the operational period.

The post-design recharge rate affects the peak concentration of mobile, semi-mobile, and less-mobile contaminants from tank residuals, and the peak concentration of semi-mobile and less-mobile contaminants from past releases. The post-design recharge rate does not affect the peak concentration of mobile contaminants from past releases; these concentrations peak before the end of barrier design life. The timing of barrier placement and the estimate of recharge occurring during the operational period affects peak concentration of mobile and semi-mobile contaminants from past releases. The timing has no effect on contaminant concentrations of less-mobile contaminants from either source, or any contaminants from tank residuals. The barrier performance during its design life appears to be inconsequential (within the estimated range of barrier effectiveness).

Key elements of the of the surface barrier performance are the post-design recharge rate, timing of barrier placement, and estimate of recharge occurring during the operational period.

Recharge sensitivity and "what if" cases examine the effects of changing parameters related to recharge on contaminant concentrations at the WMA fenceline. The following parameter effects were considered in the recharge analyses:

- Changes in the recharge rate during the tank farm operational period (1945 to 2032 for WMA C and 1952 to 2032 for WMA S-SX) (sensitivity analyses):
  - Reference case is 100 mm/yr
  - High case is 140 mm/yr (feature/process P1 maximum in Table 3-14)
  - Low case is 40 mm/yr (feature/process P1 minimum in Table 3-14)
- Recharge rate changes during and after the design life of the barrier (years 2032 to 2532) (sensitivity analyses):
  - Reference case is 0.5 mm/yr during the design life of the barrier
  - High case is 1.0 mm/yr during the design life of the barrier (feature/process P2 maximum in Table 3-14)
  - Low case is 0.1 mm/yr during the design life of the barrier (feature/process P2 minimum in Table 3-14)
  - Reference case is 1.0 mm/yr after the design life of the barrier

  - High case is 3.5 mm/yr after the design life of the barrier (feature/process P3 maximum in Table 3-14)
  - Low case is 0.5 mm/yr after the design life of the barrier (feature/process P3 minimum in Table 3-14)
  - Barrier failure in year 2332 (3.0 mm/yr at WMA C in 200 East and 4.0 mm/yr at WMA S-SX in 200 West Area) (alternative A8 in Table 3-15)
  - Barrier failure in year 2532 (3.0 mm/yr at WMA C in 200 East and 4.0 mm/yr at WMA S-SX in 200 West Area) (alternative A7 in Table 3-15)
  - Irrigated farming begins in year 2532 (50 mm/yr) (alternative A6 in Table 3-15)
- Changes in recharge resulting from different emplacement times of the barrier ("what if" analyses):
  - Reference case is final barrier placed over WMAs in year 2032
  - Interim barrier placement in year 2010 over past leaks (alternative A3 in Table 3-15)
  - Final barrier placed over WMAs in year 2020 (alternative A1 in Table 3-15)
  - Final barrier placed over WMAs in year 2050 (alternative A2 in Table 3-15).

4.11.1.1 Waste Management Area C

Recharge rates during operational period of the WMA, the design life of the barrier, or time of placement appear to have little to no impact on contaminant concentrations resulting from the release of post-closure tank residual waste (Table 4-31, rows 2-5 and 8-9). However, what happens after the design life of the barrier of 500 years does affect the resulting maximum concentrations (Table 4-31, rows 6-7 and 10-11) over the ranges in these parameters investigated in this SST PA. The maximum technetium-99 concentrations resulting from the release of post-closure tank residual waste appear essentially insensitive to changes in the operational recharge rate, the changes in recharge rate during the design life of the barrier, or time of placement, but is sensitive to the recharge estimate for the degraded barrier. If the barrier degrades after 300 or 500 years and the recharge approaches the pre-Hanford recharge estimate, then the maximum technetium-99 concentration is greater than the reference case concentration (Table 4-31, row 1) by almost a factor of 2 (Table 4-31, row 7). If farming occurs after 500 years and the recharge rate then equals 50 mm/yr (Table 4-31, row 10), then the maximum concentration is greater than the reference case concentration (Table 4-31, row 1) by a factor of almost 14. If the barrier indefinitely maintains integrity (Table 4-31, row 6), then the maximum technetium 99 concentration is one quarter of the reference case concentration (Table 4-31, row 1). The iodine-129 maximum concentration only exceeded effective zero when the recharge rate equaled or exceeded 3.0 mm/yr (Table 4-31, rows 19, 22-24) after 300 years (the end of institutional control) or 500 years (the barrier design life). The maximum concentration of uranium exceeded effective zero only when farming was assumed to occur after 500 years (Table 4-31, row 34). No ratios for these contaminants can be calculated because the reference case results (Table 4-31, row 25) are effectively zero.

Table 4-31. Waste Management Area C Recharge Sensitivity and "What If" Cases for Tank Waste Residual Releases (3 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: Tank row C-103 (1.46E+00 Ci) [a]	5.81E+00	10461	1
	Sensitivity Cases [b]			
2	Operational recharge: 40 mm/yr (100 mm/yr)	5.82E+00	10461	1.00
3	Operational recharge: 140 mm/yr (100 mm/yr)	5.81E+00	10461	1.00
4	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	5.92E+00	10491	1.02
5	Barrier recharge: 1 mm/yr (0.5 mm/yr)	5.69E+00	10431	0.98
6	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	1.47E+00	12032	0.25
7	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	1.22E+01	5001	2.10
	What If Cases [b]			
8	Barrier placement in year 2020 (year 2032)	5.82E+00	10461	1.00
9	Barrier placement in year 2050 (year 2032)	5.71E+00	10481	0.98
10	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	8.10E+01	2791	13.94
11	Barrier failure in year 2532: 3 mm/yr (1.0 mm/yr)	1.11E+01	5381	1.91
12	Barrier failure in year 2332: 3 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	1.04E+01	5281	1.79

Table 4-31. Waste Management Area C Recharge Sensitivity and "What If" Cases for Tank Waste Residual Releases (3 pages)

Row	Iodine-129	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
13	Reference case results: Tank row C-103 (8.64E-03 Ci) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
14	Operational recharge: 40 mm/yr (100 mm/yr)	0.00E+00	NA	NA
15	Operational recharge: 140 mm/yr (100 mm/yr)	0.00E+00	NA	NA
16	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
17	Barrier recharge: 1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
18	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	0.00E+00	NA	NA
19	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	2.99E-02	12032	NA
	What If Cases [b]			
20	Barrier placement in year 2020 (year 2032)	0.00E+00	NA	NA
21	Barrier placement in year 2050 (year 2032)	0.00E+00	NA	NA
22	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	1.60E-01	3381	NA
23	Barrier failure in year 2532: 3 mm/yr (1.0 mm/yr)	1.96E-02	12032	NA
24	Barrier Failure in year 2332: 3 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	1.98E-02	12032	NA

Table 4-31. Waste Management Area C Recharge Sensitivity and "What If" Cases for Tank Waste Residual Releases (3 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
25	Reference case results: Tank row C-103 (8.65E+02 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
26	Operational recharge: 40 mm/yr (100 mm/yr)	0.00E+00	NA	NA
27	Operational recharge: 140 mm/yr (100 mm/yr)	0.00E+00	NA	NA
28	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
29	Barrier recharge: 1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
30	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	0.00E+00	NA	NA
31	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	0.00E+00	NA	NA
	What If Cases [b]			
32	Barrier placement in year 2020 (year 2032)	0.00E+00	NA	NA
33	Barrier placement in year 2050 (year 2032)	0.00E+00	NA	NA
34	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	8.04E-03	4651	NA
35	Barrier failure in year 2532: 3 mm/yr (1.0 mm/yr)	0.00E+00	NA	NA
36	Barrier failure in year 2332: 3 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	0.00E+00	NA	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.

[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.

NA = not applicable

Recharge rates during the design life of the barrier also have little to no impact on contaminant concentrations resulting from past releases in WMA C (Table 4-32, rows 4-7). However, for ranges of parameters considered in this SST PA, the time of barrier placement, the operational recharge rate, and what happens after the design life of the barrier of 500 years do affect the resulting maximum concentrations (Table 4-32, rows 2-3, 8-10, 16,19,20, 22, 24-26, 33, 37). Placing an interim barrier in year 2010 over past contaminant releases or a final barrier over the entire farm in year 2020 reduces the peak technetium-99 concentration by about one-half (Table 4-32, row 8), but has no real effect on the maximum iodine-129 or uranium concentrations (Table 4-32, rows 21, 34) (the maximum uranium concentration fails to exceed effective zero regardless of when the barrier is emplaced). Not placing the final barrier over the entire farm until year 2050 results in higher maximum technetium-99 and iodine-129 concentrations by a factor of about 1.4 and 1.75, respectively (Table 4-32, rows 9, 22). The results are similarly sensitive to the operational recharge rate, with maximum technetium-99 and iodine-129 concentrations being 1.7 times greater for an operational recharge rate of 140 mm/yr (Table 4-32, rows 3, 16). The maximum uranium concentration fails to exceed effective zero regardless of the recharge rate during tank farm operations. If the operational recharge rate equals 40 mm/yr, the maximum technetium-99 concentration is 0.15 times (Table 4-32, row 2) the reference case concentration (Table 4-32, row 1), while the maximum iodine-129 concentration remains essentially unchanged (Table 4-32, row 15), but arrives at the fenceline about 2,400 years later.

The technetium-99, iodine-129, and uranium groundwater concentrations resulting from past releases are unaffected by assumed recharge rates during the design life of the barrier (Table 4-32, rows 4-5, 17-18, 30-31). Maximum technetium-99 concentrations remain unchanged regardless of the assumptions regarding post-barrier recharge estimates (Table 4-32, rows 6-7 and 11-13), which indicates that the majority of technetium-99 mass has entered the aquifer and passed the WMA fenceline before the barrier is in place. The ratio of the maximum iodine-129 concentration scales almost linearly with the recharge rate after closure, including the recharge rate associated with farming (Table 4-32, rows 19-20 and 24-26). No difference in maximum concentrations occurred if the barrier failed after 300 years rather than 500 years, although the peak iodine-129 concentration arrived at the fenceline about 160 years sooner (Table 4-32, rows 24-26). Uranium concentrations fail to exceed effective zero regardless of the assumptions regarding performance after the design life of the barrier, except if farming is assumed to occur (Table 4-32, row 37), then the maximum uranium concentration does exceed effective zero at the fenceline.

Table 4-32. Waste Management Area C Recharge Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: Tank row C-105 (2.80E-01 Ci) [a]	5.65E+02	2051	1
	Sensitivity Cases [b]			
2	Operational recharge: 40 mm/yr (100 mm/yr)	8.35E+01	2119	0.15
3	Operational recharge: 140 mm/yr (100 mm/yr)	9.75E+02	2042	1.73
4	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	5.65E+02	2051	1.00
5	Barrier recharge: 1 mm/yr (0.5 mm/yr)	5.65E+02	2051	1.00
6	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	5.65E+02	2051	1.00
7	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	5.65E+02	2051	1.00
	What If Cases [b]			
8	Barrier placement in year 2020 (year 2032)	3.07E+02	2050	0.54
9	Barrier placement in year 2050 (year 2032)	7.87E+02	2059	1.39
10	Interim barrier placed over past leaks in year 2010 (no interim barrier)	2.30E+02	2066	0.41
11	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	5.65E+02	2051	1.00
12	Barrier failure in year 2532: 3 mm/yr (1.0 mm/yr)	5.65E+02	2051	1.00
13	Barrier failure in year 2332: 3 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	5.65E+02	2051	1.00

Table 4-32. Waste Management Area C Recharge Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Iodine-129	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
14	Reference case results: Tank row C-105 (2.73E-03 Ci) [a]	3.09E-02	9621	1
	Sensitivity Cases [b]			
15	Operational recharge: 40 mm/yr (100 mm/yr)	3.15E-02	12032	1.02
16	Operational recharge: 140 mm/yr (100 mm/yr)	5.12E-02	2101	1.66
17	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	3.09E-02	9821	1.00
18	Barrier recharge: 1 mm/yr (0.5 mm/yr)	3.10E-02	9371	1.00
19	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	1.49E-02	12032	0.48
20	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	1.06E-01	5011	3.43
	What If Cases [b]			
21	Barrier placement in year 2020 (year 2032)	3.12E-02	10701	1.01
22	Barrier placement in year 2050 (year 2032)	5.41E-02	2120	1.75
23	Interim barrier placed over past leaks in year 2010 (no interim barrier)	3.12E-02	10951	1.01
24	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	1.40E+00	2791	45.31
25	Barrier failure in year 2532: 3 mm/yr (1.0 mm/yr)	9.15E-02	5351	2.96
26	Barrier failure in year 2332: 3 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	9.15E-02	5191	2.96

Table 4-32. Waste Management Area C Recharge Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
27	Reference case results: Tank row C-105 (7.00E-01 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
28	Operational recharge: 40 mm/yr (100 mm/yr)	0.00E+00	NA	NA
29	Operational recharge: 140 mm/yr (100 mm/yr)	0.00E+00	NA	NA
30	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
31	Barrier recharge: 1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
32	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	0.00E+00	NA	NA
33	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	1.14E-05	11121	NA
	What If Cases [b]			
34	Barrier placement in year 2020 (year 2032)	0.00E+00	NA	NA
35	Barrier placement in year 2050 (year 2032)	0.00E+00	NA	NA
36	Interim barrier placed over past leaks in year 2010 (no interim barrier)	0.00E+00	NA	NA
37	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	1.53E-04	3251	NA
38	Barrier failure in year 2532: 3 mm/yr (1.0 mm/yr)	0.00E+00	NA	NA
39	Barrier failure in year 2332: 3 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	0.00E+00	NA	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.

[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.

NA = not applicable

4.11.1.2 Waste Management Area S-SX

Similar to the results for WMA C, recharge rates during the design life of the barrier or time of placement appears to have little to no impact on contaminant concentrations resulting from the release of post-closure tank residual waste (Table 4-33, rows 4-5, 8-9, 16-17, 20-21, 28-29, 32-33). However, for the parameter ranges investigated in this SST PA, what happens after the design life of the barrier of 500 years does affect the resulting maximum concentrations (Table 4-33, rows 6-7, 10-12, 18-19, 22-24, 34 36). The maximum technetium-99 concentration

resulting from the release of post-closure tank residual waste appears to be essentially insensitive to changes in the operational recharge rate (Table 4-33, rows 2-3), the recharge rates during the design life of the barrier (Table 4-33, rows 4-5), or time of placement (Table 4-33, rows 8-9). If the barrier degrades after 300 or 500 years and recharge approaches the pre-Hanford rate (Table 4-33, rows 11-12), then the maximum technetium-99 concentration is greater than the reference case concentration (Table 4-33, row 1) by about a factor of 2. If farming occurs after 500 years and the recharge rate then equals 50 mm/yr (Table 4-33, row 10), then the maximum concentration is greater than the reference case concentration (Table 4-33, row 1) by a factor of about 12. If the barrier maintains integrity indefinitely (Table 4-33, row 6), then the maximum technetium-99 concentration is about 0.7 of the reference case concentration (Table 4-33, row 1). Iodine-129 maximum concentration only exceeds effective zero when the recharge rate after 300 or 500 years equals or exceeds 4.0 mm/yr (Table 4-33, rows 22-24). The peak uranium concentration exceeds effective zero only when farming is assumed to occur after 500 years (Table 4-33, rows 34).

Table 4-33. Waste Management Area S-SX Recharge Sensitivity and "What If" Cases for Tank Waste Residual Releases (3 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: Tank row S-104 (2.90E+00 Ci) [a]	3.55E+01	8191	1
	Sensitivity Cases [b]			
2	Operational recharge: 40 mm/yr (100 mm/yr)	3.56E+01	8191	1.00
3	Operational recharge: 140 mm/yr (100 mm/yr)	3.55E+01	8191	1.00
4	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	3.66E+01	8241	1.03
5	Barrier recharge: 1 mm/yr (0.5 mm/yr)	3.44E+01	8161	0.97
6	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	2.29E+01	12032	0.65
7	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	7.42E+01	4361	2.09
	What If Cases [b]			
8	Barrier placement in year 2020 (year 2032)	3.56E+01	8191	1.00
9	Barrier placement in year 2050 (year 2032)	3.49E+01	8211	0.98
10	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	4.32E+02	2741	12.2
11	Barrier failure in year 2532: 4 mm/yr (1.0 mm/yr)	8.08E+01	4161	2.28
12	Barrier failure in year 2332: 4 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	7.29E+01	4031	2.05

Table 4-33. Waste Management Area S-SX Recharge Sensitivity and "What If" Cases for Tank Waste Residual Releases (3 pages)

Row	Iodine-129	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
13	Reference case results: Tank row S-110 (1.43E-03 Ci) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
14	Operational recharge: 40 mm/yr (100 mm/yr)	0.00E+00	NA	NA
15	Operational recharge: 140 mm/yr (100 mm/yr)	0.00E+00	NA	NA
16	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
17	Barrier recharge: 1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
18	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	0.00E+00	NA	NA
19	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	1.40E-02	12032	NA
	What If Cases [b]			
20	Barrier placement in year 2020 (year 2032)	0.00E+00	NA	NA
21	Barrier placement in year 2050 (year 2032)	0.00E+00	NA	NA
22	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	6.34E-02	3371	NA
23	Barrier failure in year 2532: 4 mm/yr (1.0 mm/yr)	1.51E-02	11251	NA
24	Barrier failure in year 2332: 4 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	1.49E-02	11211	NA

Table 4-33. Waste Management Area S-SX Recharge Sensitivity and "What If" Cases for Tank Waste Residual Releases (3 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
25	Reference case results: Tank row S-101 (8.90E+03 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
26	Operational recharge: 40 mm/yr (100 mm/yr)	0.00E+00	NA	NA
27	Operational recharge: 140 mm/yr (100 mm/yr)	0.00E+00	NA	NA
28	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
29	Barrier recharge: 1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
30	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	0.00E+00	NA	NA
31	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	0.00E+00	NA	NA
	What If Cases [b]			
32	Barrier placement in year 2020 (year 2032)	0.00E+00	NA	NA
33	Barrier placement in year 2050 (year 2032)	0.00E+00	NA	NA
34	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	1.95E-02	4731	NA
35	Barrier failure in year 2532: 4 mm/yr (1.0 mm/yr)	1.48E-05	12032	NA
36	Barrier failure in year 2332: 4 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	1.72E-05	12032	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.

[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.

NA = not applicable

Recharge rates during the design life of the barrier have little to no impact on contaminant concentrations resulting from past releases in WMA S-SX (Table 4-34, rows 4-5, 17-18, 30-31). However, for the parameter ranges investigated in this SST PA, the time of barrier placement (Table 4-34, rows 8,10), the operational recharge rate (Table 4-34, rows 2-3), and what happens after the design life of the barrier of 500 years do affect the resulting maximum concentrations (Table 4-34, rows 19-20, 24-26). The technetium-99, iodine-129, and uranium groundwater concentrations resulting from past releases are unaffected by recharge rates during the design life of the barrier (Table 4-34, rows 4-5, 17-18, 30-31). Placing an interim barrier in year 2010 over past contaminant releases (Table 4-34, row 10), or a final barrier over the entire farm in year 2020 (Table 4-34, row 8) reduces the peak technetium-99 concentration by a factor of about one-half from the reference case results (Table 4-34, row 1), but has no real impact on the maximum iodine-129 or uranium concentrations (Table 4-34, rows 21, 23, and rows 34, 36, respectively). The maximum uranium concentration fails to exceed effective zero regardless of when the barrier is emplaced. Not placing the final barrier over the entire farm until year 2050 results in a slightly higher maximum technetium-99 concentration (Table 4-34, row 9), but has no effect on the iodine-129 maximum concentration (Table 4-34, row 22). The maximum technetium-99 concentration is similarly sensitive to the operational recharge rate, being about 1.5 times higher than if the operational recharge rate equals 140 mm/yr, (Table 4-34, row 3) and about a factor of 0.1 lower if the operational recharge rate equals 40 mm/yr (Table 4-34, row 2). The maximum iodine-129 concentration is not as sensitive to changes in the operational recharge rate (Table 4-34, row 16). It remains unchanged from the reference case result (Table 4-34, row 14) if the operational recharge rate equals 140 mm/yr (Table 4-34, row 16), although the maximum concentration arrives at the fenceline about 900 years earlier. Decreasing the operational recharge rate to 40 mm/yr only reduces the maximum concentration by a factor of about 0.8 (Table 4-34, row 15). The maximum uranium concentration fails to exceed effective zero regardless of the recharge rate during tank farm operations.

Maximum technetium-99 concentrations remain unchanged and uranium concentrations fail to exceed effective zero regardless of the assumptions regarding performance after the design life of the barrier (Table 4-34, rows 6-7, and 32-33, respectively). However, if farming occurs (Table 4-34, row 24), then the maximum uranium concentration exceeds effective zero at the fenceline. The ratio of the maximum iodine-129 concentrations scales almost linearly with the recharge rate after closure, including the recharge rate associated with the farming (Table 4-34, rows 19-20, 24 26). Virtually no difference in maximum concentrations occurs if the barrier failed after 300 years (Table 4-34, row 26) rather than after 500 years (Table 4-34, row 25), although the peak iodine-129 concentration arrives at the fenceline about 180 years sooner.

Table 4-34. Waste Management Area S-SX Recharge Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time Year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: Tank row SX-107 (2.09E+01 Ci) [a]	1.92E+05	2043	1
	Sensitivity Cases [b]			
2	Operational recharge: 40 mm/yr (100 mm/yr)	2.64E+04	2097	0.14
3	Operational recharge: 140 mm/yr (100 mm/yr)	2.84E+05	2035	1.48
4	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	1.92E+05	2043	1.00
5	Barrier recharge: 1 mm/yr (0.5 mm/yr)	1.92E+05	2043	1.00
6	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	1.92E+05	2043	1.00
7	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	1.92E+05	2043	1.00
	What If Cases [b]			
8	Barrier placement in year 2020 (year 2032)	1.00E+05	2042	0.52
9	Barrier placement in year 2050 (year 2032)	2.21E+05	2047	1.15
10	Interim barrier placed over past leaks in year 2010 (no interim barrier)	8.19E+04	2052	0.43
11	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	1.92E+05	2043	1.00
12	Barrier failure in year 2532: 4 mm/yr (1.0 mm/yr)	1.92E+05	2043	1.00
13	Barrier failure in year 2332: 4 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	1.92E+05	2043	1.00

Table 4-34. Waste Management Area S-SX Recharge Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Iodine-129	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
14	Reference case results: Tank row SX-107 (3.22E-01 Ci) [a]	9.18E-01	12032	1
	Sensitivity Cases [b]			
15	Operational recharge: 40 mm/yr (100 mm/yr)	7.40E-01	12032	0.81
16	Operational recharge: 140 mm/yr (100 mm/yr)	9.17E-01	11141	1.00
17	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	9.12E-01	12032	0.99
18	Barrier recharge: 1 mm/yr (0.5 mm/yr)	9.23E-01	12032	1.01
19	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	2.59E-01	12032	0.28
20	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	3.20E+00	5801	3.49
	What If Cases [b]			
21	Barrier placement in year 2020 (year 2032)	8.69E-01	12032	0.95
22	Barrier placement in year 2050 (year 2032)	9.19E-01	10911	1.00
23	Interim barrier placed over past leaks in year 2010 (no interim barrier)	8.45E-01	12032	0.92
24	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	4.12E+01	2831	44.88
25	Barrier failure in year 2532: 4 mm/yr (1.0 mm/yr)	3.65E+00	5431	3.98
26	Barrier failure in year 2332: 4 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	3.66E+00	5251	3.99

Table 4-34. Waste Management Area S-SX Recharge Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
27	Reference case results: Tank row SX-113 (7.59E+00 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
28	Operational recharge: 40 mm/yr (100 mm/yr)	0.00E+00	NA	NA
29	Operational recharge: 140 mm/yr (100 mm/yr)	0.00E+00	NA	NA
30	Barrier recharge: 0.1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
31	Barrier recharge: 1 mm/yr (0.5 mm/yr)	0.00E+00	NA	NA
32	Post-design barrier recharge: 0.5 mm/yr (1.0 mm/yr)	0.00E+00	NA	NA
33	Post-design barrier recharge: 3.5 mm/yr (1.0 mm/yr)	2.63E-04	12032	NA
	What If Cases [b]			
34	Barrier placement in year 2020 (year 2032)	0.00E+00	NA	NA
35	Barrier placement in year 2050 (year 2032)	0.00E+00	NA	NA
36	Interim barrier placed over past leaks in year 2010 (no interim barrier)	0.00E+00	NA	NA
37	Irrigated farming begins in year 2532, Recharge: 50 mm/yr (1.0 mm/yr)	3.79E-03	3431	NA
38	Barrier failure in year 2532: 4 mm/yr (1.0 mm/yr)	3.32E-04	12032	NA
39	Barrier failure in year 2332: 4 mm/yr (0.5 mm/yr 2332-2532, 1.0 mm/yr thereafter)	3.33E-04	12032	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.
[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.
NA = not applicable

4.11.1.3 Recharge Sensitivity and "What if" Results Integration Summary

This section provides an integration of results presented in the preceding sections for the recharge sensitivity and "what if" cases. Increased recharge increases peak concentration, but only if the waste is available for migration and the recharge rate is sufficient to transport the contaminants to groundwater at the time when the increased recharge is occurring. The fenceline concentration depends upon the flux rate of the contaminant into the groundwater. Two factors control the flux rate of contaminants into the groundwater: 1) the flux rate of the water

transporting the contaminants and 2) the amount of mass available to be transported. Thus, the peak or maximum fenceline concentration increases with increasing recharge, not only because the higher recharge results in a greater water flux (capable of transporting a greater mass of contaminants) but also because the higher recharge may transport more of the vadose zone plume center of mass closer to or into the groundwater. This outcome may be observed by reviewing and comparing the changes in technetium-99 and iodine-129 groundwater concentrations from past releases caused by changing the early time recharge rates.

The technetium-99 concentration responds disproportionately to changes in the barrier placement times and operational recharge rates. A 1.4 factor increase in recharge produces 1.66 and 1.48 factor increases at WMA C and WMA S-SX, respectively. Delaying the barrier placement until the year 2050 produces 1.39 and 1.15 factor increases at WMA C and WMA S-SX, respectively. The increases appear more responsive to changes in recharge at WMA C than at WMA S-SX because the contaminants have farther to travel through the vadose zone at WMA S-SX; thus, the plume center of mass moves closer to the water table at WMA C than at WMA S-SX before the surface barrier is emplaced. A 0.4 factor decrease in recharge produces 0.15 and 0.14 factor decreases at WMA C and WMA S-SX, respectively. The similarity and disproportion in the results when the operational recharge rate is decreased indicates that the plume center of mass at both WMAs remains too far above the water table when the surface barrier is emplaced to influence the results. The iodine-129 concentrations exhibit very little sensitivity to changes in the operational recharge rates or barrier placement times at WMA S-SX, indicating that these changes in recharge do not alter the location of the plume center of mass in the vadose zone enough when the surface barrier is emplaced to change the groundwater concentrations. At WMA C, only increasing the operational recharge rate or delaying surface barrier placement produces appreciable changes in the iodine-129 results, indicating that only the enhanced transport caused by those changes is sufficient to move the plume center of mass close enough to the water table to change the results.

Peak concentration from past releases only responds to later changes in recharge if any inventory remains within the vadose zone beyond the design life of the surface barrier. The technetium-99 center of mass from past releases either enters the water table or is close enough to it to drain into the groundwater before impacts of the surface barrier extend to that depth. Therefore, no change in the peak groundwater concentration occurs regardless of the post-barrier design life recharge rate. The iodine-129 center of mass from past releases remains far enough above the water table such that the impacts of the surface barrier do extend to that depth before it drains into the groundwater. Thus, the iodine-129 fenceline groundwater concentrations exhibit almost direct proportionality with the post-barrier design life recharge rate. Conversely, concentration peaks from tank residuals do not respond to early time recharge changes because the waste does not exit the (post-closure) tanks while water associated with that recharge is still in the vadose zone. No appreciable changes in the peak groundwater concentrations of technetium-99 and iodine-129 from tank residuals are observed in either WMA regardless of the operational recharge rate or time of surface barrier placement. The maximum contaminant concentrations resulting from past releases or tank residuals are not sensitive to the estimated recharge rates (ranging from 0.1 to 1.0 mm/yr) during the design life of the barrier. The movement of the plume during this 500-year period is so small that it is essentially inconsequential.

Surface barrier performance variability during the design life of the barrier has little to no impact on contaminant concentrations, but the operational recharge rate, the time of barrier placement, and what happens after the design life of the barrier do affect the resulting maximum concentrations.

4.11.2 Source Term Characteristics

In the context of the defense in depth strategy, the source term characteristics category of sensitivity and "what if" analysis cases primarily addresses the protection of groundwater provided by the grouted tank structure. The results of the sensitivity and "what if" analyses indicate that the key elements of this defense element are the:

- Inventory remaining in the tank after retrieval
- Release rate of contaminants from the grouted tank structure
- Release model for contaminants exiting the grouted tank structure.

The inventory, release rate, or release model of residual waste remaining in the tank after retrieval only affects the peak concentration of mobile contaminants. The peak concentration of semi-mobile and less-mobile contaminants from this waste source do not exceed effective zero at the WMA fenceline regardless of inventory, release rate, or release model.

The key elements affecting source term performance are the inventory remaining in the tank after retrieval, release rate of contaminants from the grouted tank structure, and release model for contaminants exiting the grouted tank structure.

Contaminant source term sensitivity and "what if" analyses examine the effects of varying source term related parameters on contaminant concentrations at the fenceline. The following source term related parameters were used in the contaminant inventory analyses:

- Changing the contaminant inventory of tank waste residuals (sensitivity case):
  - Reference case residuals remain 1 in. in height across tank bottom after retrieval
  - High case waste residuals remain 10 in. in height across tank bottom after retrieval (feature/process P5 maximum in Table 3-14; also alternative A12 in Table 3-15)
  - Low case waste residuals remain 0.1 in. in height across tank bottom after retrieval (feature/process P5 minimum in Table 3-14)
- Changing the rate of diffusion release of tank waste residuals (sensitivity case):
  - Reference case diffusion coefficient of tank waste residuals is 1.0×10^{-9} cm^2/s
  - High case diffusion coefficient of tank waste residuals is 1.0×10^{-8} cm^2/s (feature/process P4 maximum in Table 3-14)
  - Low case diffusion coefficient of tank waste residuals is 1.0×10^{-14} cm^2/s (feature/process P4 minimum in Table 3-14)

- Using different tank waste residual release models (advection release compared to diffusion release) ("what if" case):
  - Reference case is diffusion dominated tank waste residual release model
  - Advection dominated tank waste residual release model tank waste (alternative A11 in Table 3-15)
- Varying the volume (and hence contaminant inventory) of past release plumes (sensitivity case):
  - Reference case, high case, and low case past release volumes listed in Tables 3-10 and 3-11 (feature/process P8 of Table 3-14; also includes alternative A18 in Table 3-15)
- Varying the contaminant inventory of past release plumes ("what if" case):
  - Reference case contaminant inventory listed in Appendix C
  - Remove, treat, and dispose 50% of vadose zone contamination (alternative A19 in Table 3-15)
  - Remove, treat, and dispose 25% of vadose zone contamination (alternative A19 in Table 3-15)
  - Remove, treat, and dispose 5% of vadose zone contamination (alternative A19 in Table 3-15)
- Considering the possibility of leakage during retrieval ("what if" case):
  - Reference case is negligible leakage during retrieval
  - Retrieval leak of 8,000 gal from 100-Series tanks (alternative A9a in Table 3-15)
  - Retrieval leak of 20,000 gal from 100-Series tanks (alternative A9b in Table 3-15)
  - Retrieval leak of 400 gal from 200-Series tanks (alternative A10 in Table 3-15)
  - Retrieval leak of 8,000 gal from 100-Series tanks occurring over a past release (alternative A13 in Table 3-15).

4.11.2.1 Waste Management Area C

The contaminant concentration at the fenceline is directly proportional to the initial inventory for each source. The fenceline contaminant concentration is 10 times greater when the inventory is 10 times greater, and 10 times less when the inventory is 10 times less. The concentrations for technetium-99 are greater than 10^{-2} pCi/L over this range in tank waste residual inventory. However, because reference case assumptions of chemical retardation for iodine-129 (Table 4-35, row 7) and uranium (Table 4-35, row 13) prevent the great majority of residual tank waste from reaching the unconfined aquifer during the simulation (i.e., 10,000 years) regardless of initial inventory, the concentrations for these contaminants at the fenceline remain below 10^{-2} pCi/L for iodine-129 and 10^{-5} mg/L for uranium, even when the reference inventory is increased by a factor of 10.

Similarly, the diffusional release rate has a definite effect on contaminant concentrations resulting from the release of technetium-99 from the post-closure tank residual waste (Table 4-35, rows 2-3), but neither iodine-129 nor uranium exceed effective zero values for any selected diffusion coefficient. Increasing the diffusional release rate by a factor of 10 increases the maximum technetium-99 concentration by a factor of about 3 (Table 4-35, row 3), whereas decreasing the diffusional release rate by a factor of 10^{-5} decreases the maximum concentration by a factor of about 0.003 (Table 4-35, row 2) (Equation 3.6 in Section 3.2.2.3.2). Assuming conditions are such that the waste releases according to an advection model (rather than a diffusion model) result in an increase in maximum technetium-99 concentration by a factor of almost 8 (Table 4-35, row 6) over the reference case concentration (Table 4-35, row 1). For tank waste residual cases, neither the iodine-129 nor uranium concentration exceeds effective zero at the fenceline.

Table 4-35. Waste Management Area C Source Term Characteristics Sensitivity and "What If" Cases for Tank Waste Residual Releases (2 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: Tank row C-103 (1.46E+00 Ci) [a]	5.81E+00	10461	1
	Sensitivity Cases [b]			
2	Diffusion coefficient: 1E-14 cm^2/s (1E-09 cm^2/s)	1.84E-02	10461	0.003
3	Diffusion coefficient: 1E-08 cm^2/s (1E-09 cm^2/s)	1.84E+01	10461	3.17
4	Residue thickness: 0.1 in. (1 in.)	5.81E-01	10461	0.10
5	Residue thickness: 10 in. (1 in.)	5.81E+01	10461	10.0
	What If Cases [b]			
6	Advection dominated waste release (Diffusion dominated waste release)	4.56E+01	8441	7.85
Row	**Iodine-129**	**Maximum Concentration pCi/L**	**Maximum Concentration Arrival Time year**	**Peak Groundwater Concentration Ratios Relative to Reference Case**
7	Reference case results: Tank row C-103 (8.64E-03 Ci) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
8	Diffusion coefficient: 1E-14 cm^2/s (1E-09 cm^2/s)	0.00E+00	NA	NA
9	Diffusion coefficient: 1E-08 cm^2/s (1E-09 cm^2/s)	0.00E+00	NA	NA
10	Residue thickness: 0.1 in. (1 in.)	0.00E+00	NA	NA
11	Residue thickness: 10 in. (1 in.)	0.00E+00	NA	NA
	What If Cases [b]			
12	Advection dominated waste release (Diffusion dominated waste release)	0.00E+00	NA	NA

Table 4-35. Waste Management Area C Source Term Characteristics Sensitivity and "What If" Cases for Tank Waste Residual Releases (2 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
13	Reference case results: Tank row C-103 (8.65E+02 kg) [a]	0.00E+00	NA	NA
Sensitivity Cases [b]				
14	Diffusion coefficient: 1E-14 cm^2/s (1E-09 cm^2/s)	0.00E+00	NA	NA
15	Diffusion coefficient: 1E-08 cm^2/s (1E-09 cm^2/s)	0.00E+00	NA	NA
16	Residue thickness: 0.1 in. (1 in.)	0.00E+00	NA	NA
17	Residue thickness: 10 in. (1 in.)	0.00E+00	NA	NA
What If Cases [b]				
18	Advection dominated waste release (Diffusion dominated waste release)	0.00E+00	NA	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.

[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.

NA = not applicable

As shown in Table 3-10, the maximum leak volume estimates for tanks C-105 and C-111 are used for the reference case (Table 4-36 rows 1, 11, 21). The minimum leak volume estimates associated with these tanks are nominally 500 gal each. Past release inventory associated with these tanks was therefore not subject to a direct sensitivity analysis. If the leak volume estimate for tank C-101 changes from 1,000 gal (reference value) to 5,000 gal (maximum value), then the volume becomes comparable to the reference case size of the C-105 and C-111 past releases. However, as shown in Table 4-36 (rows 2, 11, 22), only the maximum technetium-99 concentration exceeds the reference case maximum concentration; the iodine-129 and uranium maximum concentrations remain unchanged. If the leak volume estimate for tanks C-105 and C-111 change from the reference values to 500 gal each (minimum values), the technetium-99 maximum concentration decreases by a factor of 0.4 (Table 4-36, row 3), and the iodine-129 and uranium maximum concentrations fail to exceed effective zero (Table 4-36, rows 13, 23).

Decreasing the contaminant inventory associated with past releases in WMA C (either through the process of revising past release inventory estimates or vadose zone remediation) may affect the technetium-99 and iodine-129 maximum concentrations (Table 4-36, rows 2-3, 8-10, 12-13, 18-20), but not for uranium because its maximum concentration does not exceed effective zero at the fenceline 10,000 years after closure (Table 4-36, rows 22-23, 28-30). As with the tank waste residuals, the fenceline concentration of technetium-99 and iodine-129 are scalable to the inventory and are 10 times greater when the inventory is 10 times greater, and 10 times less when the inventory is 10 times less. Therefore, removing 5, 25, or 50% of the vadose zone contamination through remedial measures reduces the maximum concentration at the fenceline by 5, 25, or 50% (Table 4-36, rows 8-10, 18-20).

The "what if" inventory evaluations include hypothetical retrieval leaks from:

- Tank row C-103 (containing C-103, C-106, C-109, and C-112 [the row with the highest technetium-99 and uranium pre-retrieval inventories])
- Tank row C-101 (containing C-101, C-104, C-107, and C-110 [the row with the highest iodine-129 pre-retrieval inventory])
- Tank row C-201 (the row of smaller 200-Series tanks containing C-201, C-202, C-203, and C-204 and those respective inventories of technetium-99, iodine-129, and uranium) (Table 4-36, rows 4-7, 14-17, 24-27).

Because the retrieval leaks are considered hypothetical, they are not included in the reference case (Table 4-36, rows 1, 11, 21). Therefore, there are no reference case concentrations to provide a comparison to the "what if" results. Because the presumed timing of these leaks is relatively near term and the leak mechanism is similar to a past release, the magnitude of the maximum contaminant concentrations resulting from hypothetical retrieval leaks is compared to the reference case concentrations resulting from past releases (the row of tanks C-102, C-105, C-108, and C-111). At WMA C, contaminant concentrations resulting from 8,000 gal hypothetical retrieval leaks are similar in magnitude to the contaminant concentrations resulting from past releases. The maximum technetium-99 concentration at the fenceline resulting from hypothetical retrieval leaks of 8,000 gal (Table 4-36, row 4) and 20,000 gal (Table 4-36, row 5) are factors of 0.2 less than and essentially equal to, respectively, the past release maximum concentrations. The maximum technetium-99 concentration at the fenceline resulting from hypothetical retrieval leaks of 400 gal from the 200-Series tanks is less than 1 pCi/L and negligible compared to the past release maximum concentration (Table 4-36, row 6). In the event an 8,000 gal retrieval leak commingled with the reference case past release in the vadose zone (Table 4-36, row 7), the resulting technetium-99 concentration is a factor of about 1.2 greater than the concentration resulting from the past release by itself. The maximum iodine-129 concentration resulting from a hypothetical retrieval leak of 20,000 gal is almost one-half the past release maximum concentration (Table 4-36, row 15). The maximum iodine-129 concentration resulting from hypothetical retrieval leaks of 400 or 8,000 gal does not exceed effective zero (Table 4-36, rows 14, 16), and having an 8,000-gal retrieval leak occur over the reference case past release (Table 4-36, row 17) results in no change in the maximum iodine-129 concentration at the fenceline. The concentration of uranium at the fenceline does not exceed effective zero up to 10,000 years post-closure regardless of the size of the hypothetical retrieval leak, even if it occurs over the reference case past release (Table 4-36, rows 24-27).

Table 4-36. Waste Management Area C Source Term Characteristics Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: Tank row C-105 (2.80E-01 Ci) [a]	5.65E+02	2051	1
	Sensitivity Cases [b]			
2	Maximum past leak inventory estimate C-101: 1.13E+00 Ci (2.80E-01 Ci)	2.27E+03	2051	4.01
3	Minimum past leak inventory estimate C-105 C-111: 1.18E-01 Ci (2.80E-01 Ci)	2.38E+02	2051	0.42
	What If Cases [b]			
4	Retrieval leak: 8,000 gal Tank rows C-103, C-106, C-109, and C-112	1.27E+02	2121	0.22
5	Retrieval leak: 20,000 gal Tank rows C-103, C-106, C-109, and C-112	5.62E+02	2086	0.99
6	Retrieval leak: 400 gal Tank rows C-103, C-106, C-109, and C-112	5.03E-02	6701	0.00
7	Retrieval leak: 8,000 gal over past leak	7.02E+02	2050	1.24
8	Vadose zone remediation 5% effective	5.37E+02	2051	0.95
9	Vadose zone remediation 25% effective	4.24E+02	2051	0.75
10	Vadose zone remediation 50% effective	2.83E+02	2051	0.50

Table 4-36. Waste Management Area C Source Term Characteristics Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Iodine-129	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
11	Reference case results: Tank row C-105 (2.73E-03 Ci) [a]	3.09E-02	9621	1
	Sensitivity Cases [b]			
12	Maximum past leak inventory estimate C-105 C-111: 2.73E-03 Ci (2.73E-03 Ci)	3.09E-02	9621	1
13	Minimum past leak inventory estimate C-105 C-111: 2.84E-04 Ci (2.73E-03 Ci)	0.00E+00	NA	0
	What If Cases [b]			
14	Retrieval leak: 8,000 gal Tank rows C-101, C-104, C-107, and C-110	0.00E+00	NA	0.00
15	Retrieval leak: 20,000 gal Tank Rows C-101, C-104, C-107, and C-110	1.38E-02	12032	0.45
16	Retrieval leak: 400 gal Tank Rows C-201, C-202, C-203, and C-204	0.00E+00	NA	0.00
17	Retrieval leak: 8,000 gal over past leak	3.08E-02	8961	1.00
18	Vadose zone remediation 5% effective	2.94E-02	9621	0.95
19	Vadose zone remediation 25% effective	2.32E-02	9621	0.75
20	Vadose zone remediation 50% effective	1.55E-02	9621	0.50

Table 4-36. Waste Management Area C Source Term Characteristics Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
21	Reference case results: Tank row C-105 (7.00E-01 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
22	Maximum past leak inventory estimate C-105 C-111: 7.00E-01 kg (7.00E-01 kg)	0.00E+00	NA	NA
23	Minimum past leak inventory estimate WMA C C-105 C-111: 1.04E-01 kg (7.00E-01 kg)	0.00E+00	NA	NA
	What If Cases [b]			
24	Retrieval leak: 8,000 gal Tank rows C-103, C-106, C-109, and C-112	0.00E+00	NA	NA
25	Retrieval leak: 20,000 gal Tank rows C-103, C-106, C-109, and C-112	0.00E+00	NA	NA
26	Retrieval leak: 400 gal Tank rows C-103, C-106, C-109, and C-112	0.00E+00	NA	NA
27	Retrieval leak: 8,000 gal over past leak	0.00E+00	NA	NA
28	Vadose zone remediation 5% effective	0.00E+00	NA	NA
29	Vadose zone remediation 25% effective	0.00E+00	NA	NA
30	Vadose zone remediation 50% effective	0.00E+00	NA	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.

[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.

NA = not applicable

4.11.2.2 Waste Management Area S-SX

As previously described for WMA C, the maximum concentration of the contaminants at the fenceline is directly scalable to the initial inventory in the post-closure tank residual waste in WMA S-SX. The fenceline concentration of technetium-99 is 10 times greater when the inventory is 10 times greater (Table 4-37, row 5), and 10 times less when the inventory is 10 times less (Table 4-37, row 4). Because reference case assumptions of chemical retardation for iodine-129 and uranium prevent the great majority of tank residual waste inventory from reaching the unconfined aquifer in the modeling analysis time (i.e., 10,000 years post-closure) regardless of initial inventory, the concentrations for these contaminants at the fenceline remain below 10^{-2} pCi/L for iodine-129 and 10^{-5} mg/L for uranium when the reference inventory is increased by a factor of 10.

The rate of diffusional release affects contaminant concentrations resulting from the release of technetium-99 from the post-closure tank residual waste. Increasing the diffusional release rate by a factor of 10 increases the maximum concentration by a factor of about 3 (Table 4-37, row 3), whereas decreasing the diffusional release rate by a factor of 10^{-5} decreases the maximum concentration by a factor of about 0.003 (Table 4-37, row 2). Neither the

concentration of iodine-129 nor uranium from tank waste residuals exceeds effective zero at the fenceline, regardless of the diffusional release rate (Table 4-37, rows 7-9, 13-15). Assuming conditions are such that the waste releases according to an advection-dominated release model (rather than a diffusion-dominated release model) (Table 4-37, row 6) result in an increase in maximum technetium-99 concentration by a factor of about 9 over the reference case concentration. Again, neither the concentration of iodine-129 nor uranium from tank waste residuals exceeds effective zero at the fenceline (Table 4-37, rows 12, 18).

Table 4-37. Waste Management Area S-SX Source Term Characteristics Sensitivity and "What If" Cases for Tank Waste Residual Releases (2 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: S-104 (2.90E+00 Ci) [a]	3.55E+01	8191	1
	Sensitivity Cases [b]			
2	Diffusion coefficient: 1E-14 cm^2/s (1E-09 cm^2/s)	1.12E-01	8191	0.0003
3	Diffusion coefficient: 1E-08 cm^2/s (1E-09 cm^2/s)	1.12E+02	8191	3.15
4	Residue thickness: 0.1 in. (1 in.)	3.55E+00	8191	0.10
5	Residue thickness: 10 in. (1 in.)	3.55E+02	8191	10.0
	What If Cases [b]			
6	Advection dominated waste release (Diffusion dominated waste release)	3.18E+02	6491	8.96
Row	**Iodine-129**	**Maximum Concentration pCi/L**	**Maximum Concentration Arrival Time year**	**Peak Groundwater Concentration Ratios Relative to Reference Case**
7	Reference case results: S-110 (1.43E-03 Ci) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
8	Diffusion coefficient: 1E-14 cm^2/s (1E-09 cm^2/s)	0.00E+00	NA	NA
9	Diffusion coefficient: 1E-08 cm^2/s (1E-09 cm^2/s)	0.00E+00	NA	NA
10	Residue thickness: 0.1 in. (1 in.)	0.00E+00	NA	NA
11	Residue thickness: 10 in. (1 in.)	0.00E+00	NA	NA
	What If Cases [b]			
12	Advection dominated waste release (Diffusion dominated waste release)	0.00E+00	NA	NA

Table 4-37. Waste Management Area S-SX Source Term Characteristics Sensitivity and "What If" Cases for Tank Waste Residual Releases (2 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
13	Reference case results: S-101 (8.90E+03 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
14	Diffusion coefficient: 1E-14 cm^2/s (1E-09 cm^2/s)	0.00E+00	NA	NA
15	Diffusion coefficient: 1E-08 cm^2/s (1E-09 cm^2/s)	0.00E+00	NA	NA
16	Residue thickness: 0.1 in. (1 in.)	0.00E+00	NA	NA
17	Residue thickness: 10 in. (1 in.)	0.00E+00	NA	NA
	What If Cases [b]			
18	Advection dominated waste release (Diffusion dominated waste release)	0.00E+00	NA	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.

[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.

NA = not applicable

As shown in Table 3-11, the reference case leak volume estimates for tanks SX-107, SX-108, and SX-109 (past release reference case row for technetium-99 and iodine-129) are between the minimum and maximum leak volume estimates associated with these tanks. The higher range volume estimates exceed the reference case for tanks SX-107, SX-108, and SX-109 cumulatively by a factor of 1.4 (Table 4-38, row 2, 12, 22), and the resulting fenceline concentration of technetium-99 and iodine-129 exceed the reference case concentrations by the same factor (Table 4-38, rows 1, 2, and 11, 12, respectively). The uranium concentration at the fenceline does not exceed effective zero regardless of the past leak inventory (Table 4-38, rows 21-23). The lower range volume estimates are less than the reference case for tanks SX-107, SX-108, and SX-109 cumulatively by a factor of 0.4, and the resulting fenceline concentration of technetium-99 and iodine-129 are less than the reference case concentrations by the same factor (Table 4-38, rows 1, 3, and 11, 13, respectively).

As with WMA C, decreasing the contaminant inventory associated with past releases in WMA S-SX (either through the process of revising past release inventory estimates or vadose zone remediation) may affect the maximum concentration of technetium-99 and iodine-129 (Table 4-38, rows 1, 8-10, and 11, 18-20, respectively). This is not true for uranium because the maximum concentration of uranium does not exceed effective zero at the fenceline 10,000 years after closure (Table 4-38, rows 21, 28-30). The fenceline concentration scales linearly with the inventory, so removing 5, 25, or 50% of the vadose zone contamination through remedial measures reduces the maximum concentration at the fenceline by 5, 25, or 50% (Table 4-38, rows 1, 8-10, and 11, 18-20, respectively).

The "what if" inventory evaluations include hypothetical retrieval leaks from:

- Tank row SX-104 (containing tanks SX-104, SX-105, and SX-106 [for technetium-99])
- Tank row SX-110 (containing tanks S-110, S-111, and S-112 [for iodine-129 and uranium])
- A row of 200-Series tanks (WMA S-SX contains no 200-Series tanks but other WMAs in 200 West Area, for which WMA S-SX is serving as a surrogate, do contain 200-Series tanks).

Table 4-38. Waste Management Area S-SX Source Term Characteristics Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: SX-107 (2.09E+01 Ci) [a]	1.92E+05	2043	1
	Sensitivity Cases [b]			
2	Maximum past leak inventory estimate SX-107 SX -108 SX-109: 3.00E+01 Ci (2.09E+01 Ci)	2.77E+05	2043	1.44
3	Minimum past leak inventory estimate SX-107 SX -108 SX-109: 8.40E+00 Ci (2.09E+01 Ci)	7.74E+04	2043	0.40
	What If Cases [b]			
4	Retrieval leak: 8,000 gal Tank row SX-104-106	1.96E+03	2066	0.01
5	Retrieval leak: 20,000 gal Tank row SX-104-106	7.17E+03	2054	0.04
6	Retrieval leak: 400 gal 200-Series tanks	1.70E+01	5221	0.00
7	Retrieval leak: 8,000 gal over past leak	2.30E+05	2038	1.20
8	Vadose zone remediation 5% effective	1.82E+05	2043	0.95
9	Vadose zone remediation 25% effective	1.44E+05	2043	0.75
10	Vadose zone remediation 50% effective	9.60E+04	2043	0.50

Table 4-38. Waste Management Area S-SX Source Term Characteristics Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Iodine-129	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
11	Reference case results: SX-107 (3.22E-01 Ci) [a]	9.18E-01	12032	1
	Sensitivity Cases [b]			
12	Maximum past leak inventory estimate SX-107 SX -108 SX-109: 4.65E-02 Ci (3.22E-01 Ci)	1.32E+00	12032	1.44
13	Minimum past leak inventory estimate SX-107 SX -108 SX-109: 1.30E-02 Ci (3.22E-01 Ci)	3.71E-01	12032	0.40
	What If Cases [b]			
14	Retrieval leak: 8,000 gal Tank row S-110-112	1.01E-02	12032	0.01
15	Retrieval leak: 20,000 gal Tank row S-110-112	2.78E-02	12032	0.03
16	Retrieval leak: 400 gal 200-Series tanks	0.00E+00	NA	0.00
17	Retrieval leak: 8,000 gal over past leak Row S-110-112	9.22E-01	11781	1.00
18	Vadose zone remediation 5% effective	8.72E-01	12032	0.95
19	Vadose zone remediation 25% effective	6.89E-01	12032	0.75
20	Vadose zone remediation 50% effective	4.59E-01	12032	0.50

Table 4-38. Waste Management Area S-SX Source Term Characteristics Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
21	Reference case results: SX-113 (7.59E+00 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
22	Maximum past leak inventory estimate SX-113 SX -114 SX-115: 9.22E+00 kg (7.59E+00 kg)	0.00E+00	NA	NA
23	Minimum past leak inventory estimate SX-113 SX-115: 6.13E+00 kg (7.59E+00 kg)	0.00E+00	NA	NA
	What If Cases [b]			
24	Retrieval leak: 8,000 gal Tank row S-110-112	0.00E+00	NA	NA
25	Retrieval leak: 20,000 gal Tank row S-110-112	0.00E+00	NA	NA
26	Retrieval leak: 400 gal 200-Series tanks	0.00E+00	NA	NA
27	Retrieval leak: 8,000 gal over past leak	0.00E+00	NA	NA
28	Vadose zone remediation 5% effective	0.00E+00	NA	NA
29	Vadose zone remediation 25% effective	0.00E+00	NA	NA
30	Vadose zone remediation 50% effective	0.00E+00	NA	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.

[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.

NA = not applicable

As explained previously for WMA C and for the same reasons, the magnitude of the maximum contaminant concentrations resulting from hypothetical retrieval leaks in WMA S-SX is compared to the reference case concentrations (Table 4-38, rows 1, 11, 21) resulting from past releases (the row of tanks SX-107, SX-108, and SX-109). At WMA S-SX, contaminant concentrations resulting from hypothetical retrieval leaks are much smaller in magnitude than the contaminant concentrations resulting from past releases. The maximum technetium-99 concentration at the fenceline resulting from hypothetical retrieval leaks of 8,000 and 20,000 gal are factors of 0.01 and 0.04 less, respectively (Table 4-38, rows 4-5), than the past release maximum concentrations. The maximum technetium-99 concentration at the fenceline resulting from hypothetical retrieval leaks of 400 gal from the 200-Series tanks is about 17 pCi/L and negligible compared to the past release maximum concentration (Table 4-38, row 6).
The fenceline concentration of technetium-99 resulting from past releases is a factor of about 1.2 higher if an 8,000 gal retrieval leak occurs over the reference case past release (Table 4-38, rows 1, 7). The maximum iodine-129 concentration at the fenceline resulting from hypothetical retrieval leaks of 8,000 and 20,000 gal (Table 4-38, rows 14-15) are factors of 0.01 and 0.03 less,

respectively, than the past release maximum concentrations. The maximum iodine-129 concentration at the fenceline resulting from hypothetical retrieval leaks of 400 gal from the 200-Series tanks is less than effective zero (Table 4-38, row 16). The maximum iodine-129 concentration is essentially unchanged from the reference case even if an 8,000-gal retrieval leak (Table 4-38, rows 11, 17) occurs over the reference case past release. The concentration at the fenceline of uranium does not exceed effective zero regardless of the size of the hypothetical retrieval leak, even if it occurs over the reference case past release (Table 4-38, rows 21, 24-27).

4.11.2.3 Source Term Characteristics Sensitivity and "What if" Results Integration Summary

Impacts to groundwater concentrations caused by changes of inventory quantity are only important if the travel time through the vadose zone is less than the simulation time. When the travel time is less than the simulation time, the contaminant concentration at the fenceline is directly proportional to the initial inventory for each source. For tank residual releases, with a surface barrier in place and functioning according to design, only the travel time of technetium-99 is short enough to produce concentrations above effective zero at the WMA fenceline during the 10,000-year simulation period. Iodine-129 and uranium from tank residual releases move too slowly through the vadose zone to produce concentrations at the WMA fenceline that exceed effective zero during this time. For this reason, only the reference case and source term characteristics sensitivity or "what if" case results for technetium-99 show changes in the fenceline concentrations associated with changes to the tank residual inventory or tank residual release rate. The iodine-129 fenceline concentration only exceeds effective zero when considering past releases (including hypothetical retrieval leaks) at the WMAs, and when there is sufficient inventory to produce fenceline concentrations above effective zero (compare rows 11-16 in both Tables 4-36 and 4-38). The fenceline concentration of uranium does not exceed effective zero for any of the sensitivity or "what if" cases associated with the source term characteristics.

The contaminant concentration at the fenceline is directly proportional to the initial inventory for each source.

For technetium-99 from tank residual releases, the peak concentration at the WMA fenceline appears to scale almost geometrically with respect to changes in the diffusion coefficient (3^N where N is the order of magnitude change in the diffusion coefficient, Tables 4-35 and 4-37, rows 1-3), scales linearly with respect to changes in the amount of inventory remaining in the tank after retrieval (Tables 4-35 and 4-37, rows 4, 5), and increases by a factor of almost 8 if the residual waste releases according to an advection process rather than a diffusion process (Tables 4-35 and 4-37, row 6). All of these changes relate to the rate and amount of inventory released at the source during the 10,000 year simulation period. As stated previously, for the same single source type, the resulting fenceline groundwater concentration is directly scalable to the inventory. For similar source types with different release mechanisms, the time and rate of release of contaminants also factor into the calculation of the peak or maximum concentration. An increased rate of release means that more contaminant mass releases earlier and has more time to travel through the vadose zone and reach the WMA fenceline. The advection process releases almost the entire inventory of contaminants almost immediately. Thus, the entire inventory of contaminants has almost the entire simulation period to travel through the vadose

zone and reach the groundwater and the WMA fenceline. The diffusion process releases the inventory much more gradually through time, and the entire inventory is not released in the reference case during the 10,000 year simulation period. Increasing the diffusion coefficient increases not only the rate of contaminant release, but also the total mass of contaminant released over the 10,000 year simulation period.

The diffusion release rate from the post-closure tank residual waste has a definite effect on the maximum contaminant concentrations of technetium-99, but neither iodine-129 nor uranium concentrations exceed effective zero regardless of the diffusion release rate.

For technetium-99 and iodine-129 from past releases, the peak concentration at the WMA fenceline scales linearly with respect to changes in the amount of inventory. Relative to past release estimates, these changes are observable for technetium-99 in Tables 4-36 and 4-38 (rows 1-3), but only in Table 4-38 (rows 11-13) for iodine-129. The reference case for WMA C includes the maximum past release estimate of iodine-129, and the minimum estimated inventory is insufficient to produce concentrations that exceed effective zero at the fenceline. In the event inventory is removed by vadose zone remediation, the fenceline concentrations for both technetium-99 and iodine-129 scale linearly with respect to the change in the amount of inventory.

The relative retrieval leak contribution is a function of the relative inventory of the retrieval leak and the past leaks that have occurred in the WMAs. At WMA C, the retrieval leak volume and inventory is comparable to the past leak volume and inventory associated with tanks C-105 (1,000 gal) and C-111 (5,500 gal); hence, the technetium 99 fenceline concentrations associated with 8,000 gal and 20,000 gal retrieval leaks (occurring from each tank in the row) are comparable to the fenceline concentrations associated with the past leaks (the concentration ratios equal 0.2 and 1.0 for 8,000 gal and 20,000 gal retrieval leaks, respectively [Table 4-36, rows 4-5]). Only the 20,000 gal retrieval leak from each tank in the row includes sufficient inventory of iodine-129 to produce a concentration exceeding effective zero at the WMA C fenceline (Table 4-36, rows 14-15). In the event a retrieval leak occurs over a past leak, the peak fenceline concentration of technetium-99 and iodine-129 increases by a factor of about 1.2 over the retrieval leak case, whereas the maximum concentration of iodine-129 is essentially unchanged from the reference case result (Table 4-36, rows 7 and 17, respectively).

At WMA S-SX, the retrieval leak volume and inventory is much less than the past leak volume and inventory associated with tanks SX-107 (15,000 gal), SX-108 (35,000 gal), and SX-109 (2,000 gal); therefore, the technetium-99 and iodine-129 fenceline concentrations associated with 8,000 gal and 20,000 gal retrieval leaks are much less than the fenceline concentrations associated with the past leaks. At WMA S-SX, there is sufficient iodine-129 inventory in the 8,000 gal retrieval leak to produce a concentration exceeding effective zero at the fenceline, but only because of the shorter travel time (there is a difference of about 3 m between the distance from the bottom of the tanks in WMA S-SX to the water table and the distance from the bottom of the tanks in WMA C to the water table). The iodine-129 inventory is actually greater in the row C-101 retrieval leak than in the tank row S-110 retrieval leak (compare Tables 4-36, rows 11, 14 and Table 4-38, rows 11, 14). The technetium-99 and iodine-129 concentrations at the WMA fenceline resulting from 8,000-gal and 20,000-gal retrieval leaks are about two orders

of magnitude less than the concentrations resulting from past releases (Table 4-38, rows 4-5, 14-15). In the event a retrieval leak occurs over a past leak, the peak fenceline concentration of technetium-99 and iodine-129 increases by a factor of about 1.4 over the retrieval leak case, whereas the maximum concentration of iodine-129 is essentially unchanged from the reference case result (Table 4-38, rows 7 and 17, respectively).

The importance of a retrieval leak depends on the history of past releases associated with a tank farm. For those tank farms that experienced only small volume past releases, retrieval leaks may add significantly to the peak concentration associated with past releases. For those tank farms that experienced relatively large volume past releases, impacts from retrieval leaks may be negligible compared to those from past releases.

4.11.3 Hydrology

In the context of the defense in depth strategy, the hydrology category of sensitivity and "what if" analysis cases primarily addresses the protection of groundwater provided by the vadose zone function. The results of the sensitivity and "what if" analyses indicate that the key elements of this defense element are the:

- Contaminant mobility (as expressed by the contaminant K_d through the vadose zone geologic units)
- Hydraulic properties of the vadose zone
- Travel time through the vadose zone of contaminants to the water table (as effected by the initial [year 2000] depth of contaminants from past releases, and the future elevation of the water table).

Contaminant mobility may be the single most important parameter affecting the peak concentration of contaminants at the WMA fenceline. The K_d (within the bounds of the sensitivity) affects the peak concentration of mobile (0 mL/g < K_d [0 mL/g] < 0.1 mL/g, the reference case value is shown in the brackets) and semi-mobile (0.1 mL/g < K_d [0.2 mL/g] <2 mL/g) contaminants from tank residuals and past releases, and less-mobile contaminants (0.2 mL/g < K_d [0.6 mL/g] < 4 mL/g) from past releases. The hydraulic properties of the vadose zone affect the WMA fenceline concentrations of mobile contaminants from past releases and tank residuals, and, to a small degree, the fenceline concentrations of semi-mobile contaminants from past releases. The initial depth in the vadose zone of contaminants from past releases affects fenceline concentrations of mobile and semi-mobile contaminants; however, the change in water table elevation produced only small changes in the fenceline concentrations of the these contaminants. None of the changes to the vadose zone properties, including those associated with the travel time sensitivity and "what if" cases, produced concentrations greater than effective zero for the less-mobile contaminants.

The key elements of the hydrology category are the contaminant mobility, hydraulic properties of the vadose zone, and travel time of contaminants through the vadose zone to the water table.

Hydrologic parameter sensitivity and "what if" analyses examine the effects of variation in hydrologic parameters on contaminant concentrations at the fenceline. The parameter changes used include:

- Changing contaminant distribution coefficient (K_d) for tank waste residuals and past releases (sensitivity case):
  - Reference case contaminant K_d of technetium-99 is 0 mL/g
  - High case contaminant K_d of technetium-99 is 0.1 mL/g (feature/process P12 maximum in Table 3-14)
  - Reference case contaminant K_d of iodine-129 is 0.2 mL/g
  - High case contaminant K_d of iodine-129 is 2 mL/g (feature/process P11 maximum in Table 3-14)
  - Low case contaminant K_d of iodine-129 is 0.1 mL/g (feature/process P11 minimum in Table 3-14)
  - Reference case contaminant K_d of uranium is 0.6 mL/g
  - High case contaminant K_d of uranium is 4 mL/g (feature/process P10 maximum in Table 3-14)
  - Low case contaminant K_d of uranium is 0.2 mL/g (feature/process P10 minimum in Table 3-14)
- Varying the depth of past release plumes (sensitivity case):
  - Reference case past release contaminant plume located 150 ft bgs at WMA C in 200 East Area
  - High case past release contaminant plume located 130 ft bgs at WMA C in 200 East Area (feature/process P6 minimum in Table 3-14)
  - Low case past release contaminant plume located 170 ft bgs at WMA C in 200 East Area (feature/process P6 maximum in Table 3-14; also alternative A17 in Table 3-15)
  - Reference case past release contaminant plume located 130 ft bgs at WMA S-SX in 200 West Area
  - High case past release contaminant plume located 110 ft bgs at WMA S-SX in 200 West Area (feature/process P7 minimum in Table 3-14)
  - Low case past release contaminant plume located 150 ft bgs at WMA S-SX in 200 West Area (feature/process P7 maximum in Table 3-14; also alternative A17 in Table 3-15)

- Differences in the hydraulic conductivity of the vadose zone units (sensitivity analyses):
  - Reference case hydraulic conductivity of the vadose zone units
  - Higher case of unsaturated hydraulic conductivity of the vadose zone units in which the saturated hydraulic conductivity of individual units is increased by a factor of 10 (feature/process P9 maximum in Table 3-14)
  - Lower case of unsaturated hydraulic conductivity of the vadose zone units in which the saturated hydraulic conductivity of individual units is decreased by a factor of 0.1 (feature/process P9 minimum in Table 3-14)
- Changes in the aquifer hydraulic conductivity (sensitivity analyses):
  - Reference case hydraulic conductivity of the aquifer unit is 3,000 m/day at WMA C and 25 m/day at WMA S-SX
  - Higher case of aquifer hydraulic conductivity with the reference value increased to 4,000 m/day at WMA C and 50 m/day at WMA S-SX (feature/process P13 and P14 maximum in Table 3-14; also alternative A21 in Table 3-15)
  - Lower case of aquifer hydraulic conductivity with the reference value decreased to 2,000 m/day at WMA C and 7.5 m/day at WMA S-SX (feature/process P13 and P14 minimum in Table 3-14; also alternative A21 in Table 3-15)
- Variation in the rate of water table decline ("what if" analyses):
  - Reference case water table elevation at WMA C is 79 m bgs and at WMA S-SX is 78 m bgs
  - Water table elevation at WMA C is 77 m bgs and at WMA S-SX is 76 m bgs (alternative A16 in Table 3-15)
- The presence of clastic dikes ("what if" analyses):
  - Retrieval leak of 8,000 gal from 100-Series tanks occurring over a clastic dike (alternative A15 in Table 3-15)
- The impact of not including anisotropic hydraulic conductivity parameters:
  - Reference case includes moisture dependent anisotropy function (Polmann model) to calculate vadose zone hydraulic conductivity for individual geologic units
  - Vadose zone hydraulic conductivity assumed to be isotropic (alternative A20 in Table 3-15).

4.11.3.1 Waste Management Area C

The maximum technetium-99 fenceline concentration is very sensitive to the contaminant distribution coefficient (K_d). If the technetium-99 K_d equals 0.1 mL/g, the maximum concentration resulting from post-closure tank residual waste is a factor of 0.001 less than the reference case concentration (Table 4-39, row 2). The maximum iodine-129 concentration resulting from post-closure tank residual waste does not exceed effective zero if the K_d is equal to or greater than 0.1 mL/g (Table 4-39, row 10). The uranium concentration resulting from post-closure tank residual waste releases does not exceed effective zero at the fenceline, even if the K_d equals 0.2 mL/g (Table 4-39, row 19).

The maximum technetium-99 concentration resulting from post-closure tank residual waste releases is correlated to the vadose zone units' saturated hydraulic conductivity and inversely correlated to the aquifer hydraulic conductivity (Table 4-39, rows 3-6). The reference case aquifer hydraulic conductivity is 3,000 m/day (Table 4-39, row 1). If the hydraulic conductivity is decreased to 2,000 m/day, then the maximum technetium-99 concentration increases by a factor of about 1.5 (Table 4-39, row 5). If the hydraulic conductivity is increased to 4,000 m/day, then the maximum technetium-99 concentration decreases by a factor of about 0.75 (Table 4-39, row 6). The maximum technetium-99 concentration is only about 1.2 times greater than the reference case results when the hydraulic conductivity of the vadose zone units is increased by a factor of 10 (Table 4-39, row 4) over the reference case, and a factor of about 0.8 less when the saturated hydraulic conductivity of the vadose zone units is decreased by a factor of 0.1 (Table 4-39, row 3) over the reference case. If the water table does not decline as projected (Table 4-39, row 7), the maximum technetium 99 concentration is only about 1.1 times greater than the reference case results. In the case of tank residuals, assuming the vadose zone unsaturated hydraulic conductivity to be isotropic, results in the maximum technetium-99 concentration being about a factor of 0.8 less (Table 4-39, row 8) than if the vadose zone unsaturated hydraulic conductivity includes the effects of the moisture dependent anisotropy. Neither iodine-129 nor uranium concentrations exceed effective zero at the fenceline for any of the hydrologic parameter sensitivity or "what if" cases regarding post-closure tank residual waste releases (Table 4-39, rows 9-26).

Table 4-39. Waste Management Area C Hydrology Sensitivity and "What If" Cases for Tank Waste Residual Releases (3 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: Tank row C-103 (1.46E+00 Ci) [a]	5.81E+00	10461	1
	Sensitivity Cases [b]			
2	Technetium K_d: 0.1 mL/g (0 mL/g)	3.88E-02	12032	0.01
3	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	4.44E+00	12032	0.76
4	Vadose zone unsaturated K: 10 × reference case unsaturated K	6.72E+00	8991	1.16
5	Aquifer K_{sat}: 2,000 m/day (3,000 m/day)	8.72E+00	10461	1.50
6	Aquifer K_{sat}: 4,000 m/day (3,000 m/day)	4.36E+00	10461	0.75
	What If Cases [b]			
7	Water level decline is 2 m less	6.19E+00	10371	1.07
8	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	4.87E+00	12032	0.84

Table 4-39. Waste Management Area C Hydrology Sensitivity and "What If" Cases for Tank Waste Residual Releases (3 pages)

Row	Iodine-129	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
9	Reference case results: Tank row C-103 (8.64E-03 Ci) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
10	Iodine-129 K_d: 0.1 mL/g (0.2 mL/g)	0.00E+00	NA	NA
11	Iodine-129 K_d: 2 mL/g (0.2 mL/g)	0.00E+00	NA	NA
12	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	0.00E+00	NA	NA
13	Vadose zone unsaturated K: 10 × reference case unsaturated K	0.00E+00	NA	NA
14	Aquifer K_{sat}: 2,000 m/day (3,000 m/day)	0.00E+00	NA	NA
15	Aquifer K_{sat}: 4,000 m/day (3,000 m/day)	0.00E+00	NA	NA
	What If Cases [b]			
16	Water level decline is 2 m less	0.00E+00	NA	NA
17	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	0.00E+00	NA	NA

Table 4-39. Waste Management Area C Hydrology Sensitivity and "What If" Cases for Tank Waste Residual Releases (3 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
18	Reference case results: Tank row C-103 (8.65E+02 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
19	Uranium K_d: 0.2 mL/g (0.6 mL/g)	0.00E+00	NA	NA
20	Uranium K_d: 4.0 mL/g (0.6 mL/g)	0.00E+00	NA	NA
21	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	0.00E+00	NA	NA
22	Vadose zone unsaturated K: 10 × reference case unsaturated K	0.00E+00	NA	NA
23	Aquifer K_{sat}: 2,000 m/day (3,000 m/day)	0.00E+00	NA	NA
24	Aquifer K_{sat}: 4,000 m/day (3,000 m/day)	0.00E+00	NA	NA
	What If Cases [b]			
25	Water level decline is 2 m less	0.00E+00	NA	NA
26	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	0.00E+00	NA	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.

[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.

NA = not applicable

For past releases, if the K_d of technetium-99 equals 0.1 mL/g, the maximum concentration resulting from past releases is a factor of 0.04 less than the reference case results (Table 4-40, row 2). The maximum iodine-129 concentration resulting from past releases is 7.5 times greater than the reference case results if the K_d equals 0 mL/g, whereas it does not exceed effective zero if the K_d is greater than or equal to 2 mL/g (Table 4-40, rows 14-15).

The technetium-99 and iodine-129 (but not uranium) results are also sensitive to the location of the past release plume in the vadose zone (Table 4-40, rows 3-4, 16-17, 29-30). The maximum concentrations of technetium-99 and iodine-129 are factors of about 1.6 and 3 higher, respectively (Table 4-40, rows 3 and 16, respectively), than the reference case (Table 4-40, rows 1, 13) if the plume is located 170 ft belowground, whereas the maximum concentrations are only factors of 0.6 and 0.9 less, respectively, than the reference case if the plume is located 130 ft belowground (Table 4-40, rows 4 and 17, respectively).

Changing the aquifer and vadose zone properties produces similar effects on the maximum technetium-99 concentration resulting from past releases in WMA C as those resulting from tank waste residual releases. Changes in the vadose zone units' hydraulic conductivity has a greater effect on the technetium-99 concentration resulting from past releases than from the post-closure

tank residual waste. The maximum technetium-99 concentration is about a factor of 0.6 less when the hydraulic conductivity of the vadose zone units is decreased by a factor of 0.1 (Table 4-40, row 5) from the reference case (Table 4-40, row 1), and about 1.7 times greater than the reference case results when the hydraulic conductivity of the vadose zone units is increased by a factor of 10 (Table 4-40, row 6). Decreasing the aquifer hydraulic conductivity from the reference case value of 3,000 m/day to 2,000 m/day (Table 4-40, row 7) results in the maximum technetium-99 concentration increasing by a factor of about 1.5 over the reference case results, whereas increasing the aquifer hydraulic conductivity from the reference case value of 3,000 m/day to 4,000 m/day (Table 4-40, row 8) results in the maximum technetium-99 concentration decreasing by a factor of about 0.8 less than the reference case results. If the water table does not decline as projected (Table 4-40, row 9), the maximum technetium-99 concentration is only about 1.1 times greater than the reference case results. The higher water table reduces the distance (and consequently the travel time) required for the contaminants to travel to the aquifer, as well as reducing the amount of mixing that may occur while the contaminants travel to the aquifer. If the hydraulic conductivity of the vadose zone geologic units is assumed to be isotropic (Table 4-40, row 10), the maximum technetium-99 concentration is about a factor of 1.6 times greater than if the moisture dependent anisotropy is incorporated into the model. In the event a retrieval leak occurs over a clastic dike (Table 4-40, row 11), the maximum technetium-99 concentration is a factor of about 0.4 less than the reference case past release result, but about 1.8 times greater than the concentration resulting from a retrieval leak if there is no clastic dike (Table 4-40, row 12). Overall, all assumed changes in hydrologic parameters result in peak concentrations of less than a factor of 2 greater than the reference case results.

Iodine-129 fenceline concentration resulting from past releases exceeds effective zero for the reference case, and changes almost identically to the technetium-99 concentration if the aquifer hydraulic conductivity is 2,000 or 4,000 m/day (Table 4-40, rows 20-21), rather than the reference case value of 3,000 m/day (Table 4-40, row 13). However, the effect of changing the hydraulic conductivity of the vadose zone units is less pronounced on the maximum iodine-129 concentration than on the maximum technetium-99 concentration resulting from past releases. Decreasing the hydraulic conductivity values by a factor of 0.1 (Table 4-40, row 18) results in the maximum iodine-129 concentrations decreasing by factors of 0.9 less than the reference case results (Table 4-40, row 13) (compared to 0.6 for the maximum technetium-99 concentration). Increasing the vadose zone hydraulic conductivity values by a factor of 10 (Table 4-40, row 19) over the reference case values results in the maximum technetium-99 and iodine-129 concentrations increasing by factors of 1.7 over the reference case results. If the water table does not decline as projected (Table 4-40, row 22), the maximum iodine-129 concentration is only a factor of about 1.1 times greater than the reference case results. If the hydraulic conductivity of the vadose zone geologic units is assumed to be isotropic (Table 4-40, row 23), the maximum iodine-129 concentration is about a factor of 1.7 times greater than if the moisture dependent anisotropy is incorporated into the model. The maximum iodine-129 concentration at the fenceline does not exceed effective zero for a retrieval leak, even if the hypothetical retrieval leak occurs over a clastic dike (Table 4-40, rows 24-25). Overall, all assumed changes in hydrologic parameters result in peak concentrations that are less than a factor of 2 greater than the reference case results.

Table 4-40. Waste Management Area C Hydrology Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: Tank row C-105 (2.80E-01 Ci) [a]	5.65E+02	2051	1
	Sensitivity Cases [b]			
2	Technetium K_d: 0.1 mL/g (0 mL/g)	2.38E+01	2095	0.04
3	Depth in year 2000: 130 ft (150 ft)	3.24E+02	2058	0.57
4	Depth in year 2000: 170 ft (150 ft)	8.88E+02	2044	1.57
5	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	3.20E+02	2062	0.57
6	Vadose zone unsaturated K: 10 × reference case unsaturated K	9.51E+02	2042	1.68
7	Aquifer K_{sat}: 2,000 m/day (3,000 m/day)	8.28E+02	2052	1.47
8	Aquifer K_{sat}: 4,000 m/day (3,000 m/day)	4.29E+02	2050	0.76
	What If Cases [b]			
9	Water level decline is 2 m less	6.36E+02	2050	1.13
10	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	9.27E+02	2042	1.64
11	Retrieval leak: 8,000 gal over clastic dike	2.23E+02	2086	0.39
12	Retrieval leak: 8,000 gal over clastic dike ratio to 8,000-gal retrieval leak	NA	NA	1.76

Table 4-40. Waste Management Area C Hydrology Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Iodine-129	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
13	Reference case results: Tank row C-105 (2.73E-03 Ci) [a]	3.09E-02	9621	1
	Sensitivity Cases [b]			
14	Iodine-129 K_d: 0.1 mL/g (0.2 mL/g)	2.32E-01	2095	7.51
15	Iodine-129 K_d: 2 mL/g (0.2 mL/g)	0.00E+00	NA	0
16	Depth in year 2000: 130 ft (150 ft)	2.83E-02	12032	0.92
17	Depth in year 2000: 170 ft (150 ft)	9.06E-02	2109	2.93
18	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	2.65E-02	8791	0.86
19	Vadose zone unsaturated K: 10 × reference case unsaturated K	3.35E-02	10141	1.08
20	Aquifer K_{sat}: 2,000 m/day (3,000 m/day)	4.64E-02	9621	1.50
21	Aquifer K_{sat}: 4,000 m/day (3,000 m/day)	2.32E-02	9611	0.75
	What If Cases [b]			
22	Water level decline is 2 m less	3.40E-02	8661	1.10
23	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	5.11E-02	2104	1.65
24	Retrieval leak: 8,000 gal over clastic dike	0.00E+00	NA	0.00
25	Retrieval leak: 8,000 gal over clastic dike ratio to 8,000-gal retrieval leak	NA	NA	NA

Table 4-40. Waste Management Area C Hydrology Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
26	Reference case results: Tank row C-105 (7.00E-01 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
27	Uranium K_d: 0.2 mL/g (0.6 mL/g)	0.00E+00	NA	NA
28	Uranium K_d: 4.0 mL/g (0.6 mL/g)	0.00E+00	NA	NA
29	Depth in year 2000: 130 ft (150 ft)	0.00E+00	NA	NA
30	Depth in year 2000: 170 ft (150 ft)	0.00E+00	NA	NA
31	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	0.00E+00	NA	NA
32	Vadose zone unsaturated k: 10 × reference case unsaturated K	0.00E+00	NA	NA
33	Aquifer K_{sat}: 2,000 m/day (3,000 m/day)	0.00E+00	NA	NA
34	Aquifer K_{sat}: 4,000 m/day (3,000 m/day)	0.00E+00	NA	NA
	What If Cases [b]			
35	Water level decline is 2 m less	0.00E+00	NA	NA
36	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	0.00E+00	NA	NA
37	Retrieval leak: 8,000 gal over clastic dike	0.00E+00	NA	NA
38	Retrieval leak: 8,000 gal over clastic dike ratio to 8,000-gal retrieval leak	NA	NA	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.

[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.

NA = not applicable

4.11.3.2 Waste Management Area S-SX

The maximum technetium-99 and iodine-129 fenceline concentrations are very sensitive to the contaminant distribution coefficient (K_d). If the K_d of technetium-99 equals 0.1 mL/g, the maximum concentration resulting from post-closure tank residual waste is a factor of 0.001 (Table 4-41, row 2) less than the reference case results (Table 4-41, row 1). The maximum iodine-129 concentration resulting from post-closure tank residual waste does not exceed effective zero even if the K_d equals 0.1 mL/g (Table 4-41, row 10). The concentration of uranium resulting from post-closure tank residual waste releases does not exceed effective zero at the fenceline, even if the K_d equals 0.2 mL/g (Table 4-41, row 19).

As in WMA C, the maximum technetium-99 concentration resulting from post-closure tank residual waste releases appears to be correlated to the vadose zone units' hydraulic conductivity and inversely correlated to the aquifer hydraulic conductivity (Table 4-41, rows 3-6). The maximum technetium-99 concentration is a factor of 0.8 less if the hydraulic conductivity of the vadose zone units is decreased by a factor of 0.1 (Table 4-41, row 3) from the reference case, and only 1.2 times greater than the reference case results when the hydraulic conductivity of the vadose zone units is increased by a factor of 10 (Table 4-41, row 4) over the reference case. The reference case (Table 4-41, rows 1, 9, 18) aquifer hydraulic conductivity is 25 m/day (Table 4-41). If the hydraulic conductivity is decreased to 7.5 m/day, then the maximum technetium-99 concentration (Table 4-41, row 5) resulting from tank waste residual releases increases by a factor of about 3.3. If the hydraulic conductivity of the aquifer is increased to 50 m/day (Table 4-41, row 6), then the maximum technetium-99 concentration decreases by a factor of about 0.5. There is no change in the maximum technetium-99 concentration even if the water table does not decline as projected (Table 4-41, row 7). If the hydraulic conductivity of the vadose zone geologic units and aquifer is assumed to be isotropic (Table 4-41, row 7), the maximum technetium-99 concentration is about a factor of 0.7 less than if the moisture dependent anisotropy is incorporated into the model. Neither iodine-129 nor uranium concentrations exceed effective zero at the fenceline for any of the hydrologic parameter sensitivity or "what if" cases regarding post-closure tank residual waste releases. Overall, all assumed changes in hydrologic parameters result in peak concentrations that are less than a factor of 2 greater than the reference case results.

Table 4-41. Waste Management Area S-SX Hydrology Sensitivity and "What If" Cases for Tank Waste Residual Releases (2 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: S-104 (2.90E+00 Ci) [a]	3.55E+01	8191	1
	Sensitivity Cases [b]			
2	Technetium K_d: 0.1 mL/g (0 mL/g)	8.53E-01	12032	0.02
3	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	2.67E+01	10581	0.75
4	Vadose zone unsaturated K: 10 × reference case unsaturated K	4.17E+01	6941	1.17
5	Aquifer K_{sat}: 7.5 m/day (25 m/day)	1.18E+02	8201	3.32
6	Aquifer K_{sat}: 50 m/day (25 m/day)	1.78E+01	8191	0.50
	What If Cases [b]			
7	Water level decline is 2 m less	3.56E+01	8091	1.00
8	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	2.51E+01	11221	0.71

Table 4-41. Waste Management Area S-SX Hydrology Sensitivity and "What If" Cases for Tank Waste Residual Releases (2 pages)

Row	Iodine-129	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
9	Reference case results: S-110 (1.43E-03 Ci) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
10	Iodine-129 K_d: 0.1 mL/g (0.2 mL/g)	0.00E+00	NA	NA
11	Iodine-129 K_d: 2 mL/g (0.2 mL/g)	0.00E+00	NA	NA
12	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	0.00E+00	NA	NA
13	Vadose zone unsaturated K: 10 × reference case unsaturated K	0.00E+00	NA	NA
14	Aquifer K_{sat}: 7.5 m/day (25 m/day)	0.00E+00	NA	NA
15	Aquifer K_{sat}: 50 m/day (25 m/day)	0.00E+00	NA	NA
	What If Cases [b]			
16	Water level decline is 2 m less	0.00E+00	NA	NA
17	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	0.00E+00	NA	NA
Row	**Uranium**	**Maximum Concentration mg/L**	**Maximum Concentration Arrival Time year**	**Peak Groundwater Concentration Ratios Relative to Reference Case**
18	Reference case results: S-101 (8.90E+03 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
19	Uranium K_d: 0.2 mL/g (0.6 mL/g)	0.00E+00	NA	NA
20	Uranium K_d: 4.0 mL/g (0.6 mL/g)	0.00E+00	NA	NA
21	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	0.00E+00	NA	NA
22	Vadose zone unsaturated K: 10 × reference case unsaturated K	0.00E+00	NA	NA
23	Aquifer K_{sat}: 7.5 m/day (25 m/day)	0.00E+00	NA	NA
24	Aquifer K_{sat}: 50 m/day (25 m/day)	0.00E+00	NA	NA
	What If Cases [b]			
25	Water level decline is 2 m less	0.00E+00	NA	NA
26	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	0.00E+00	NA	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.

[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.

NA = not applicable

The maximum technetium-99, iodine-129, and uranium fenceline concentrations from past releases also appear to be very sensitive to the contaminant distribution coefficient (K_d). If the K_d of technetium-99 equals 0.1 mL/g, the maximum concentration resulting from past releases is a factor of 0.04 less than the reference case results (Table 4-42, row 2). The maximum iodine-129 concentration resulting from past releases is about 320 times greater than the reference case results if the K_d equals 0 mL/g, whereas it does not exceed effective zero if the K_d is greater than or equal to 2 mL/g (Table 4-42, rows 13-15). Only if the uranium K_d is less than or equal to 0.2 mL/g does the fenceline concentration exceeds effective zero (Table 4-42, row 27).

The technetium-99 and iodine-129 (but not uranium) results are sensitive to the location of the past release plume in the vadose zone. The maximum concentrations are factors of 0.5 and 0.7 less, respectively, than the reference case if the plume is located 110 ft belowground (Table 4-42, rows 3, 16), whereas the maximum concentrations of technetium-99 and iodine-129 are factors of about 1.5 and 1.1 larger, respectively, than the reference case if the plume is located 150 ft belowground (Table 4-42, rows 4, 17). The uranium concentration does not exceed effective zero at the WMA fenceline regardless of the initial depth of the plume (Table 4-42, rows 26, 29-30).

Changing the vadose zone and aquifer properties produces similar effects on the maximum technetium-99 concentration resulting from past releases as those resulting from tank waste residual releases. Changing the hydraulic conductivity of the vadose zone units is less pronounced on the maximum technetium-99 concentration resulting from past releases than that resulting from tank residuals. Decreasing the hydraulic conductivity values by a factor of 0.1 results in the maximum technetium-99 concentrations decreasing by factor of 0.6 less (Table 4-42, row 5) than the reference case results (Table 4-42, row 1), whereas increasing the vadose zone hydraulic conductivity values by a factor of 10 over the reference case value results in the maximum technetium-99 concentrations increasing by factors of 1.5 over the reference case results (Table 4-42, row 6). Decreasing the aquifer hydraulic conductivity from the reference case (Table 4-42, row 1) value of 25 m/day to 7.5 m/day (Table 4-42, row 7) results in the maximum technetium-99 concentration increasing by a factor of 2.7 over the reference case results, whereas increasing the aquifer hydraulic conductivity from the reference case value of 25 m/day to 50 m/day (Table 4-42, row 8) results in the maximum technetium-99 concentration decreasing by a factor of about 0.5 less than the reference case results. If the water table does not decline as projected (Table 4-42, row 9), the maximum technetium-99 concentration is only about 1.1 times greater than the reference case results. If the hydraulic conductivity of the geologic units is assumed to be isotropic (Table 4-42, row 10), the maximum technetium-99 concentration is about a factor of 1.4 times greater than if the moisture dependent anisotropy is incorporated into the model. In the event a retrieval leak occurs over a clastic dike, the maximum technetium-99 concentration is a factor of about 0.02 (Table 4-42, row 11) less than the reference case past release results, but about 1.9 times greater than the concentration resulting from a retrieval leak if there is no clastic dike (Table 4-42, row 12) included in the geologic depiction. Overall, all assumed changes in hydrologic parameters result in peak technetium-99 concentrations that are less than a factor of 2 greater than the reference case results.

The iodine-129 fenceline concentration resulting from past releases exceeds effective zero for the reference case (Table 4-42, row 13). Decreasing the vadose zone hydraulic conductivity values

by a factor of 0.1 results in the maximum iodine-129 concentrations decreasing by a factor of 0.9 less than (Table 4-42, row 18) the reference case results. Increasing the vadose zone hydraulic conductivity values by a factor of 10 over the reference case values results in the maximum iodine-129 concentrations increasing by factors of 1.1 over the reference case results (Table 4-42, row 19). Decreasing the aquifer hydraulic conductivity from the reference case value of 25 m/day to 7.5 m/day results in the maximum iodine-129 concentration increasing by a factor of 3.3 over the reference case results (Table 4-42, row 20), whereas increasing the aquifer hydraulic conductivity from the reference case value of 25 m/day to 50 m/day results in the maximum iodine-129 concentration decreasing by a factor of about 0.5 less than the reference case results (Table 4-42, row 21). If the water table does not decline as projected or the hydraulic conductivity of the geologic units is assumed to be isotropic (Table 4-42, rows 22-23), the maximum iodine-129 concentration is about the same as the reference case results. The maximum iodine-129 concentration at the fenceline is a factor of about 1.85 times higher if the hypothetical retrieval leak occurs over a clastic dike (Table 4-42, row 24) than if no clastic dike is included in the geologic depiction. Overall, all assumed changes in hydraulic properties result in peak iodine-129 concentrations that are less than a factor of 4 greater than the reference case results.

Table 4-42. Waste Management Area S-SX Hydrology Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Technetium-99	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
1	Reference case results: SX-107 (2.09E+01 Ci) [a]	1.92E+05	2043	1
	Sensitivity Cases [b]			
2	Technetium K_d: 0.1 mL/g (0 mL/g)	1.04E+03	2132	0.01
3	Depth in year 2000: 110 ft (130 ft)	9.51E+04	2050	0.50
4	Depth in year 2000: 150 ft (130 ft)	2.79E+05	2034	1.45
5	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	1.12E+05	2053	0.58
6	Vadose zone unsaturated K: 10 × reference case unsaturated K	2.96E+05	2036	1.54
7	Aquifer K_{sat}: 7.5 m/day (25 m/day)	5.18E+05	2049	2.70
8	Aquifer K_{sat}: 50 m/day (25 m/day)	1.02E+05	2042	0.53
	What If Cases [b]			
9	Water level decline is 2 m less	2.03E+05	2042	1.06
10	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	2.76E+05	2035	1.44
11	Retrieval leak: 8,000 gal over clastic dike	3.62E+03	2057	0.02
12	Retrieval leak: 8,000 gal over clastic dike ratio to 8,000-gal retrieval leak	NA	NA	1.85

Table 4-42. Waste Management Area S-SX Hydrology Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Iodine-129	Maximum Concentration pCi/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
13	Reference case results: SX-107 (3.22E-01 Ci) [a]	9.18E-01	12032	1
	Sensitivity Cases [b]			
14	Iodine-129 K_d: 0.1 mL/g (0.2 mL/g)	1.60E+00	2132	1.74
15	Iodine-129 K_d: 2 mL/g (0.2 mL/g)	0.00E+00	NA	0.00
16	Depth in year 2000: 110 ft (130 ft)	6.16E-01	12032	0.67
17	Depth in year 2000: 150 ft (130 ft)	1.03E+00	9261	1.12
18	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	8.42E-01	12032	0.92
19	Vadose zone unsaturated K: 10 × reference case unsaturated K	9.81E-01	12032	1.07
20	Aquifer K_{sat}: 7.5 m/day (25 m/day)	3.04E+00	12032	3.31
21	Aquifer K_{sat}: 50 m/day (25 m/day)	4.60E-01	12032	0.50
	What If Cases [b]			
22	Water level decline is 2 m less	9.55E-01	11651	1.04
23	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	9.19E-01	11111	1.00
24	Retrieval leak: 8,000 gal over clastic dike	1.87E-02	11781	0.02
25	Retrieval leak: 8,000 gal over clastic dike ratio to 8,000-gal retrieval leak	NA	NA	1.85

Table 4-42. Waste Management Area S-SX Hydrology Sensitivity and "What If" Cases for Past Releases (3 pages)

Row	Uranium	Maximum Concentration mg/L	Maximum Concentration Arrival Time year	Peak Groundwater Concentration Ratios Relative to Reference Case
26	Reference case results: SX-113 (7.59E+00 kg) [a]	0.00E+00	NA	NA
	Sensitivity Cases [b]			
27	Uranium K_d: 0.2 mL/g (0.6 mL/g)	2.17E-04	12032	NA
28	Uranium K_d: 4.0 mL/g (0.6 mL/g)	0.00E+00	NA	NA
29	Depth in year 2000: 110 ft (130 ft)	0.00E+00	NA	NA
30	Depth in year 2000: 150 ft (130 ft)	0.00E+00	NA	NA
31	Vadose zone unsaturated K: 0.1 × reference case unsaturated K	0.00E+00	NA	NA
32	Vadose zone unsaturated K: 10 × reference case unsaturated K	0.00E+00	NA	NA
33	Aquifer K_{sat}: 7.5 m/day (25 m/day)	0.00E+00	NA	NA
34	Aquifer K_{sat}: 50 m/day (25 m/day)	0.00E+00	NA	NA
	What If Cases [b]			
35	Water level decline is 2 m less	0.00E+00	NA	NA
36	No anisotropy in hydraulic conductivity (Polmann moisture dependant anisotropy)	0.00E+00	NA	NA
37	Retrieval leak: 8,000 gal over clastic dike	0.00E+00	NA	NA
38	Retrieval leak: 8,000 gal over clastic dike ratio to 8,000-gal retrieval leak	NA	NA	NA

[a] Values in parentheses for reference case results are the reference case contaminant inventories.
[b] Values in parentheses for sensitivity and "what if" case results are the reference case parameter values.
NA = not applicable

4.11.3.3 Hydrology Sensitivity and "What if" Results Integration Summary

The K_d value of a contaminant in the vadose zone soil layers may be the single most important parameter affecting the peak or maximum concentration at the WMA fenceline. Increasing the K_d of technetium-99 from 0 to 0.1 mL/g reduced the peak fenceline concentration by almost two orders of magnitude for both tank residual releases and past releases at both WMAs C and S-SX. In addition to the reduction in concentration caused by the retarding of the contaminant movement, the higher K_d also causes the plume center of mass from past releases to remain high enough above the water table such that the impacts of the surface barrier extend to that depth and restrain its movement before it drains into the groundwater.

Contaminant mobility may be the single most important parameter affecting the peak concentration of contaminants at the WMA fenceline.

The distance between the source and the aquifer also impacts the peak fenceline concentration, especially if the resulting change in travel time overlaps the time of placement of the surface barrier. The technetium-99 fenceline concentrations resulting from past releases respond similarly at WMA C and WMA S-SX to changes in initial contaminant depth, indicating that the plume center of mass is still above the water table when the surface barrier is emplaced, although it is deep enough in the vadose zone to drain into the aquifer before the impacts of the surface barrier extend entirely to that depth. The iodine-129 results present a much different picture. At WMA C, the peak fenceline concentration of the contaminants is almost a factor of 3 greater and occurs much sooner than in the reference case (year 2109 versus year 9621) when the initial placement of the contaminants is 20 ft lower in the vadose zone than in the reference case. Comparatively little change occurs between the reference case peak concentration and the peak concentration when the initial placement of the contaminants is 20 ft higher in the vadose zone. These results indicate that the contaminants beginning 20 ft lower in the vadose zone than in the reference case are close enough to the water table when the surface barrier is emplaced that the plume center of mass drains into the groundwater before the impact of the barrier extends entirely to that depth. At WMA S-SX, there is little change between the reference case peak iodine-129 groundwater concentration and the peak concentration when the contaminants begin 20 ft lower in the vadose zone. These results indicate that the iodine-129 associated with past releases at WMA S-SX remains too far above the water table when the surface barrier is emplaced to drain into the groundwater before the impact of the barrier extends to that depth.

Impacts to groundwater contaminant concentrations caused by changes in the hydrologic parameters result in peak concentration changes that are less than a factor of 4 greater than the reference case results. The maximum concentration at the fenceline of technetium-99 from either past releases or post-closure tank residuals and iodine-129 from past releases appears to be inversely correlated to the aquifer hydraulic conductivity, and to a lesser extent, correlated to the vadose zone hydraulic conductivity. None of the hydrologic parameter sensitivity or "what if" cases from either post-closure tank residual or past release contaminant sources result in the maximum iodine-129 or uranium concentration exceeding effective zero.

The maximum technetium-99 concentration resulting from post-closure tank residual, and the maximum technetium-99 and iodine-129 concentrations resulting from past releases, appear to be correlated to the hydraulic conductivity of the vadose zone units and inversely correlated to the aquifer hydraulic conductivity.

4.11.4 Integration of Sensitivity and "What If" Analyses Effects on Groundwater Impacts at the Waste Management Area Fencelines

By selecting the set of sensitivity and "what if" analyses described in Section 3.5, the impacts of changes in system characteristics affecting contaminant migration in the subsurface, both environmental (e.g., hydrologic parameters) and manmade (e.g., waste and barrier properties) were evaluated. The associated changes in peak times and peak values in groundwater relative to reference case results were compared for three broad set of characteristics. These included variable recharge rates and recharge histories (Tables 4-31 through 4-34 in Section 4.11.1), source term characteristics (Tables 4-35 through 4-38 in Section 4.11.2), and hydrologic parameters (Tables 4-39 through 4-42 in Section 4.11.3). In this section, the relative importance between all these parameters with respect to specific contaminants and waste types is discussed. This analysis showed that the relative importance of particular parameters within the total parameter set changed as a function of the initial waste type (past releases and residual tank wastes) and contaminants (Sections 4.11.4.1 through 4.11.4.4). This analysis also provided the basis for two additional analyses. First, multiplication factors to estimate a range of plausible peak values were derived from single parameter variabilities that estimated the effect of multiple simultaneous parameter variabilities on peak values for relevant contaminant/waste type combinations (Section 4.11.5). Second, to address the robustness of the defense in depth approach, similar factors were derived to evaluate the impact of single barrier or engineered barriers underperformance on total system performance (Section 4.11.6).

Comparison of sensitivity and "what if" case results with reference case results are discussed below for combinations of two waste types and three categories of contaminant mobility in the subsurface. Although there were a variety of waste sources (e.g., tanks, past leaks, ancillary equipment), they fell into two categories relative to properties affecting contaminant migration: 1) wastes already distributed in the vadose zone and 2) wastes encapsulated by tank structures. The main difference between the two waste types was the greater availability of contaminants in past releases to recharge water.

Three contaminants (technetium-99, iodine-129, and uranium) encompassed the range of contaminant mobility that allowed non-negligible breakthrough into the unconfined aquifer within the simulation period (years 2000 to 12032). In the reference case, these contaminants had assumed K_d values of 0, 0.2 and 0.6 mL/g, respectively. These three contaminants and some mobile chemical species (e.g., chromium and nitrate whose migration patterns are represented by technetium-99) were the most prominent mobile constituents in tank waste that could degrade groundwater quality above acceptable limits, depending on their inventory levels in a given location. Because projected groundwater impacts were estimated within the simulation period, both sensitivity to other properties affecting contaminant migration and associated variability inherent in these properties were expected to cause variability in peak contamination estimates. Conversely, the greater chemical reactivity of most other tank waste contaminants combined with the hydrogeologic characteristics of the Hanford Site Central Plateau (thick vadose zone and low natural recharge) prevented them from reaching the unconfined aquifer within the simulation period. Thus, within this time frame, sensitivity of migration rates to variability in other system properties was not apparent.

The reference case results and the sensitivity and "what if" case results in Tables 4-31 through 4-42 showed that breakthrough into groundwater and subsequent migration to the WMA fenceline occurred consistently only for technetium-99 migrating from either past release or residual waste sources and for iodine-129 migrating from past release sources. These outcomes were consistent with the expectation that these three combinations were the most favorable to maximum migration rates. Therefore, these three contaminant/waste type conditions are the focus of this summary (Sections 4.11.4.1 through 4.11.4.3). In cases where maximum recharge rates are assumed, iodine-129 derived from tank waste residuals and less mobile uranium (K_d = 0.6 mL/g) derived from past releases reach the WMA fenceline in the unconfined aquifer in non-negligible quantities. These are also discussed briefly in Section 4.11.4.4.

Tables 4-43 through 4-48 summarize the changes in peak values for specific sensitivity or "what if" analyses relative to the reference case values for a given contaminant/waste type condition and WMA (e.g., technetium-99 initially present in past releases from WMA C, Table 4-43). In each table, three pieces of information are provided: 1) the sensitivity and "what if" cases and the reference case parameter value being varied, 2) the change from the reference case parameter value defined by the sensitivity and "what if" cases, and 3) the ratio of the peak value from the sensitivity and "what if" cases to the peak value from the reference case. In the iodine-129 cases (Tables 4-45 and 4-46), the times at which peak values were calculated (e.g., peak times) are also shown for each case. Peak times were shown in these tables because, unlike most of the technetium-99 cases, they varied considerably between cases.

In some cases, the ratio was not a true peak-to-peak value comparison because peak values were not reached at the end of the modeling time frame, necessitating substitution of the lower maximum calculated value into ratio calculations. This result occurred mostly with the iodine-129 cases including the WMA S-SX reference case and numerous sensitivity and "what if" cases. Maximum values are indicated for a given sensitivity/"what if" cases in Tables 4-45 through 4-46 when a peak time of year 12032 is listed. Listed ratios were somewhat above or below true peak-to-peak value estimates, depending on the use of maximum values in the numerator, denominator, or both. However, these ratio values are close to the true peak-to-peak value estimates because the analyses indicate that maximum values are within a few percent of peak values at the end of the modeled time frame.

For most parameter changes, peak value ratios were specific to the contaminant/waste type condition. Two parameter changes and peak value responses were consistent in all cases. First, peak values increased or decreased proportionately with corresponding changes to inventory. Second, peak values varied inversely with changes in aquifer saturated hydraulic conductivity values. These values reflect the amount of aquifer water mixing with contaminants entering the aquifer.

The results are arranged from the highest to the lowest ratio. The highest and lowest ratios indicate the greatest potential for increase or decrease in peak value relative to the reference case estimate due to parameter value variability. Ratios of unity indicate no change in peak value relative to the reference case, showing that the range of site-specific parameter values had no influence on contaminant migration for the evaluated contaminant/waste type combination. Ratios derived from paired analyses that assumed maximum and minimum values of a given

parameter can also be used as multiplication factors to estimate a plausible site-specific range of peak values around the reference peak. This range of peak values represents variability in groundwater impacts induced by the variability of that parameter for the given contaminant/waste type combination. The peak value range estimate is relevant to the site-specific condition because the range of parameter values around the reference case value is considered to be site-specific (e.g., parameter value variability was estimated from observed natural or source term heterogeneities or possible future human actions).

Table 4-43. Comparison (by Ratio) of Sensitivity and "What If" to Reference Case Peak Values for Technetium-99 Initially Present in Past Releases at Waste Management Area C

Sensitivity and "What If" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	K_d = 0 mL/g (Tc-99) Past Releases
High past release inventory (reference)	Location specific	4
High operational recharge (100 mm/yr)	140 mm/yr	1.73
High vadose zone hydraulic properties (reference)	10 × reference	1.68
Isotropic vadose zone hydraulic conductivity (anisotropic)	Isotropic	1.64
Lower depth (150 ft bgs)	170 ft bgs	1.57
Low aquifer K_{sat} (3,000 m/day)	2,000 m/day	1.47
Late barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2050	1.39
8,000-gal retrieval leak over past leak (past leak only)	8 kgal + inventory	1.24
Higher water table (reference)	2 m higher	1.13
Low barrier recharge (0.5 mm/yr)	0.1 mm/yr	1
High barrier recharge (0.5 mm/yr)	1 mm/yr	1
Low post-design barrier recharge (1 mm/yr in 2532)	0.5 mm/yr in 2532	1
Barrier failure recharge (1 mm/yr in 2532)	3 mm/yr in 2532	1
High post-design barrier recharge (1 mm/yr in 2532)	3.5 mm/yr in 2532	1
Early barrier failure recharge (1 mm/yr in 2532)	3 mm/yr in 2332	1
Irrigated farming (1 mm/yr in 2532)	50 mm/yr in 2532	1
High aquifer K_{sat} (3,000 m/day)	4,000 m/day	0.76
Shallower depth (150 ft bgs)	130 ft bgs	0.57
Low vadose zone hydraulic properties (reference)	0.1 × reference	0.57
Early barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2020	0.54
Low past release inventory (reference)	Location specific	0.5
Interim barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2010	0.41
Low operational recharge (100 mm/yr)	40 mm/yr	0.15
Technetium K_d (0 mL/g)	0.1 mL/g	0.04

Table 4-44. Comparison (by Ratio) of Sensitivity and "What If" to Reference Case Peak Values for Technetium-99 Initially Present in Past Releases at Waste Management Area S-SX

Sensitivity and "What If" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	K_d = 0 mL/g (Tc-99) Past Releases
Low aquifer K_{sat} (25 m/day)	7.5 m/day	2.7
High vadose zone hydraulic properties (reference)	10 × reference	1.54
High operational recharge (100 mm/yr)	140 mm/yr	1.48
Lower depth (130 ft bgs)	150 ft bgs	1.45
High past release inventory (reference)	Location specific	1.44
Isotropic vadose zone hydraulic conductivity (anisotropic)	Isotropic	1.44
8,000-gal retrieval leak over past leak (past leak only)	8 kgal + inventory	1.2
Late barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2050	1.15
Higher water table (reference)	2 m higher	1.06
Low barrier recharge (0.5 mm/yr)	0.1 mm/yr	1
High barrier recharge (0.5 mm/yr)	1 mm/yr	1
Low post-design barrier recharge (1 mm/yr in 2532)	0.5 mm/yr in 2532	1
High post-design barrier recharge (1 mm/yr in 2532)	3.5 mm/yr in 2532	1
Irrigated farming (1 mm/yr in 2532)	50 mm/yr in 2532	1
Barrier failure recharge (1 mm/yr in 2532)	4 mm/yr in 2532	1
Early barrier failure recharge (1 mm/yr in 2532)	4 mm/yr in 2332	1
Low vadose zone hydraulic properties (reference)	0.1 × reference	0.58
High aquifer K_{sat} (25 m/day)	50 m/day	0.53
Early barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2020	0.52
Shallower depth (130 ft bgs)	110 ft bgs	0.5
Interim barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2010	0.43
Low past release inventory (reference)	location specific	0.4
Low operational recharge (100 mm/yr)	40 mm/yr	0.14
Technetium K_d (0 mL/g)	0.1 mL/g	0.01

4.11.4.1 Technetium-99 Migration from Past Releases

For technetium-99 in past releases at WMAs C and S-SX (Tables 4-43 and 4-44), the center of mass reached the aquifer under the influence of operational recharge in all analyses. Because technetium-99 was assumed to be completely mobile, it migrated with the water. Consequently, the peak time occurred before year 2200, less than 200 years after closure even for the sensitivity case where a reduced operational recharge rate of 40 mm/yr was assumed. At the maximum recharge rate of 140 mm/yr, a larger peak value and earlier peak time was calculated relative to the reference case. Increased vadose zone unsaturated hydraulic conductivities, reduced depth interval between the waste and the water table, or extended time of operational recharge also enhanced the effectiveness of the operational recharge to maximize the technetium-99 migration

rate. Consequently, increased mass flux into the aquifer and reduced mixing because of shorter travel times resulted in higher peaks (see the top set of parameters in Tables 4-43 and 4-44). All increases from these effects were less than a factor of 2. The ranking by ratio was slightly different in WMA C versus WMA S-SX due to differences in vadose zone properties and assumed depths of the contaminants for each WMA. Peak value increases because of inventory and aquifer hydraulic conductivity changes were comparable.

Because the technetium-99 center of mass was driven to groundwater by operational recharge, subsequent changes in barrier recharge induced by barrier performance or even elevated recharge from post-closure irrigated farming (the second group of parameters in Tables 4-43 and 4-44) had no impact on technetium-99 contamination of groundwater. The recharge and vadose zone factors that reduced technetium-99 peak values were those that extended the travel time or increased mixing in the vadose zone during the operational recharge phase. These included reducing operational recharge rate, placing the barrier on earlier, increasing the depth between waste and the water table, or lowering the hydraulic properties of vadose zone soils (the bottom group of parameters in Tables 4-43 and 4-44). Peak value decreases because of inventory and aquifer hydraulic conductivity changes were comparable.

4.11.4.2 Iodine-129 Migration from Past Releases

For iodine-129 in past releases at WMA C (Table 4-45), the times at which the center of mass reached the WMA fenceline in the collection of sensitivity and "what if" cases spanned most of the simulation time frame. Peak times fell into four categories in Table 4-45, with the earliest peak times most darkly shaded. The different peak time categories and associated parameter changes that caused the changes in peak values indicated which of the different recharge rates were controlling contaminant migration when the center of mass entered the aquifer.

Of the parameter changes examined by the sensitivity and "what if" cases, maximum peak value increases by factors of 1.65 to 45.31 (in the top group of parameters in Table 4-45) were associated with those parameters that minimized travel time through the vadose zone as indicated by the corresponding earliest peak times. The largest peak altering parameter changes were enhanced post-closure (500 years) recharge rates due to irrigated farming and the reduction of iodine-129 sorption. Decreased travel times and associated larger peaks occurred in two ways:

- First, factors that improved the effectiveness of operational recharge rates caused the center of mass to reach the aquifer under the influence of the maximum recharge rate. These included reducing the degree of sorption, increasing the operational recharge rate, decreasing the vadose zone thickness, or removing the anisotropic aspect of flow in the vadose zone. The very early peak times (<year 2200) show that the center of mass reached the aquifer under the influence of the operational recharge rate, thereby increasing the peak value relative to the reference case by virtue of greater recharge and associated mass flux relative to the reference case.
- Second, if operational recharge period parameters were unchanged relative to the reference case, the center of mass did not reach the unconfined aquifer before year 2200. Consequently, later recharge rates moved the center of mass into the aquifer. In this case, increasing the post-closure (500 years) recharge rate relative to the reference case decreased travel time and increased mass flux into the aquifer. Peak times ranged from

years 2791 to 5351. Peak value increases were approximately proportional to recharge rate increases relative to reference case values. The most extreme case was the irrigated farmer where recharge rates increased by a factor of 50 at 500 years and corresponding peak values were about 45 times the reference value in year 2791. The other cases assumed degraded barrier recharge rates of 3 to 3.5 times the reference case values with similar peak value increases and peak times from years 5011 to 5351.

Table 4-45. Comparison (by Ratio) of Sensitivity and "What If" to Reference Case Peak Values for Iodine-129 Initially Present in Past Releases at Waste Management Area C [a] (2 pages)

Sensitivity and "What If" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	K_d = 0.2 mL/g (I-129) Past Releases	Peak/Max Time
Irrigated farming (1 mm/yr in 2532)	50 mm/yr in 2532	45.31	2791
Lower iodine-129 sorption (K_d =0.2 mL/g)	K_d =0.1 mL/g	7.5	2095
High post-design barrier recharge (1 mm/yr in 2532)	3.5 mm/yr in 2532	3.43	5011
Barrier failure recharge (1 mm/yr in 2532)	3 mm/yr in 2532	2.96	5351
Early barrier failure recharge (1 mm/yr in 2532)	3 mm/yr in 2332	2.96	5191
Lower depth (150 ft bgs)	170 ft bgs	2.93	2109
Late barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2050	1.75	2120
High operational recharge (100 mm/yr)	140 mm/yr	1.66	2101
Isotropic vadose zone hydraulic conductivity (anisotropic)	Isotropic	1.65	2104
Low aquifer K_{sat} (3,000 m/day)	2,000 m/day	1.5	9621
High past release inventory (reference)	Location specific	1.44	9621
Higher water table (reference)	2 m higher	1.1	8661
High vadose zone hydraulic properties (reference)	10 × reference	1.08	10141
Low operational recharge (100 mm/yr)	40 mm/yr	>1.02	12032
Interim barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2010	1.01	10951
Early barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2020	1.01	10701
8,000-gal retrieval leak over past leak (past leak only)	8,000 gal + inventory	1	8961
Low barrier recharge (0.5 mm/yr)	0.1 mm/yr	1	9821
High barrier recharge (0.5 mm/yr)	1 mm/yr	1	9371
Shallower depth (150 ft bgs)	130 ft bgs	>0.92	12032
Low vadose zone hydraulic properties (reference)	0.1 × reference	0.86	8791
High aquifer K_{sat} (3,000 m/day)	4,000 m/day	0.75	9611
Low past release inventory (reference)	Location specific	0.5	9621
Low post-design barrier recharge (1 mm/yr in 2532)	0.5 mm/yr in 2532	>0.48	12032

[a] In the cases where peak/max time is listed at year 12032, a peak value was not reached before the end of the modeled time frame. Therefore, the listed ratio compares the maximum value calculated for the sensitivity and "what if" cases (a value less than the true peak value) to the reference case peak value. The true peak value to peak value ratio is larger.

Progressively lighter shading indicates slower migration rates and later peak times.

The third group of peak times ranged from years 8661 to 10951. The reference case peak time (year 9621) falls into this category and peak value changes relative to the reference case were relatively small (factors range from 0.5 to 1.5). In these cases, parameter changes were insufficient to change the basic iodine-129 migration pattern found in the reference case. That is, sorption reactions in the vadose zone retarded iodine-129 migration enough to prevent maximum flux into the aquifer during the operational recharge period. The center of mass remained in the vadose zone when the barrier was emplaced, and subsequently migrated at a much slower rate in response to greatly reduced recharge rates induced by barrier emplacement. A peak time of year 9621 indicated post-closure (500 years) recharge rates controlled migration rates when the center of mass entered the aquifer. The largest increases were bounded by parameter changes independent of vadose zone properties, such as increased inventory or decreased aquifer hydraulic conductivity values. Largest decreases were due to decreased inventory or higher aquifer hydraulic conductivity. Changes in barrier placement timing, barrier recharge rates, minimal reduction in vadose zone thickness, or changes in vadose zone hydraulic properties had little effect.

The final group of peak times occurred at the end of the simulation period and associated values were still rising. Therefore, these were maximum calculated values but not true peak values (however, the shape of the curves suggests the peak value was being approached). Consequently, the ratios listed would be somewhat larger if the peak value were known and substituted for the maximum value. In this final group, the maximum vadose zone travel time was induced by lowering the operational recharge rate, increasing the vadose zone thickness between waste and the water table, or reducing the post-closure (500 years) recharge rate. Essentially no increase and minimal decrease (factor of 0.48) in maximum value were calculated.

For iodine-129 in past releases at WMA S-SX (Table 4-46), similar relationships between parameters and peak value changes were calculated. Like WMA C, the times at which the center of mass reached the WMA S-SX fenceline in the collection of sensitivity and "what if" cases spanned most of the simulation time frame and, as with WMA C results, four categories of peak times were calculated. The earliest peaks and largest peak increases were attributed to parameters that enhanced iodine-129 migration during the operational period or increased post-closure (500 years) recharge rates. As in WMA C, other parameter changes (e.g., different barrier placement, barrier recharge rates before assumed degradation, vadose zone hydraulic properties) had little effect on peak values relative to the reference case.

Despite these similarities, some differences in the effects of parameter changes on peak values were noted and are attributed to increased hydraulic and geochemical resistivity to downward migration at WMA S-SX. This is because the less conductive Cold Creek unit and perhaps the Ringold Formation underlie WMA S-SX versus the more conductive Hanford formation that underlies WMA C. An additional factor was the assumed greater vadose zone thickness between waste and the water table at WMA S-SX. These features caused several changes in contaminant migration patterns that are illustrated by comparison of both the reference case and sensitivity and "what if" case results between WMAs S-SX and C.

- Peak times were longer at WMA S-SX for comparable cases. For example, in the reference case, the iodine-129 peak occurred in year 9621 at the WMA C fenceline and groundwater concentrations were still rising at WMA S-SX fenceline in year 12032,

a travel time difference of more than 2,000 years. Similarly, in the post-closure (500 years) increased recharge cases, the peak times ranged from years 5011 to 5351 at WMA C versus years 5251 to 5801 at WMA S-SX.

- Operational recharge rates dispersed iodine-129 less widely at WMA S-SX. Only the two parameters that best enhanced migration rates during the operational period at WMA C (reduced sorption and reduced vadose zone thickness between waste and the water table) were adequate to increase the effectiveness of the maximum recharge rates at WMA S-SX such that a peak value was calculated before year 2200.
- Reduction of iodine-129 sorption K_d values at WMA S-SX caused significantly smaller impact on peak values. The increased factor was a maximum of 1.7 at WMA S-SX versus 7.5 for WMA C. Decreased sorption combined with less conductive strata reduced the fraction of initial iodine-129 inventory that contributed to the early peak at WMA S-SX. The iodine 129 concentration versus time history of the $K_d = 0.1$ mL/g sensitivity case showed a second peak of nearly the same value occurred around year 6000 indicating that a significant part of the iodine-129 inventory did not reach the aquifer before barrier emplacement. At WMA C, no comparable later peak occurred showing that a larger fraction of the iodine-129 inventory contributed to the early peak.

Given the reduced capability of these other parameters to change peak values, the most important parameters providing variability about iodine-129 migration and peak impacts at WMA S-SX are increases in post-300 or -500 year recharge rates because of barrier degradation.

Table 4-46. Comparison (by Ratio) of Sensitivity and "What If" to Reference Case Peak Values for Iodine-129 Initially Present in Past Releases at Waste Management Area S-SX [a] (2 pages)

Sensitivity and "What If" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	K_d = 0.2 mL/g (I-129) Past Releases	Peak/Max Time
Irrigated farming (1 mm/yr in 2532)	50 mm/yr in 2532	<44.88	2831
Early barrier failure recharge (1 mm/yr in 2532)	4 mm/yr in 2332	<3.99	5251
Barrier failure recharge (1 mm/yr in 2532)	4 mm/yr in 2532	<3.98	5431
High post-design barrier recharge (1 mm/yr in 2532)	3.5 mm/yr in 2532	<3.49	5801
Low aquifer K_{sat} (25 m/day)	7.5 m/day	3.31	12032
Lower iodine-129 sorption (K_d =0.2 mL/g)	K_d =0.1 mL/g	<1.7	2132
High past release inventory (reference)	Location specific	1.44	12032
Lower depth (130 ft bgs)	150 ft bgs	<1.12	9261
High vadose zone hydraulic properties (reference)	10 × reference	<1.07	12032
Higher water table (reference)	2 m higher	<1.04	11651
High barrier recharge (0.5 mm/yr)	1 mm/yr	<1.01	12032
High operational recharge (100 mm/yr)	140 mm/yr	<1	11141
Late barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2050	<1	10911
8,000-gal retrieval leak over past leak (past leak only)	8,000 gal + inventory	<1	11781
Isotropic vadose zone hydraulic conductivity (anisotropic)	Isotropic	<1	11111
Low barrier recharge (0.5 mm/yr)	0.1 mm/yr	~0.99	12032
Early barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2020	~0.95	12032
Interim barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2010	~0.92	12032
Low vadose zone hydraulic properties (reference)	0.1 × reference	~0.92	12032
Low operational recharge (100 mm/yr)	40 mm/yr	~0.81	12032
Shallower depth (130 ft bgs)	110 ft bgs	~0.67	12032
High aquifer K_{sat} (25 m/day)	50 m/day	0.5	12032
Low past release inventory (reference)	Location specific	0.4	12032
Low post-design barrier recharge (1 mm/yr in 2532)	0.5 mm/yr in 2532	~0.28	12032

[a] Ratio values with the < symbol compare sensitivity and "what if" cases peak values to the reference case maximum value calculated during the modeling time frame. Because the reference case peak value is larger than the maximum calculated value, the true peak-to-peak value ratio is smaller. Approximate ratio values (shown by the ~ symbol) compare maximum values from sensitivity, "what if", and reference cases. Exact ratio values also compare maximum values but the changed parameter maintains true proportionality between the sensitivity and "what if" and reference case groundwater concentration curves.

Progressively lighter shading indicates slower migration rates and later peak times.

4.11.4.3 Technetium-99 Migration from Tank Waste Residuals

For tank waste residual technetium-99 releases from both WMA C and WMA S-SX (Tables 4-47 and 4-48), contaminant migration was strongly affected by diffusional release from the grouted tank structure into the vadose zone beginning in year 2032. Because the barrier was emplaced at the same time in the reference case (or at most extended to year 2050 in one sensitivity case), maximum recharge rates during the operational period had virtually no impact on subsequent migration. Consequently, changes in those parameters that affected the operational recharge impacts on migration (e.g., increased operational recharge rates, changes in barrier placement times) had virtually no impact on peak values. The changes in barrier recharge rates during its 500-year, fully functioning period also had essentially no impact on technetium-99 migration because this time interval was too short relative to travel time in the vadose zone. Of the expected post-closure system properties varied in the sensitivity and "what if" cases (e.g., diffusional release from the grouted structure and hydrologic parameters), the most significant peak value increases occurred with increases in diffusion coefficients, post-500 year recharge rates, and decreased volumes of aquifer mixing, which were regulated by a decreased saturated hydraulic conductivity value in the sensitivity analysis. A maximum increase of about a factor of 3 occurred in these cases. The maximum decrease in peak value occurs with the assumption of a decreased diffusion coefficient (a factor of 0.003).

Maximum increases in peak value occurred for assumptions of irrigated farming (factors of about 12 to 14), an advection-dominated release rather than a diffusion-dominated release (a factor of about 8 to 9), and increased residual thickness (a factor of 10), a proxy for inventory change. While these factors are the largest, they are not expected to drive variability around peak values at closure (see Section 4.11.4.5 for additional discussion).

Table 4-47. Comparison (by Ratio) of Sensitivity and "What If" to Reference Case Peak Values for Technetium-99 Initially Present in Tank Waste Residuals at Waste Management Area C (2 pages)

Sensitivity and "What If" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	K_d = 0 mL/g (Tc-99) Residuals
Irrigated farming (1 mm/yr in 2532)	50 mm/yr in 2532	13.94
Higher residual thickness (1 in.)	10 in.	10
Advection release rate (diffusion controlled)	Advection	7.85
High diffusion coefficient (1E-09 cm^2/s)	1E-08 cm^2/s	3.17
High post-design barrier recharge (1 mm/yr in 2532)	3.5 mm/yr in 2532	2.1
Barrier failure recharge (1 mm/yr in 2532)	3 mm/yr in 2532	1.91
Early barrier failure recharge (1 mm/yr in 2532)	3 mm/yr in 2332	1.79
Low aquifer K_{sat} (3,000 m/day)	2,000 m/day	1.5
High vadose zone hydraulic properties (reference)	10 × reference	1.16
Higher water table (reference)	2 m higher	1.07

Table 4-47. Comparison (by Ratio) of Sensitivity and "What If" to Reference Case Peak Values for Technetium-99 Initially Present in Tank Waste Residuals at Waste Management Area C (2 pages)

Sensitivity and "What If" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	K_d = 0 mL/g (Tc-99) Residuals
Low barrier recharge (0.5 mm/yr)	0.1 mm/yr	1.02
Low operational recharge (100 mm/yr)	40 mm/yr	1
High operational recharge (100 mm/yr)	140 mm/yr	1
Early barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2020	1
Late barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2050	0.98
High barrier recharge (0.5 mm/yr)	1 mm/yr	0.98
Isotropic vadose zone hydraulic conductivity (anisotropic) [a]	Isotropic	> 0.84
Low vadose zone hydraulic properties (reference) [a]	0.1 × reference	> 0.76
High aquifer K_{sat} (3,000 m/day)	4,000 m/day	0.75
Low post-design barrier recharge (1 mm/yr in 2532) [a]	0.5 mm/yr in 2532	> 0.25
Lower residual thickness (1 in.)	0.1 in.	0.1
Low diffusion coefficient (1E-09 cm^2/s)	1E-14 cm^2/s	0.003
Technetium K_d (0 mL/g) [a]	0.1 mL/g	> 0.04

[a] In these cases, a peak value was not reached before the end of the modeled time frame. Therefore, the ratio compares the maximum modeled contaminant value from the sensitivity and "what if" cases to the reference case peak value. Because the maximum calculated value is less than the peak value, the true peak value to peak value ratio is larger.

Table 4-48. Comparison (by Ratio) of Sensitivity and "What If" to Reference Case Peak Values for Technetium-99 Initially Present in Tank Waste Residuals at Waste Management Area S-SX (2 pages)

Sensitivity and "What If" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	K_d = 0 mL/g (Tc-99) Residuals
Irrigated farming (1 mm/yr in 2532)	50 mm/yr in 2532	12.2
Higher residual thickness (1 in.)	10 in.	10
Advection release rate (diffusion controlled)	Advection	8.96
Low aquifer K_{sat} (25 m/day)	7.5 m/day	3.32
High diffusion coefficient (1E-09 cm^2/s)	1E-08 cm^2/s	3.15
Barrier failure recharge (1 mm/yr in 2532)	4 mm/yr in 2532	2.28
High post-design barrier recharge (1 mm/yr in 2532)	3.5 mm/yr in 2532	2.09
Early barrier failure recharge (1 mm/yr in 2532)	4 mm/yr in 2332	2.05
High vadose zone hydraulic properties (reference)	10 × reference	1.17

Table 4-48. Comparison (by Ratio) of Sensitivity and "What If" to Reference Case Peak Values for Technetium-99 Initially Present in Tank Waste Residuals at Waste Management Area S-SX (2 pages)

Sensitivity and "What If" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	K_d = 0 mL/g (Tc-99) Residuals
Low barrier recharge (0.5 mm/yr)	0.1 mm/yr	1.03
Low operational recharge (100 mm/yr)	40 mm/yr	1
High operational recharge (100 mm/yr)	140 mm/yr	1
Early barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2020	1
Higher water table (reference)	2 m higher	1
Late barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2050	0.98
High barrier recharge (0.5 mm/yr)	1 mm/yr	0.97
Low vadose zone hydraulic properties (reference)	0.1 × reference	0.75
Isotropic vadose zone hydraulic conductivity (anisotropic)	Isotropic	0.71
Low post-design barrier recharge (1 mm/yr in 2532) [a]	0.5 mm/yr in 2532	>0.65
High aquifer K_{sat} (25 m/day)	50 m/day	0.5
Lower residual thickness (1 in.)	0.1 in.	0.1
Low diffusion coefficient (1E-09 cm^2/s)	1E-14 cm^2/s	0.003
Technetium K_d (0 mL/g) [a]	0.1 mL/g	>0.02

[a] In these cases, a peak value was not reached before the end of the modeled time frame. Therefore, the ratio compares the maximum modeled contaminant value from the sensitivity and "what if" cases to the reference case peak value. Because the maximum calculated value is less than the peak value, the true peak value to peak value ratio is larger.

4.11.4.4 Iodine-129 Migration from Residual Waste and Uranium Migration from Past Releases and Tank Residual Waste

In the reference case, iodine-129 and uranium migration from residual waste did not reach aquifer with concentrations above effective zero within the simulation time period because of sorption and greater initial distance between waste and the water table relative to past releases. Also, uranium migration from past releases did not reach the aquifer above effective zero except for tank row B-103 in WMA B-BX-BY. The lack of significant breakthrough into the aquifer for these initial conditions is attributed to sorption assumptions causing retarded migration rates. However, in some of the sensitivity and "what if" cases where recharge rates were increased relative to reference case values at 300 or 500 years post-closure, non-negligible aquifer concentrations from these radionuclide/waste type initial conditions were calculated.

Table 4-49 summarizes those increased recharge cases where concentrations above effective zero occurred within the simulation time frame as a function of radionuclide/waste type initial conditions and WMA. Recharge rates (by row) are arranged by decreased rates from the top down and radionuclide/waste type initial conditions (by column) are arranged from left to right by decreasing mobility. Note that the order of recharge rate cases is different at WMA S-SX versus WMA C because post-300 or -500 year recharge rates of 4 mm/yr at WMA S-SX versus 3 mm/yr at WMA C were assumed.

The cumulative set of results shows a continuum of migration rates and groundwater contamination levels caused by variable recharge rates and sorption differences. At the high end, peak values were calculated when system factors enhanced migration rates (lower sorption K_d for iodine-129, more rapid migration from past releases or higher post-300 or -500 year recharge rates and migration through WMA S-SX vadose zone). The maximum peak value occurred in the irrigated farming case where the recharge rate assumption exceeded other enhanced recharge rates by factors of 15 to 20. At the low end, negligible contamination reached the aquifer when system factors reduced migration rates (higher sorption K_d for uranium, lower post-300 or -500 year recharge rates and migration through the WMA C vadose zone). These results also show that non-negligible contamination levels occur more frequently at WMA S-SX, and because of the increased post-300 to -500 year recharge rate and a shorter distance between waste and the unconfined aquifer.

Table 4-49. Summary of Groundwater Contamination Impacts from Increased Recharge Rate Cases for Iodine-129 and Uranium Migration from Tank Residual Waste and Uranium Migration from Past Releases [a]

WMA	Sensitivity and "What If" Cases	Recharge Rates (Start Year)	Non-Negligible Concentrations within Modeled Time Frame		
			I-129 (TR)	U (PR)	U (TR)
WMA C	Irrigated farming	50 mm/yr (2532)	Yes (peak)	Yes (peak)	Yes (peak)
	High post-design barrier recharge	3.5 mm/yr (2532)	Yes (max)	Yes (peak)	No
	Early barrier failure	3 mm/yr (2332)	Yes (max)	No	No
	Late barrier failure	3 mm/yr (2532)	Yes (max)	No	No
WMA S-SX	Irrigated farming	50 mm/yr (2532)	Yes (peak)	Yes (peak)	Yes (max)
	Early barrier failure	4 mm/yr (2332)	Yes (peak)	Yes (max)	Yes (max)
	Late barrier failure	4 mm/yr (2532)	Yes (peak)	Yes (max)	Yes (max)
	High post-design barrier recharge	3.5 mm/yr (2532)	Yes (max)	Yes (max)	No

[a] Peak indicates contaminants that reached peak concentration within the model time period. Max indicates contaminants that reached the aquifer in non-negligible concentrations but had not peak at the end of the modeled time period. Dark shading indicates maximum migration rates and peak values calculated within the modeled time period. Light shading indicates intermediate migration rates and peak values did not occur before the end of the modeled time period.

PS = contaminant migrates from past releases

TR = contaminant migrates from tank waste residuals

4.11.4.5 Cumulative Parameter Variability Effects on Peak Value Estimates

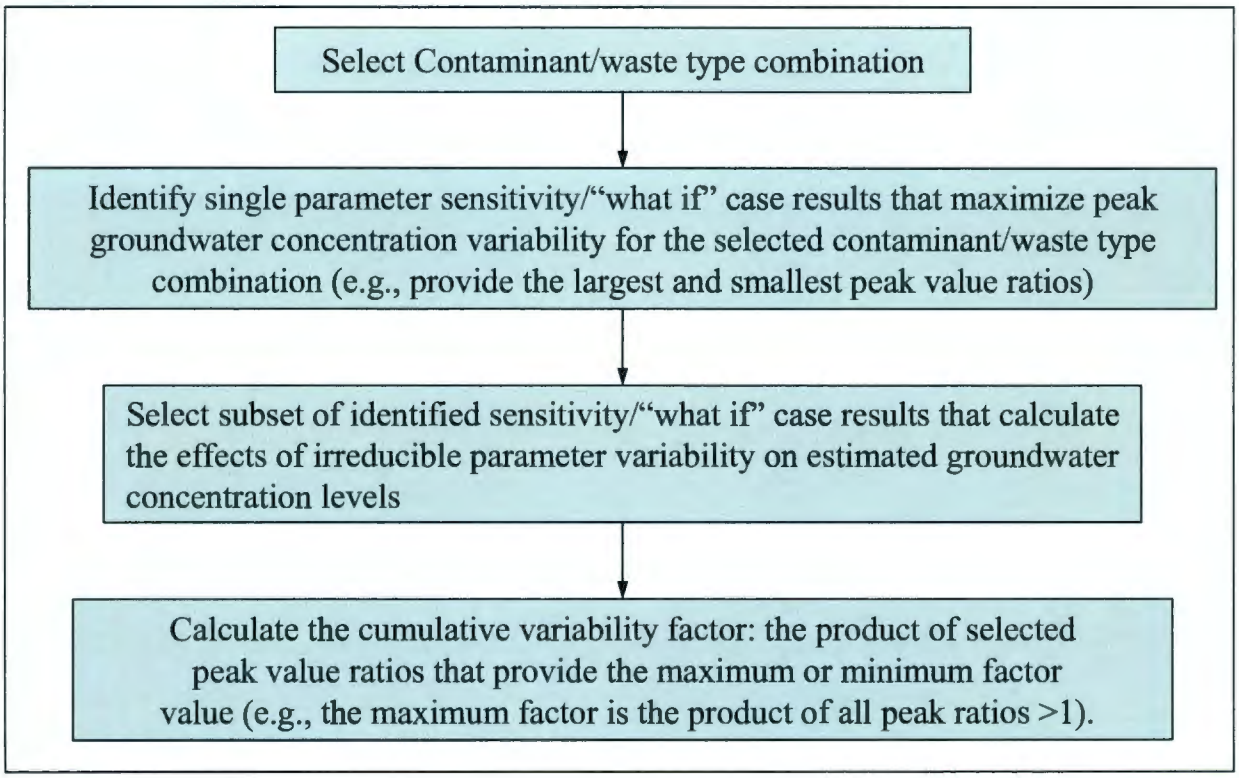
The preceding discussion has shown that several system properties and processes are influencing contaminant migration. Each of the analyses discussed above has evaluated these input-response relationships individually by changing the reference case input value of a single parameter that represents a particular property or process. The consequence of the parameter value change was then determined by comparing the calculated change in peak time and peak value to that of the appropriate reference case. These calculations were done for parameter values above and below the reference case value to reflect the inherent variability of the parameter in a heterogeneous system. In a real system, of course, multiple properties and processes influence contaminant

migration simultaneously and some means of evaluating the cumulative effects is desirable. To make this estimate, cumulative variability factors were estimated.

Cumulative variability factors estimated either peak value increases or decreases relative to the reference peak value. A four-step process was employed to make the calculation for a select contaminant and waste type combination (Figure 4-46). First, the specific contaminant/waste type combination was selected. Second, a relevant set of parameter changes and associated sensitivity/"what if" case results were selected. Third, a subset of identified case results was selected that calculated the effects of irreducible parameter variability on estimated groundwater contamination levels (Table 4-50). Fourth, the product of peak ratios from the subset of case results was taken that quantified the cumulative variability factor (Table 4-51).

These factors were then used to estimate a plausible range of peak values based on site-specific system variability. This calculated range provides a means for qualitatively assessing the overall degree of plausible variability associated with projections of future groundwater contamination levels. The cumulative variability factor approach is viable only if features and processes simultaneously affecting contaminant migration also act independently. Corresponding numerical multiple parameter change analyses have been completed whose peak increases compare well with those calculated by the cumulative variability factor method (generally within 10 to 20%. The observed close agreement verifies this underlying assumption.

Figure 4-46. Cumulative Variability Analysis Approach



For this approach to be valid, the effects of single parameter variability on groundwater contamination as expressed by the peak value ratios must be largely unaffected by variability in other parameters simultaneously affecting contaminant migration (i.e., independent parameters). To address the issue of parameter independence, additional sensitivity and "what if" analyses were run that changed the values of multiple parameters whose ratios were multiplied in the cumulative variability factor calculations. As discussed below, comparison of peak value changes predicted by the cumulative variability factors and the multiple parameter change analyses showed good agreement.

This approach does not determine the likelihood of a particular outcome within the estimated range of peak values other than to presume a general tendency to favor the reference case result that was based on expected values for significant parameters.

Table 4-50. Categorization of Sensitivity and "What If" Cases with Respect to Potential for Reduction in Variability Effects on Peak Groundwater Contamination Values (2 pages)

Sensitivity and "What If" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	Applicability	
		Past Release	Tank Residuals
Comparative Parameter Value Cases			
Irrigated farming (1 mm/yr in 2532)	50 mm/yr in 2532	Yes	Yes
Advection release rate (diffusion)	Advection	No	Yes
Isotropic vadose zone hydraulic conductivity (anisotropic)	Isotropic	Yes	Yes
Technetium K_d (0 mL/g)	0.1 mL/g	Yes	Yes
Variability Reduction by Closure Actions (e.g., retrieval, barrier placement)			
Higher residual thickness (1 in.)	10 in.	No	Yes
Lower residual thickness (1 in.)	0.1 in.	No	Yes
Interim barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2010	Yes	No
Early barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2020	Yes	Yes
Late barrier placement (0.5 mm/yr in 2032)	0.5 mm/yr in 2050	Yes	Yes
Retrieval leak (none)	0.4, 8, 20 kgal	No	No
Retrieval leak over past leak (none)	8 kgal + inventory	Yes	No
Vadose zone remediation (none)	5, 25, 50 %	Yes	No
Variability Reduction by Site-Specific Data Collection (e.g., retrieval, cover placement)			
High operational recharge (100 mm/yr)	140 mm/yr	Yes	Yes
Low operational recharge (100 mm/yr)	40 mm/yr	Yes	Yes
High diffusion coefficient (1E-09 cm^2/s)	1E-08 cm^2/s	No	Yes
Low diffusion coefficient (1E-09 cm^2/s)	1E-14 cm^2/s	No	Yes
Shallower inventory depth (130 ft bgs)	110 ft bgs	Yes	No
Lower inventory depth (130 ft bgs)	150 ft bgs	Yes	No

Table 4-50. Categorization of Sensitivity and "What If" Cases with Respect to Potential for Reduction in Variability Effects on Peak Groundwater Contamination Values (2 pages)

Sensitivity and "What If" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	Applicability	
		Past Release	Tank Residuals
Limited Variability Reduction			
Waste Management Area C			
High past release inventory WMA C (reference)	4 × reference	Yes	No
Low past release inventory WMA C (reference)	0.5 × reference	Yes	No
Early barrier failure recharge (1 mm/yr in 2532)	3 mm/yr in 2332	Yes	Yes
Barrier failure recharge (1 mm/yr in 2532)	3 mm/yr in 2532	Yes	Yes
Low aquifer K_{sat} (3,000 m/day)	2,000 m/day	Yes	Yes
High aquifer K_{sat} (3,000 m/day)	4,000 m/day	Yes	Yes
Waste Management Area S-SX			
High past release inventory WMA S-SX (reference)	1.44 × reference	Yes	No
Low past release inventory WMA S-SX (reference)	0.4 × reference	Yes	No
Early barrier failure recharge (1 mm/yr in 2532)	4 mm/yr in 2332	Yes	Yes
Barrier failure recharge (1 mm/yr in 2532)	4 mm/yr in 2532	Yes	Yes
Low aquifer K_{sat} (25 m/day)	7.5 m/day	Yes	Yes
High aquifer K_{sat} (25 m/day)	50 m/day	Yes	Yes
Waste Management Areas C and S-SX			
Low post-design barrier recharge (1 mm/yr in 2532)	0.5 mm/yr in 2532	Yes	Yes
High post-design barrier recharge (1 mm/yr in 2532)	3.5 mm/yr in 2532	Yes	Yes
Low barrier recharge (0.5 mm/yr)	0.1 mm/yr	Yes	Yes
High barrier recharge (0.5 mm/yr)	1 mm/yr	Yes	Yes
Higher water table (reference)	2 m higher	Yes	Yes
Low vadose zone hydraulic properties (reference)	0.1 × reference	Yes	Yes
High vadose zone hydraulic properties (reference)	10 × reference	Yes	Yes
Iodine-129 K_d (0.2 mL/g)	0.1 mL/g	Yes	Yes

In Table 4-50, all analyzed sensitivity and "what if" cases are listed and divided into four categories. These categories were developed to address the relevance of the associated cases to a useful cumulative variability estimate as follows.

- The first set of analyses labeled as comparative cases represents extreme conditions that were evaluated for reasons other than evaluating expected post-closure conditions. Irrigated farming is a possible event but not one being considered as a likely land use option whose health impacts will be the basis for waste remediation decisions. Advection-dominated release of contaminants from tank waste residuals and a vadose zone whose hydraulic properties are isotropic for a given vadose zone stratigraphic unit are not plausible post-closure conditions. They were evaluated to gauge the effect of

diffusional release and anisotropic vadose zone hydraulic properties on contaminant migration. The technetium-99 sorption value of 0.1 mL/g evaluates the impacts of limited sorption on peak values for those contaminants assigned a K_d value of 0 mL/g in the reference case. For technetium-99 specifically, the consensus of field and laboratory observations in tank farm vadose soils is that technetium-99 is non-sorbing. Therefore, a range of K_d values is not considered appropriate for technetium-99 in this analysis.

- The second and third sets of analyses include parameter variability effects that exist currently because specific closure actions have not occurred or additional site-specific data are yet to be collected or exist and have not been applied to the specific WMA in this analysis.
- The fourth set of analyses includes parameter variability effects that may be reduced by further data collection but some essentially irreducible variability is expected to persist.

Of these categories, the fourth set is the only one considered in this analysis to provide a qualitative cumulative variability estimate. The effects of variability from these parameters on system performance provide an estimate of the fundamental variability in system performance expected to be present at closure. With the exception of parameter variability identified in the first set (which assumes unrealistic system conditions post-closure), additional variability in system performance due to variability in other parameters in the second and third sets may be warranted eventually. The justification for adding additional sources of variability will be determined as additional information is collected in future actions leading up to closure (e.g., retrieval, field characterization, laboratory testing). It is expected that much of the variability assumed for these parameters will be eliminated. Over time, real variability will be much better defined and the cumulative variability estimate will be revised to incorporate additional effects.

Given this subset of sensitivity and "what if" case results, cumulative variability factors were generated around the reference case peak values for those constituents that reach the unconfined aquifer at peak or maximum values during the simulation. The selected sensitivity and "what if" cases factors for estimating cumulative high-side and low-side variability factors are provided in Table 4-51. High and low factors are provided for technetium-99 and iodine-129 from past releases and technetium-99 from tank waste residuals at both WMAs C and S-SX.

Cumulative variability factors were calculated by taking the product of peak-to-peak value ratios for all relevant parameters contributing to the estimated change in peak value from the reference case. A qualitative range in peak values was then determined by taking the product of the appropriate reference case peak value and the high- and low-side cumulative variability factors. This estimate is qualitative because of the underlying assumption that the various processes represented by these factors are independent of each other as they simultaneously influence contaminant migration.

Table 4-51. Cumulative Variability Factors for Mobile and Semi-Mobile Radionuclides that Reach Peak/Maximum Values within the Modeled Time Period (12032)

Parameters (Reference Values)	Sensitivity and "What If" Parameter Values	Past Release Nuclides		Residual Nuclides
		Tc-99	I-129	Tc-99
Waste Management Area C				
Lower iodine-129 sorption (K_d =0.2 mL/g)	Kd =0.1 mL/g	NA	7.5	NA
High past release inventory (reference)	Location specific	4	1.44	NA
High post-design barrier recharge (1 mm/yr in 2532)	3.5 mm/yr in 2532	1	3.43 [a]	2.1
High vadose zone hydraulic properties (reference)	10 × reference	1.68	1.08	1.16
Low aquifer K_{sat} (3,000 m/day)	2,000 m/day	1.47	1.5	1.5
Higher water table (reference)	2 m higher	1.13	1.1	1.07
Cumulative High Side Variability Factor		**11.16**	**19.25**	**3.91**
Low past release inventory (reference)	Location specific	0.5	0.5	NA
Low post-design barrier recharge (1 mm/yr in 2532)	0.5 mm/yr in 2532	1	0.48	0.25
Low vadose zone hydraulic properties (reference)	0.1 × reference	0.57	0.86	0.76
High aquifer K_{sat} (3,000 m/day)	4,000 m/day	0.76	0.75	0.75
Cumulative Low Side Variability Factor		**0.22**	**0.15**	**0.14**
Waste Management Area S-SX				
Early barrier failure recharge (1 mm/yr in 2532)	4 mm/yr in 2332	1	3.99	2.05 [b]
Low aquifer K_{sat} (25 m/day)	7.5 m/day	2.7	3.31	3.32
Lower iodine-129 sorption (K_d =0.2 mL/g)	K_d =0.1 mL/g	NA	1.7	NA
High past release inventory (reference)	Location specific	1.44	1.44	NA
High vadose zone hydraulic properties (reference)	10 × reference	1.54	1.07	1.17
Barrier failure recharge (1 mm/yr in 2532)	4 mm/yr in 2532	1	3.98 [b]	2.28
Higher water table (reference)	2 m higher	1.06	1.04	1
S-SX Cumulative High Side Variability Factor		**6.35**	**35.98**	**8.86**
Low post-design barrier recharge (1 mm/yr in 2532)	0.5 mm/yr in 2532	1	0.28	0.65
Low past release inventory (reference)	Location specific	0.4	0.4	NA
High aquifer K_{sat} (25 m/day)	50 m/day	0.53	0.5	0.5
Low vadose zone hydraulic properties (reference)	0.1 × reference	0.58	0.92	0.75
S-SX Cumulative Low Side Variability Factor		**0.12**	**0.05**	**0.24**

[a] The post-500 year recharge rate did not influence the cumulative high side peak value because the reduced sorption (K_d = 0.1 caused the peak value to occur well before then (e.g., year 2132 or earlier). Therefore, this factor was not included in the cumulative high side variability factor calculation

[b] This factor was not included in the calculated WMA S-SX cumulative high side variability factor. Two barrier degradation increased recharge rate factors were available for this cumulative factor calculation and the larger factor was selected.

NA = not applicable

To test the validity of independence between parameters used in the cumulative variability factor calculations, sensitivity analyses were completed that matched all the parameter value changes assumed in cumulative variability factor calculation and the resulting peak value estimates were compared to the reference case peak values. These ratios were then compared to the appropriate cumulative variability factors. Agreement between these ratios was quite good, ranging from no difference to differences of no more than a factor of 2, thus validating that features and processes represented by these parameters are largely independent. Some of the observed discrepancy is attributed to the use of maximum concentration estimates in the ratio calculations rather than true peak values. In these cases, peak values did not occur within the simulation period.

Maximum high-side variability factors were calculated for iodine-129 from past releases. At WMA C, the largest individual variability factor was caused by the reduction in K_d value from 0.2 to 0.1 mL/g. At WMA S-SX, the most significant factors were the increased post-300 year recharge rates and the reduced volume of aquifer mixing relative to reference case. Conversely, the greatest potential decrease in peak values relative to the reference peak value occurred for iodine-129, which was caused by the assumed reduction in 500 years post-closure recharge rates. Minimum variability ranges were calculated for technetium-99 released from tank waste residuals and the most significant factors were changes in 500 years post-closure recharge rate assumptions.

4.11.5 Impacts of Individual Barrier Underperformance on Total System (Multiple Barrier) Performance

In accordance with the defense in depth philosophy, a multiple barrier system has been assumed in this analysis to control the impacts of contaminant releases from residual waste left in tanks. The multiple barriers include two engineered components, the surface barrier and the grouted tank structure, and one natural component, the vadose zone. A key concept of the defense in depth philosophy is that the barriers provide independent and redundant functions to control projected environmental impacts (Section 1.6). In this manner, if one or more barriers fails or performs below expectations, total system performance will still be adequate. To estimate the effects of individual barrier underperformance on total system performance, cumulative variability factors have been used.

Additionally, the effects of underperformance of the surface barrier and the vadose zone assumed to mitigate the groundwater impacts from contaminants in past releases were considered in a similar manner. Because only two barriers could be considered operational with regard to reducing past release impacts and the ability to maintain compliance with performance objectives at the WMA fencelines was limited (Chapter 6.0), a true defense in depth philosophy could not be implemented for past releases. However, it is instructional to consider the relative impacts of these two barriers with this approach.

To estimate cumulative barrier underperformance factors for a given contaminant and waste type combination, a four-step process was completed for significant barriers for each waste type (Figure 4-47). First, significant barriers and barrier functions for each waste type were defined. Second, given the barrier function, the parameters that describe that function were identified. Third, the sensitivity and "what if" cases evaluated to investigate impacts of variability in those parameter values were identified. Fourth, for each relevant parameter and associated sensitivity

and "what if" case, the increase in peak value estimated from that sensitivity and "what if" analysis relative to the reference case (denoted by the peak-to-peak value ratio of the sensitivity and "what if" to reference cases) was selected. The product of those ratios determined the barrier underperformance factor.

This ratio provided an estimate of decreased total system performance because of the underperformance of that barrier. If more than one parameter change could simultaneously degrade barrier function, the product of the relevant ratios (identified in Tables 4-52 and 4-53 as the cumulative underperformance factors) represented the estimate of decreased total system performance. An increase in this factor for a given barrier showed the increased potential for degradation of the performance of that barrier to degrade total system performance.

Figure 4-47. Barrier Underperformance Analysis Approach

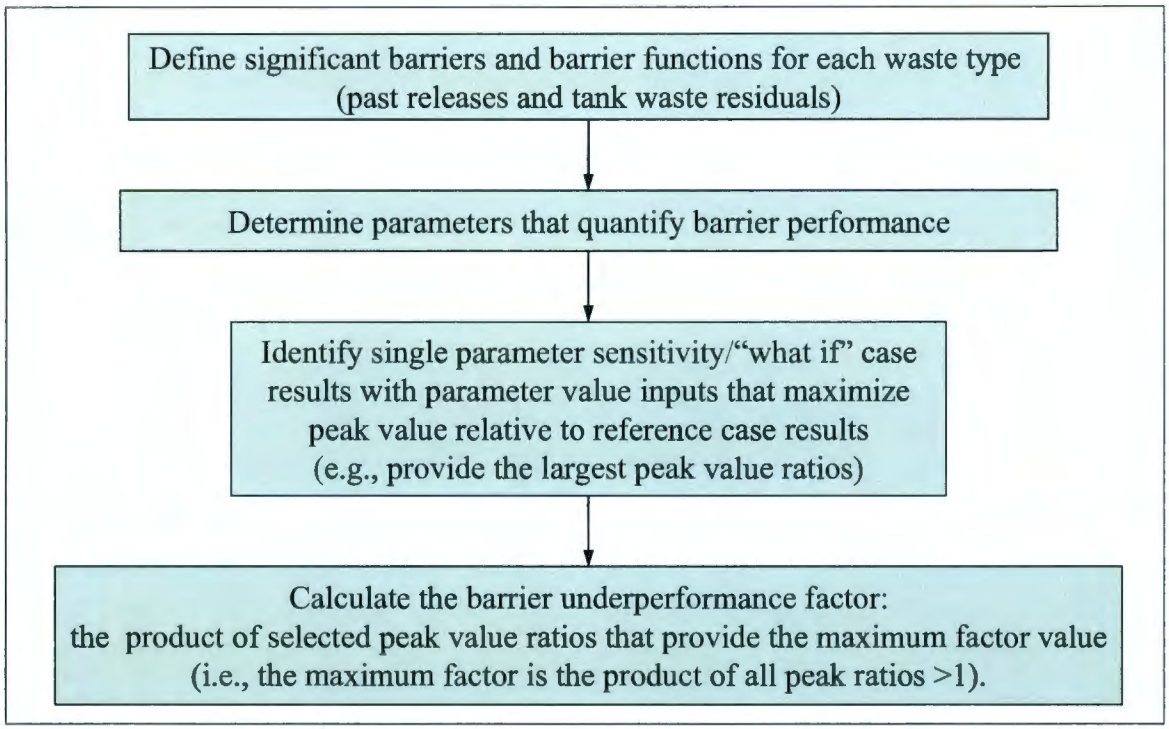


Table 4-52 summarizes estimated increases in peak concentrations of mobile contaminants (K_d = 0 mL/g) released from tank residual waste when underperformance of a given barrier was assumed. Underperformance of the engineered system (surface barrier and grouted tank structure) was also estimated. Because no chemically reactive contaminants ($K_d \geq 0.2$ mL/g) from tank residual waste reached the unconfined aquifer in the simulation period for reference case conditions, underperformance of barrier functions could only be determined from the sensitivity and "what if" case results for mobile contaminants.

The sensitivity and "what if" cases and associated parameter changes listed in Table 4-52 describe the barrier function and its degradation relative to the reference case as follows:

- The primary function of the surface barrier with respect to controlling groundwater contamination is to limit recharge rates. For tank residual waste, contaminants were assumed accessible to recharge water after surface barrier emplacement, but rarely, and then only briefly, to recharge water during the operational period. Because the design life of the barrier was only 500 years and travel times in the vadose zone for the center of mass of the residual waste contaminants occurred over thousands of years, the post-design period recharge had the greatest influence on contaminant migration. Therefore, degradation of barrier function was primarily due to increases in the post-design recharge rate.
- The primary function of the grouted tank structure is to control the contaminant release rate. The reference case assumed diffusion controlled release. Two alternative release rate conditions were evaluated in the sensitivity and "what if" cases, one being an increase in the diffusion coefficient, and the second being a loss of grouted structure integrity to the point that higher release rates due to advection occur. The two release rate mechanisms provide a range of possible contaminant release rate increases into the vadose zone. As described earlier, the advection case is considered unlikely, given the extreme degree of degradation needed to create this condition.
- The function of the vadose zone is to maximize travel time and disperse contaminants during migration. Hydraulic properties, vadose zone thickness between waste and the unconfined aquifer, and geochemical reactions between contaminants and vadose zone sediments affect travel time and contaminant dispersion. For tank residuals, increased hydraulic conductivity and reduced vadose zone thickness decrease vadose zone function.

Comparison of cumulative underperformance factors for each barrier that limits tank residual waste impacts on groundwater showed that the greatest potential for total system performance degradation occurred if the ability of the grouted tank structure to control contaminant release was less than that assumed in the reference case. The maximum potential for total system degradation occurred when both components of the engineered system underperformed.

Table 4-52. Impacts of Single or Multiple Barrier Degradation on Total System Performance for Mobile Contaminants Released from Tank Residual Waste at Waste Management Areas C and S-SX

Sensitivity and "What if" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	WMA C	WMA S-SX
Underperformance of Surface Barrier			
Late barrier placement (0.5 mm/yr in 2532)	0.5 mm/yr in 2050	1	1
Early barrier failure WMA C (1 mm/yr in 2532)	3 mm/yr in 2332	1.8	NA
Early barrier failure WMA S-SX (1 mm/yr in 2532)	4 mm/yr in 2332	NA	2.1
Cumulative Underperformance Factor		**1.8**	**2.1**
Underperformance of Grouted Tank Structure			
Advection release rate (diffusion)	Advection	7.9	9.0
High diffusion coefficient (1E -09 cm^2/s)	1E-08 cm^2/s	3.2	3.3
Cumulative Underperformance Factor		**3.2 – 7.9**	**3.3 – 9.0**
Underperformance of Vadose Zone			
High vadose zone hydraulic properties (reference)	10 x reference	1.2	1.2
Higher water table (reference)	2 m higher	1.1	1
Cumulative Underperformance Factor		**1.2**	**1.2**
Underperformance of Engineered System (Surface barrier plus grouted tank structure)			
Late barrier placement (0.5 mm/yr in 2532)	0.5 mm/yr in 2050	1	1
Early barrier failure WMA C (1 mm/yr in 2532)	3 mm/yr in 2332	1.79	NA
Early barrier failure WMA S-SX (1 mm/yr in 2532)	4 mm/yr in 2332	NA	2.1
Advection release rate (diffusion)	Advection	7.9	9.0
High diffusion coefficient (1E -09 cm^2/s)	1E-08 cm^2/s	3.2	3.3
Cumulative Underperformance Factor		**5.6 – 13.8**	**6.7 – 18**

NA = not applicable

Table 4-53 summarizes estimated increases in peak concentrations of mobile and semi-mobile (K_d = 0.2 mL/g) contaminants released from past releases in WMAs C and S-SX when underperformance of the surface barrier or the vadose zone was assumed. These were two of the contaminants that reached the unconfined aquifer at significant levels assuming reference case assumptions. Other less-mobile contaminants failed to reach the aquifer in significant quantities within the simulation period because of geochemical retardation effects.

Table 4-53. Impacts of Single Barrier Degradation on Total System Performance for Mobile and Semi-Mobile Contaminants in Past Releases at Waste Management Areas C and S-SX

Sensitivity and "What if" Cases (Reference Values)	Sensitivity and "What If" Parameter Values	Mobile Contaminants		Semi-Mobile Contaminants	
		WMA C	WMA S-SX	WMA C	WMA S-SX
Underperformance of Surface Barrier					
Late barrier placement (0.5 mm/yr in 2532)	0.5 mm/yr in 2050	1.4	1.2	1.8	1
Early barrier failure WMA C (1 mm/yr in 2532)	3 mm/yr in 2332	1	NA	3.0	NA
Early barrier failure WMA S-SX (1 mm/yr in 2532)	4 mm/yr in 2332	NA	1	NA	4.0
Cumulative Underperformance Factor		**1.4**	**1.2**	**5.2**	**4.0**
Underperformance of Vadose Zone					
High vadose zone hydraulic properties (reference)	10 x reference	1.7	1.5	1.1	1.1
I-129 K_d (0.2 mL/g)	0.1 mL/g	NA	NA	7.5	1.7
Higher water table (reference)	2 m higher	1.1	1.1	1.1	1.0
Lower depth WMA C (150 ft bgs)	170 ft bgs	1.6	NA	2.9	NA
Lower depth WMA S-SX (130 ft bgs)	150 ft bgs	NA	1.45	NA	1.12
Cumulative Underperformance Factor		**3.0**	**2.4**	**26**	**2.1**

NA = not applicable

The primary functions of the surface barrier and vadose zone are the same as those for the tank residual waste. However, additional parameters describe barrier functions with regard to past release contaminants. First, because semi-mobile contaminants in past releases are chemically reactive with soil, changes in their sorption levels indicated by changes in K_d values are relevant to vadose zone performance, particularly at WMA S-SX. An additional parameter that affects vadose zone performance with past release contaminants is the thickness of vadose zone between waste and the unconfined aquifer. Unlike tank residual waste which is fixed at the tank bottom, past release contamination is already present in the vadose zone over a range of depths in the various WMAs.

Comparison of the various cumulative underperformance factors showed that degraded barrier performance had a greater potential to increase groundwater contamination levels of iodine-129 compared to technetium-99. The most significant underperformance factor was the reduction of the iodine-129 K_d from 0.2 to 0.1 mL/g at WMA S-SX followed by increased post-barrier design recharge at WMAs C and S-SX.

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5.0 INADVERTENT INTRUDER ANALYSIS FOR RESIDUAL WASTE

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5.0 INADVERTENT INTRUDER ANALYSIS FOR RESIDUAL WASTE

5.1 INTRODUCTION

This chapter of the SST PA presents the analysis of estimated doses to a hypothetical individual who inadvertently exhumes waste remaining in a WMA. This individual is referred to as an "inadvertent intruder." Inadvertent intrusion into the closed WMAs will be minimized by active and passive controls as required by DOE, state, and federal requirements. The exact nature of the passive controls has not yet been defined but is likely to include a combination of monolithic warning structures, markers buried in the physical barrier, and formalized records.

This analysis does not make any implications on the likelihood of an inadvertent intrusion, but simply provides the impacts to an individual, living a variety of lifestyles, who is exposed to materials remaining after the initial intrusion. The information presented in this chapter is based on expected estimates and assumptions about what the needs of an individual may be in the future while living on the Hanford Site. One major assumption is that the individual may need to drill a well to obtain water for drinking, irrigation, or other purposes.

The likelihood of a well being driven through the waste site has not been included in this analysis. It is assumed that a well may be driven through any of the waste locations. The location with the largest dose is selected for comparison with the performance objectives.

Complete closure of the SST system is currently planned for 2032. As noted in Section 1.7, the time of comparison is 500 years after site closure. However, results will also be presented for the period of 100 to 1,000 years after site closure. The performance objective for the driller scenario is 500 mrem effective dose equivalent (EDE) for a one-time exposure, while the performance objective for the rural farmer, suburban resident, and commercial farmer is 100 mrem (EDE) per year for a continuous exposure.

The following topics are addressed in this chapter:

- Overview – Section 5.2
- Exposure scenarios – Section 5.3
- Waste and well characteristics – Section 5.4
- Estimated doses (acute and chronic) to the inadvertent intruder – Section 5.5
- Sensitivity and uncertainty in dose results – Section 5.6
- Conclusions – Section 5.7.

5.2 OVERVIEW

Two general cases of intruder exposures were evaluated. The first considers the radiation dose to an individual who excavates or drills a well into the closed WMA and brings some of the waste to the surface receiving an acute dose (i.e., contact with the waste for a relatively short period of time). The second considers the radiation dose to an individual who lives near the completed well receiving a chronic dose (i.e., exposure over a number of years).

Two acute cases were evaluated. The first case involves excavating for a basement or building foundation or highway. Because the WMA will be covered with at least a 15-ft soil surface barrier, the proposed excavations would not extend far enough below the ground surface to uncover any waste. The excavation scenario gives no radiation dose and is not evaluated any further. The second acute case involves drilling a well through the buried waste. The construction of water wells in the 200 Areas is plausible due to the distance between the WMA and the nearest surface water (i.e., greater than 10 mi).

Three chronic cases were evaluated: 1) the rural farmer with a dairy cow, 2) the suburban resident with a garden, and 3) the commercial farmer. The chronic scenarios differ by what is done with the material taken from the well (drill cuttings). The rural pasture scenario considers the drill cuttings being scattered in a cow pasture. The suburban garden scenario considers a family planting a garden in the drill cuttings. The commercial farm scenario considers the drill cuttings being present in an area that is planted with dry-land wheat, hay, or other crop that is harvested and sold for profit. The owner of the commercial farm does not consume any of the crops himself. His only exposure to the exhumed waste occurs during the production of the crop.

Note that by design, the intruder analyses do not consider the effect of contaminated groundwater on the intruder (DOE 1999d). A complete evaluation of the exposure to the intruder would take into account the presence of mobile, long-lived radionuclides in the groundwater used by post-intrusion residents. However, as discussed in Chapters 4.0 and 6.0, groundwater protection for members of the public was evaluated, albeit in a somewhat different context. Thus, following current regulatory practices, the intruder analysis only evaluates the effect on the intruder from inadvertent contact with exhumed waste. Exposure to contaminated groundwater is not included.

Each tank and soil plume has different relative amounts of the various radionuclides that are found in the underground tanks. Each radionuclide contributes uniquely to the various exposure pathways that make up the acute and chronic scenarios. Thus, the intrusion scenario doses were calculated for all 149 SSTs, 50 past tank leaks, and 17 UPRs to soil. The objective was to determine the location with the maximum dose.

- For a well driller at 500 years after closure, the projected dose is below the performance objective of 500 mrem at all drilling locations. At 100 years after closure, the performance objective is exceeded at the well location with the highest dose.
- For the scenario of a rural pasture (Section 5.3.3.1) at 500 years after closure, the maximum dose is below the performance objective of 100 mrem/yr at all drilling locations. At 100 years after closure, the performance objective is exceeded at the well location with the highest dose.
- For the scenario of a suburban garden (Section 5.3.3.2), the projected dose of three WMAs (i.e., A-AX, S-SX, TX-TY) is above the performance objective of 100 mrem/yr at 500 years after site closure.
- For the commercial farm scenario, the performance objective of 100 mrem/yr is never exceeded.

The residual tank waste and the soil contamination from past leaks have different characteristics. Intruder dose from residual waste in a tank is entirely dominated by isotopes of plutonium and americium. Most of the soluble contaminants have been removed from the tank. Intruder dose from soil contamination due to UPRs has significant contributions from soluble contaminants such as technetium-99 and tin-126, because such contaminants were present in the leaked fluid.

The performance objective (500 mrem) for the individual who drills the well is met at all waste locations for times greater than 140 years after site closure.

The performance objective (100 mrem/yr) for the rural pasture scenario is met at all waste locations for times greater than 210 years after site closure.

5.3 EXPOSURE SCENARIO DESCRIPTIONS

5.3.1 Introduction

The well drilling scenario results in both acute and chronic exposure to the exhumed waste. Acute exposures are received by the individual who drills the well. The assumed exposure time is 40 hrs spread over 5 days. Chronic exposures are received by individuals who live near the completed well. Chronic doses are calculated during the first year after the well is drilled. Doses in later years are not calculated because they would be smaller due to radioactive decay and leaching from the surface soil.

The intruder scenarios evaluated in this section are listed in Table 5-1 and are summarized below. Additional details about the exposure pathways, such as the amounts inhaled, ingested, and the duration of external exposure, are given in *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment* (Rittmann 2004). Borehole diameter is related to the quantity of water needed in each scenario. Larger diameter wells accommodate larger pumps. They also bring more waste to the surface. Effective spreading area indicates the dilution that occurs on the ground surface. The larger the spreading area, the smaller the average contamination level and resulting doses. Although the exhumed waste is not uniformly distributed over the affected area, the exposure scenarios have an averaging effect. For example, in the rural pasture scenario, the exhumed waste would be in one portion of the pasture. Because the cow grazes from various parts of the contaminated pasture, the milk concentration will vary during the year. The average milk concentration during the year is calculated from the average contamination level in the pasture. The annual dose from milk is calculated from the average milk concentration. Unique exposure pathways indicate special routes for the exhumed waste to expose the affected individual.

Table 5-1. Acute and Chronic Exposure Scenarios

Exposure Scenario	Borehole Diameter [a]	Effective Spreading Area [b]	Unique Exposure Pathways [c]
Well driller	6.5 to 16.5 in.	Varies	None
Suburban garden	6.5 in.	100 m^2	Garden
Rural pasture	10.5 in.	5,000 m^2	Cow milk
Commercial farm	16.5 in.	647,000 m^2	None

[a] Borehole diameter is related to the quantity of water needed in each scenario. Larger diameter wells accommodate larger pumps. They also bring more waste to the surface.

[b] Effective spreading area indicates the dilution that occurs on the ground surface. The areas are derived in (Rittmann 2004) from the typical areas needed in each exposure scenario.

[c] Unique exposure pathways indicate special routes for the exhumed waste to expose the affected individual.

5.3.2 Acute Scenario: Well Driller

This is the only acute scenario evaluated. The well driller scenario estimates the dose to the individual operating the drill rig. The exposure occurs during a drilling operation that lasts 40 hrs spread over 5 days. Most of the material removed from the borehole is uncontaminated soil. As an example, if the waste thickness is about 1% of the length of the borehole, the actual exposure of the well driller to the waste takes place over a period of about 0.4 hrs.

During the period that the buried waste is being removed from the hole, the driller is exposed to airborne particulate and external radiation. If the drill cuttings are placed in one pile, the waste is covered with uncontaminated soil that lies below the buried waste, which reduces or eliminates the exposures. If the drill cuttings are spread around, the exhumed waste may lie exposed on the surface for some time. In this situation, the increased exposure time will raise the resulting dose. However, the average distance between the well driller and the contamination increases, thereby lowering the resulting dose and offsetting the increase from greater exposure times. Water may or may not be present to control airborne dust at the work site.

For modeling purposes, the driller is assumed to be exposed to average concentrations in soil and air for the entire 40-hr drilling operation. In this way, the challenge of estimating actual exposure rates and times during a future drilling operation can be avoided. The average concentration in the drill cuttings (activity per unit mass) is the activity exhumed divided by the total mass of the cuttings.

This is the only scenario that needs the borehole depth to calculate the doses. Because the underground waste is represented as an upright cylinder with uniform thickness and waste concentration, the average concentration in the drill cuttings is independent of well diameter. The worker is exposed to the borehole-averaged waste concentration for a period of 40 hrs, the assumed drilling time. Exposure pathways include inhalation of contaminated dust, ingestion of trace amounts of soil, and external exposure from general contamination of the work site. Details for this exposure scenario are described in Rittmann (2004).

5.3.3 Chronic Scenarios

In all three chronic scenarios (i.e., rural pasture scenario, suburban garden, and commercial farm), the dose to the individual depends on the total material brought to the surface during the well drilling. Hence, the dose is proportional to the square of the well diameter and does not depend on the well depth. The rural pasture scenario is considered the reference case exposure scenario for the SST PA. The suburban garden and commercial farm scenarios are alternatives that illustrate the range of potential dose results.

5.3.3.1 Rural Pasture Scenario

The rural pasture scenario estimates the dose to an individual who lives near the well and has a milk cow. The drill cuttings are spread within the pasture. It is assumed that enough mixing occurs during drilling that over time, the exhumed waste is diluted to the point that grass will grow normally. Thus, grass may grow and be available to the milk cow although contaminants may be present in relatively high concentrations.

Note that the pasture area is much larger than the likely spreading area for the drill cuttings. The cow forages over the drill cuttings and elsewhere in the pasture until it obtains the amount of food (grass) it eats in a year. The contaminant concentration in the grass varies during the year, but the average is proportional to the average soil concentration in the pasture. Details for this exposure scenario are described in Rittmann (2004).

The dose to the exposed individual is calculated using average consumption rates for milk in the United States (Putnam and Allshouse 1999). The cow provides 50% of the annual milk intake, based on observed usage rates (EPA 1997b). Other pathways include inhalation of contaminated dust, ingestion of trace amounts of soil, and external exposure during periods in the pasture. Due to the larger averaging area (5,000 m^2), this case has smaller doses than the suburban garden scenario.

5.3.3.2 Suburban Garden Scenario

The suburban garden scenario estimates the dose to an individual who lives near the well and grows a vegetable garden in the drill cuttings. All of the exhumed waste is located in the garden. It is assumed that enough mixing occurs when tilling the garden that the exhumed waste is diluted to the point that the various food items will grow normally. Thus, the presence of contaminants in relatively high concentration in parts of the garden does not alter the productivity of the garden.

The contaminant concentration in the garden produce will vary from plant to plant due to the non-homogeneity of the soil contamination. As the various food items are consumed, the exposed individual accumulates the projected dose. The total dose accumulated over the year is calculated using the average soil concentration. Details for this exposure scenario are described in Rittmann (2004).

The dose to the exposed individual is calculated using average consumption rates for garden produce in the United States (Putnam and Allshouse 1999). The garden provides 25% of the annual vegetable intake, based on observed usage rates (EPA 1997b). Other pathways include

inhalation of contaminated dust, ingestion of trace amounts of soil, and external exposure during periods in the garden. Due to the small averaging area (100 m^2), this case has the highest doses.

5.3.3.3 Commercial Farm Scenario

The commercial farm scenario estimates the dose to an individual who lives near the well and uses the land to raise various crops for market. The drill cuttings are spread within the fields. The exhumed waste is averaged over the entire plot because the farmer spends time in all areas equally. Using the soil average avoids selecting an actual cuttings area and estimating the time spent in this area during the year. Using the total area and the average concentration leads to a representative dose.

Exposure pathways include inhalation of contaminated dust, ingestion of trace amounts of soil, and external exposure during periods in the fields. Details for this exposure scenario are described in Rittmann (2004). Due to the large averaging area (160 acres or 647,000 m^2), this case has the smallest doses.

5.4 WASTE AND WELL CHARACTERISTICS

5.4.1 Introduction

The residual tank waste is primarily located in the lower portion of the underground tank. Contaminated soil from tank leaks is located below the tank. Depending on location, a well could intercept only the tank waste, only the leak plume, or it could intercept both. Therefore, three cases are considered for each of the significant tank leaks:

- Tank residual only
- Tank leak only
- Tank residual and tank leak combined.

Leaks into the soil from other UPRs begin a short distance below the original ground surface and extend downward. Leaks into the soil during tank waste retrieval have not been included in the present analysis; the volume or composition of such potential leaks is unknown.

A well drilled through the contamination present in the UPRs encounters only soil. A well that passes through an underground tank encounters the steel reinforced concrete dome, the grout fill, the steel liner, and the reinforced concrete base of the tank. To carry out intruder dose estimates, it is assumed that the driller is not deterred by the resistance encountered.

5.4.2 Well Diameters and Depths

The main well parameters are the diameter and depth of the well.

5.4.2.1 Well Diameter

The typical well diameter for domestic wells in the area surrounding the Hanford Site is 6 in. The basis for this diameter is the current (i.e., December 2003) database of water well logs for the counties near the Hanford Site, as described in more detail in Section A7.0 of Rittmann (2004). About 70% of the water wells between 200 ft and 400 ft deep have a 6-in. diameter.

The actual diameter of the borehole is slightly larger than 6 in. due to the typical technique used to drill the well. The well is drilled with a bit that is slightly less than 6 in. It is lowered down a steel casing with an inside diameter of 6 in. The lower edge of the casing is made of hardened steel so the casing can be driven from above to follow the bit. However, if the casing cannot be driven any deeper, then the well may be drilled further without the casing. The actual well hole is about 6.5 in. diameter. To calculate the volume of soil removed from the borehole, it is assumed to have a diameter of 6.5 in. over its entire length.

The irrigation of the rural pasture is a small-scale operation, but requires a larger pump than normal domestic service. Hence, an increased well diameter of 10 in. (10.5-in. borehole diameter) was selected for the rural pasture scenario.

A commercial irrigator typically uses a larger diameter well to extract water at a higher flow rate. Irrigation well diameters range from 6 to 30 in. A 16-in. diameter well (16.5-in. borehole diameter) is used as a representative diameter in this setting.

5.4.2.2 Well Depth

The depth of a well depends on the WMA in which it is drilled, due to the varying depths to groundwater at each tank farm. In the present analysis, these depths were assumed to be the measured depth to groundwater near a WMA plus 20 ft (6.1 m). Depths to groundwater range from 75 to 88 m (246 ft to 289 ft) in the 200 East Area and 68 to 72 m (223 to 236 ft) in the 200 West Area. Table 5-2 shows the depths to groundwater used for each tank farm. An additional 20-ft depth is added for the intruder analysis taking into account 15 ft for the surface barrier plus drilling an additional 5 ft into the unconfined aquifer.

Table 5-2. Depth to Groundwater Near Single-Shell Tank Farms

Tank Farm	Depth [a]	Tank Farm	Depth [a]
A	88 m	S	68 m
AX	84 m	SX	68 m
B	76 m	T	72 m
BX	78 m	TX	68 m
BY	75 m	TY	69 m
C	79 m	U	68 m

[a] Above depths are measured from the ground surface to the top of the unconfined aquifer at wells within 200 m of the tank farm (HEIS 2003).

5.4.3 Characteristics of Wastes

The characteristics of the waste that determine impacts to the inadvertent intruder are the inventory (Section 3.4.1), the geometry of the waste, and the availability of the contaminants in the waste.

5.4.3.1 Geometry of the Waste

The fraction of the tank waste or soil contamination plume that is brought to the surface depends on the geometry of the waste. A cylindrical shape is assumed to represent the average waste distribution. For the underground tanks, the contaminated area is the entire tank bottom. The average waste thickness is about 1 in. and is assumed uniform across the tank bottom. The fraction of waste brought to the surface is calculated as the borehole cross-sectional area divided by the cross-sectional area for the tank.

For the past tank leaks and UPRs, the geometric shape is assumed to be a cylinder with a vertical axis. The diameter and height of the cylinder are equal to provide an average intruder case. The volume of the cylinder area is estimated from the volume of liquid leaked and an average soil filling fraction. The volumes of liquid are estimated from available historical records. The soil filling fraction is assumed to be 10%; that is, about 10% of the soil volume is occupied by the aqueous waste that leaked. The fraction of waste brought to the surface is calculated as the borehole cross-sectional area divided by the cross-sectional area for the contaminated soil. Section E1.0 of Appendix E contains a more detailed discussion of the waste geometry models, and gives the waste fraction brought to the surface for each tank and soil plume for each intruder scenario.

5.4.3.2 Availability of the Waste

Not all of the waste material (cuttings) taken from the borehole is available for inhalation or ingestion by the various intruders. The particle size distribution of the cuttings typically includes larger pieces that cannot be inhaled or ingested. The large particles are consequences of drilling technology that breaks rocks only as much as needed to facilitate removal from the hole. This minimizes wear on the drill bit.

Cable tool and rotary are the two most likely methods for drilling the well. The cable tool method uses a heavy drill bit that is raised and lowered on a cable. The rotary method uses a rotating cutting bit to grind through the sediment and rock. In each method, the bit breaks the sediment and rock into pieces called cuttings and the cuttings are cleaned out of the hole by mechanical means. Both drilling methods generate fine particles that may be inhaled or ingested. The rotary bit method generates the largest fraction of fine particles. The fine particulate is typically less than 25% of the total by weight; this is the fraction that is available for inhalation. A somewhat larger fraction could be ingested directly (inadvertent soil ingestion). A larger fraction still would be available for uptake in plants located in a garden or pasture, assuming the exhumed waste has a chemical form that permits plants to extract nutrients. Radioactivity in chemically inert compounds would be less available. The inert compounds would resist uptake by plant roots, reducing ingestion dose. They would also resist dissolution of inhaled dust in lung fluid, reducing inhalation dose.

Applying these perspectives to the exhumed waste leads to the conclusion that a portion of the exhumed waste may be unavailable to give internal dose. The two waste forms (i.e., contaminated soil and residual tank waste) are different. The waste located in the UPRs is part of the soil. It adheres to the surfaces of soil particles and is readily available for inhalation, ingestion, and uptake by plants. All of the exhumed soil contamination is assumed to give internal dose to the intruders.

The waste located inside the underground tanks is attached to interior (iron) surfaces of the underground tank. The majority of this waste is located on the bottom of the tank, with grout on top of the waste. At the time the tanks are filled with grout, this waste is in a form that resists both dissolution and mechanical removal. In addition, the radioactivity is distributed throughout the material (rather than being on the surface of relatively inert soil particles). Thus, when brought to the surface, the larger waste particles cannot be inhaled or ingested, and are largely unavailable to plants.

Although the fraction of the tank residual waste that can give internal dose to the intruders should be less than 1, it will be assumed that all of the exhumed tank waste gives internal dose to the intruders. Assuming all the exhumed waste is available to give internal dose tends to exaggerate the dose. The intruder doses will not be reduced due to the granularity or chemical inertness of the exhumed tank waste.

5.5 ESTIMATED DOSES TO THE INADVERTENT INTRUDER

5.5.1 Introduction

For the Hanford Site SST system, final closure is the closure of all SST farm WMAs according to the terms and conditions of an approved RCRA closure plan. Closure is expected by calendar year 2032.

The maximum intruder doses for the intruder scenarios decrease with time during the first 1,000 years, as shown in Figures 5-1 through 5-6. Hence, the doses are calculated for the assumed end of institutional control, namely, 500 years after site closure. The maximum intruder scenario doses at each WMA are listed in Table 5-3. The intruder doses from all SSTs and significant soil plumes in each WMA are listed in Appendix E, Section E2.0.

Tank TX-118 gives the largest intrusion dose for all scenarios. Note that tank TX-118 has no past leak plume associated with it. As shown in Table 5-3, tank SX-115 gives slightly smaller doses than TX-118. The doses calculated for tank SX-115 assume the well goes through both the tank and the leak plume. Nearly all the dose comes from the tank residual rather than the past leak, as shown in Appendix E, Table E-4.

Figure 5-1. Well Driller Doses for Tank TX-118 Showing Major Constituents

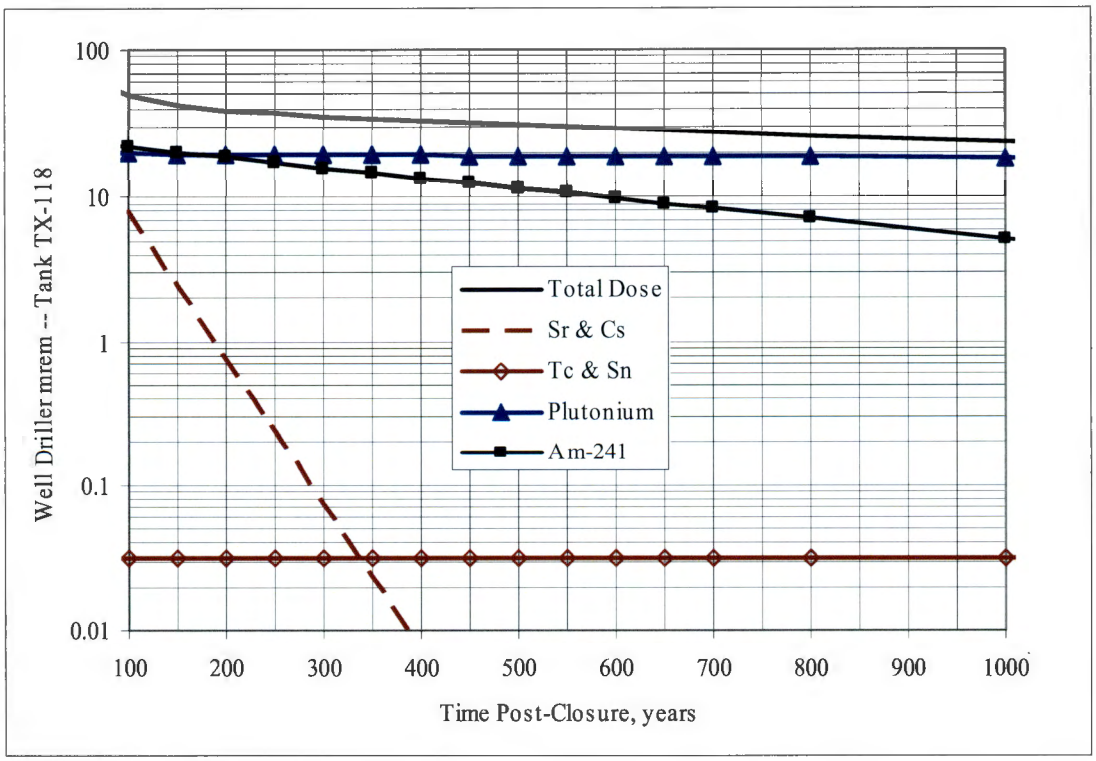

Figure 5-2. Well Driller Doses for Tank TX-118 Showing Major Exposure Pathways

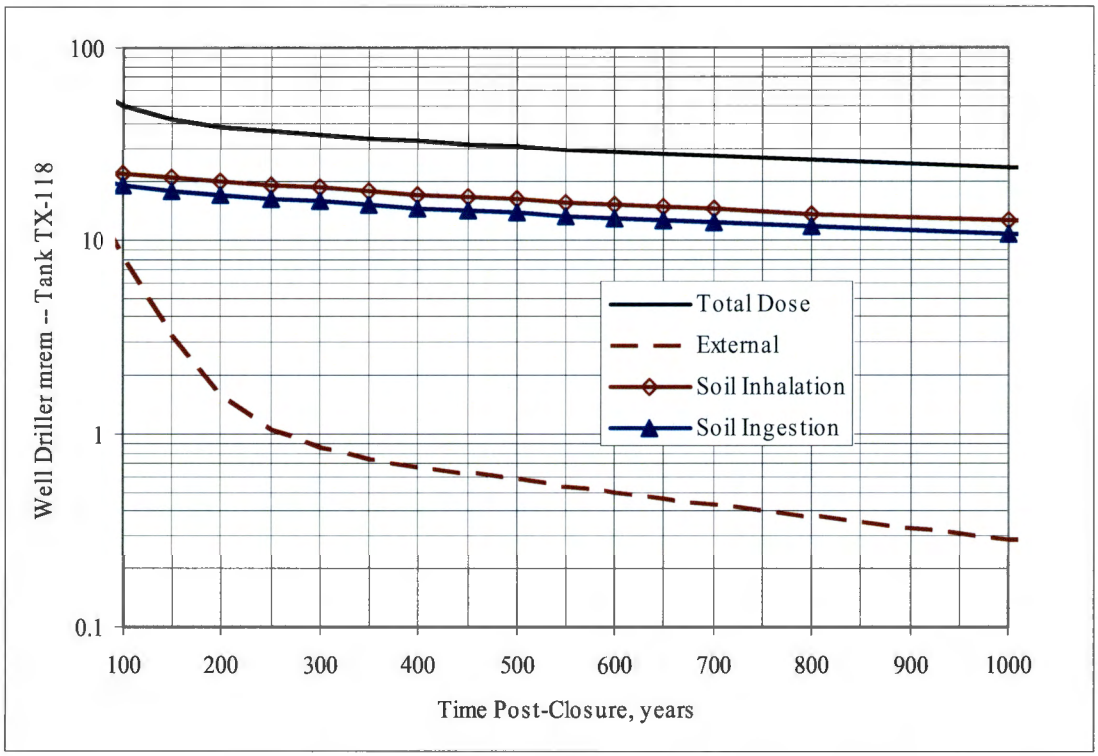

Figure 5-3. Suburban Garden Doses for Tank TX-118 Showing Major Constituents

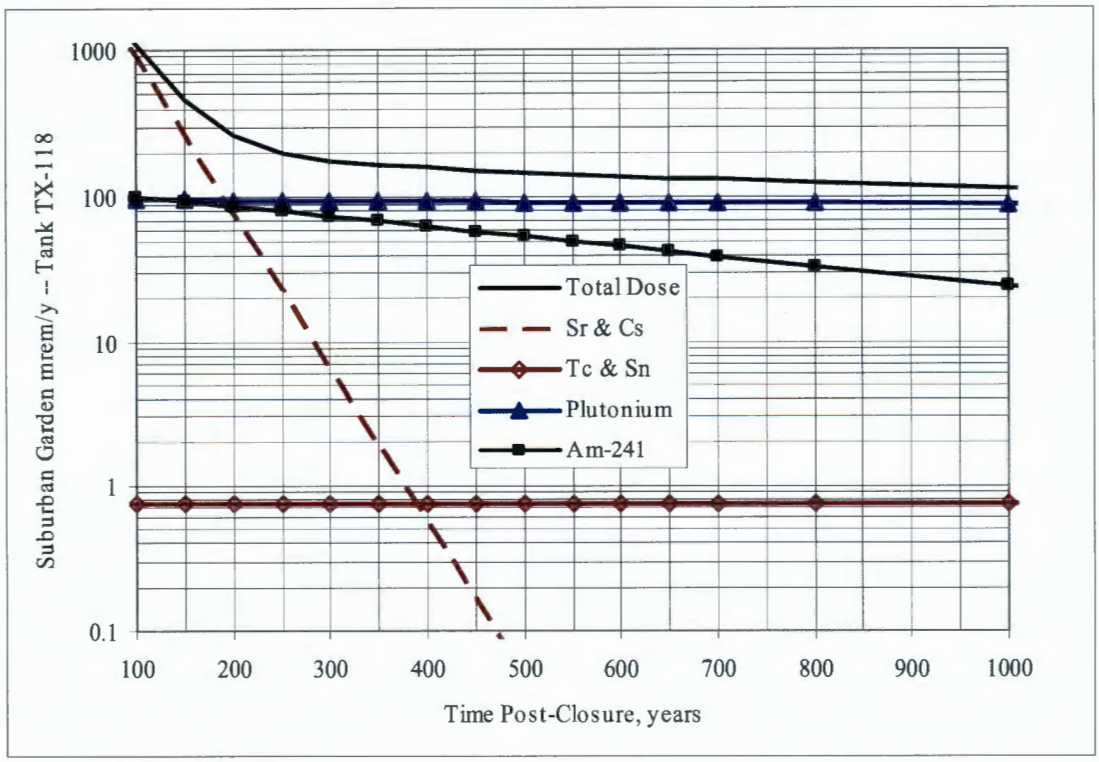

Figure 5-4. Suburban Garden Doses for Tank TX-118 Showing Major Exposure Pathways

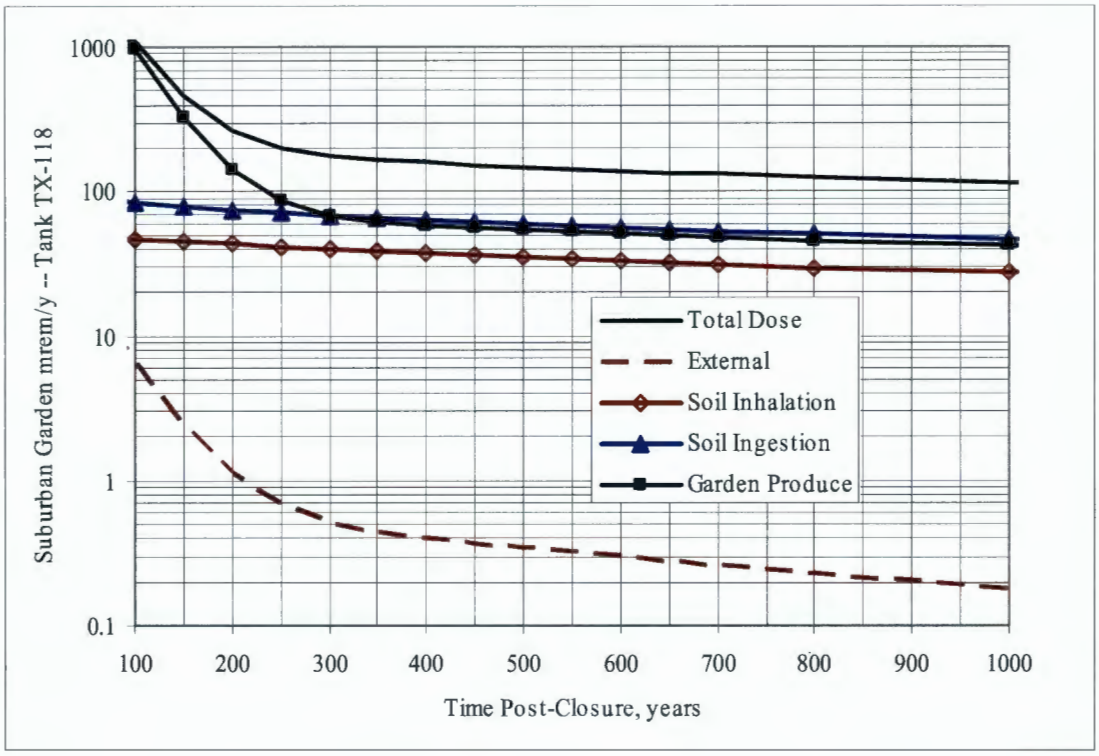

Figure 5-5. Rural Pasture Scenario Doses for Tank TX-118 Showing Major Constituents

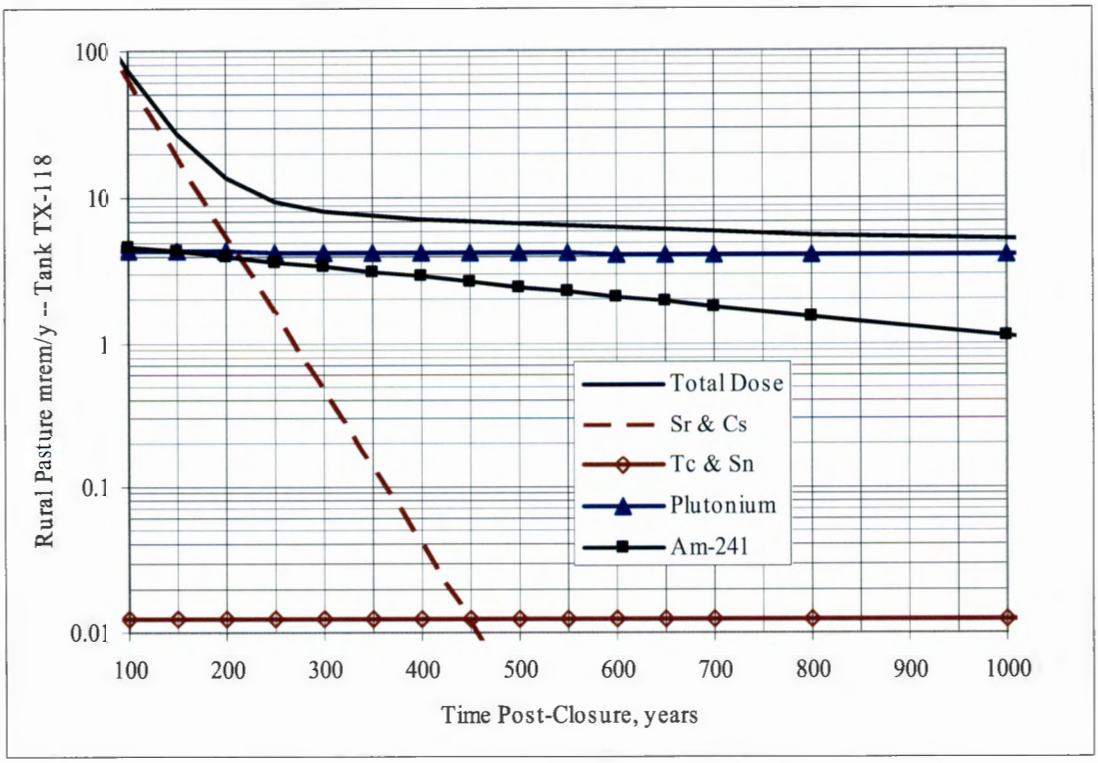

Figure 5-6. Rural Pasture Doses for Tank TX-118 Showing Major Exposure Pathways

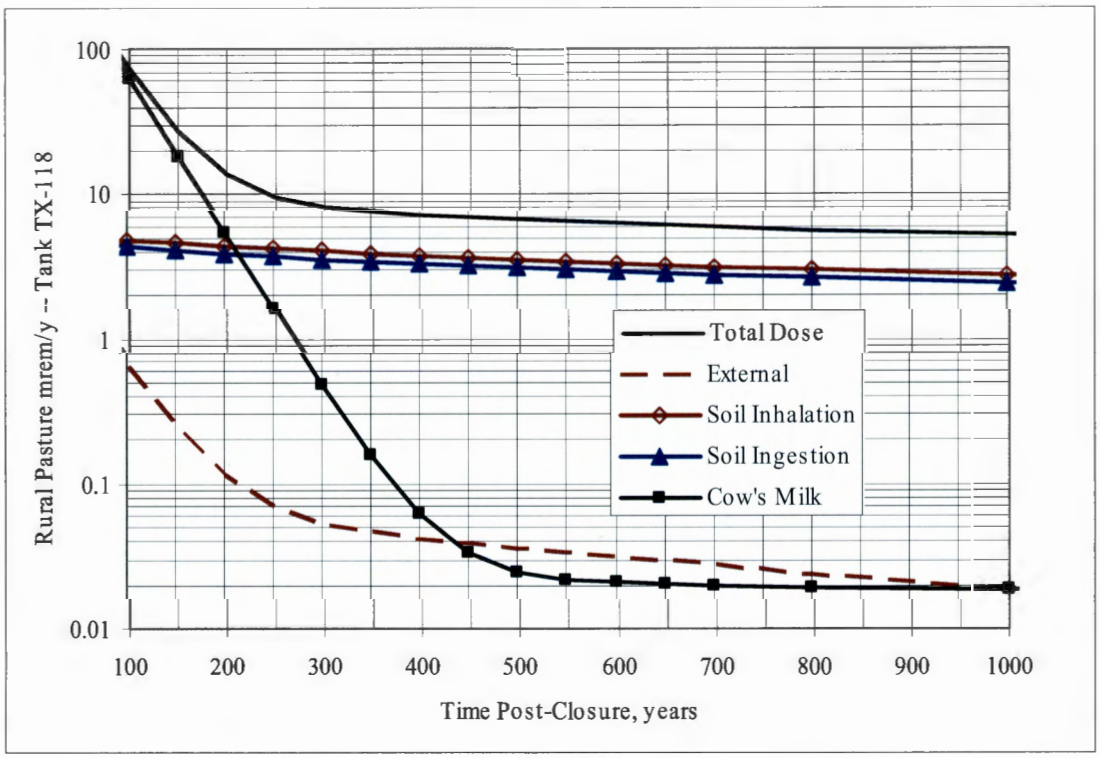

Table 5-3 shows the dose at 500 years after closure (i.e., year 2532). The performance objectives are met at 500 years after closure for the well driller, rural pasture, and commercial farm scenarios. The performance objectives are not met at 500 years after closure for the suburban garden scenario at three WMAs (i.e., A-AX, S-SX, TX-TY). Numbers in parentheses indicate the calendar year the source location with highest dose falls below the performance objective. Doses without a time in parentheses meet the objective within 100 years of WMA closure.

Table 5-3. Intruder Scenario Doses at 500 Years After Closure (Year 2532)

WMA	Source Location with Highest Dose	Reference Cases		Sensitivity Cases	
		Well Driller mrem	Rural Pasture [a] mrem/y	Suburban Garden [a] mrem/y	Commercial Farm mrem/y
A-AX	AX-102 (tank plus leak)	18	4.8 (2183)	**108 (2590)**	0.13
B-BX-BY	B-101	4.2	1.0	23 (2239)	0.029
C	C-201 (tank plus leak)	12	2.9	65 (2277)	0.082
S-SX	SX-115 (tank plus leak)	29	6.6 (2237)	**147 (4885)**	0.18
T	T-106 (tank plus leak)	1.3	0.46	22 (2241)	0.0072
TX-TY	TX-118	30	6.7	**148 (3522)**	0.19
U	U-106	6.4	1.4	31 (2228)	0.039

[a] The times in parentheses are calendar years. At the time shown in parentheses, the intruder dose matches the performance objective of 500 mrem for the acute exposure, or 100 mrem for the chronic exposure. Doses without a time in parentheses meet the objective within 100 years of WMA closure.

Bold indicates potentially above performance objective.

In the suburban garden scenario, tanks SX-115 and TX-118 exceed the performance objective for more than 1,000 years. The main reason for the longer time is that the doses are dominated by plutonium and americium, which have long decay half-lives. Figure 5-3 shows the contribution of various radionuclides to the total dose. In this figure, the plutonium and americium are the main components at 500 years.

5.5.2 Intruder Scenario Doses

The intruder scenario doses for TX-118 are plotted in Figures 5-1 through 5-6 to indicate the time dependence of the dose from 100 years to 1,000 years after closure. Shown in the figures are the time dependence of important constituents and major exposure pathways. The intruder scenario graphs are very similar. The main contributors to the dose at 500 years are plutonium isotopes and americium-241.

The main isotopes producing the doses at 500 years are listed in Table 5-4, which shows the fractional contributions by radionuclide for the source location with highest dose in each WMA. Because intrusion is delayed, long-lived isotopes give most of the intruder dose. Isotopes of plutonium and americium are significant for all tanks and UPRs. The residual waste in the tanks is depleted in the more soluble components, such as technetium. Thus, more soluble components such as technetium-99 and tin-126 are only important for the soil plume sources.

The radionuclides not listed in Table 5-4 give less than 1% of the total dose at that location. Cells with dashes mean the dose is less than 0.1% of the total for that location.

The doses computed for a radionuclide include the dose from any radioactive progeny that accumulate with time. For example, the dose from the initial plutonium-241 inventory includes the dose from the americium-241 that accumulates from the decay of plutonium-241. In Table 5-4, the separate column with americium-241 dose fractions is calculated from the initial americium-241 inventory. It should be noted that inclusion of progeny dose with the parent nuclide has little effect on the relative amount of plutonium and americium dose. The dose from plutonium-241 is a minor addition to that from plutonium-239.

Table 5-4. Intruder Dose Fractions by Radionuclide for Each Waste Management Area [a, b] (2 pages)

Source [c]	C-14	Sr-90	Tc-99	Sn-126	Cs-137	Np-237	Pu [d]	Am-241 [b]
Well Driller Scenario								
AX-102+ [e]	—	—	—	1.2%	—	0.1%	17.3%	81.0%
B-101	—	—	—	—	—	—	96.8%	3.1%
C-201+	—	—	—	—	—	—	86.0%	13.7%
SX-115+ [e]	—	—	—	0.3%	0.1%	—	74.1%	25.3%
T-106+ [e]	—	—	0.1%	34.4%	1.1%	2.3%	29.8%	32.0%
TX-118	—	—	—	0.1%	—	—	62.2%	37.6%
U-106	—	—	—	0.7%	—	0.2%	43.3%	55.6%
Rural Pasture Scenario								
AX-102+ [e]	—	0.3%	1.1%	0.5%	—	0.1%	17.7%	80.0%
B-101	—	0.4%	—	—	—	—	96.5%	3.0%
C-201+ [e]	—	0.1%	0.1%	—	—	—	86.2%	13.3%
SX-115+ [e]	—	0.9%	0.7%	0.1%	0.1%	—	73.7%	24.4%
T-106+ [e]	0.7%	0.6%	46.6%	9.2%	0.7%	1.2%	19.9%	20.7%
TX-118	—	—	0.1%	—	—	—	62.9%	36.8%
U-106	—	0.2%	0.1%	0.3%	—	0.2%	44.2%	55.0%
Suburban Garden Scenario								
AX-102+ [e]	—	0.2%	3.7%	0.2%	—	0.2%	17.4%	77.9%
B-101	—	0.2%	—	—	—	—	96.6%	3.0%
C-201+ [e]	—	0.1%	0.3%	—	—	0.1%	86.1%	13.1%
SX-115+ [e]	—	0.6%	2.4%	0.1%	—	0.1%	73.0%	23.8%
T-106+ [e]	0.2%	0.2%	76.4%	1.9%	0.1%	1.7%	9.5%	9.8%
TX-118	—	—	0.5%	—	—	—	62.9%	36.4%
U-106	—	0.1%	0.3%	0.1%	—	0.5%	44.4%	54.5%

Table 5-4. Intruder Dose Fractions by Radionuclide for Each Waste Management Area [a, b] (2 pages)

Source [c]	C-14	Sr-90	Tc-99	Sn-126	Cs-137	Np-237	Pu [d]	Am-241 [b]
Commercial Farm Scenario								
AX-102+ [e]	—	—	—	0.7%	—	0.1%	17.8%	81.1%
B-101	—	—	—	—	—	—	96.9%	3.1%
C-201+ [e]	—	—	—	—	—	—	86.4%	13.4%
SX-115+ [e]	—	—	—	0.2%	0.1%	—	74.8%	24.9%
T-106+ [e]	—	—	0.1%	22.5%	0.7%	2.2%	36.3%	37.9%
TX-118	—	—	—	0.1%	—	—	62.9%	37.0%
U-106	—	—	—	0.4%	—	0.2%	44.2%	55.2%

[a] The numbers on this table are the dose from a given radionuclide divided by the total dose for that source. Cells with — indicate the fraction is less than 0.1%. Some rows do not sum to 100% due to omission of minor nuclides and rounding.

[b] The doses on which these fractions are based include the dose from the radioactive progeny that accumulate with time. For example, the dose from the initial Pu-241 inventory includes the dose from the Am-241 that accumulates. The dose from Am-241 is from the initial Am-241 in the buried waste.

[c] The sources shown are the source location with highest dose for each waste management area.

[d] The column labeled "Pu" [plutonium] is the sum of the contributions from the various plutonium isotopes.

[e] For some tanks, the "+"indicates the summing of doses from the leak plume and the tank residual waste.

The fractional contributions by pathway for the source location with highest dose in each WMA are shown in Tables 5-5 and 5-6. Table 5-5 has just three pathways: 1) external dose from proximity to a contaminated area, 2) internal dose from ingestion of trace amounts of soil, and 3) internal dose from inhalation of contaminated dust. Table 5-6 adds internal dose from ingestion of locally grown food. In the rural pasture scenario, the food item is milk. In the suburban garden scenario, the food item is garden produce.

The internal doses are typically much larger than the external doses because plutonium and americium are not significant external hazards. The notable exception is tank T-106 because these doses are dominated by the past leak, and thereby contain more of the soluble radionuclides such as technetium-99 and tin-126. The dose from milk in the rural pasture scenario is small for most WMAs because plutonium and americium are poorly absorbed by cows.

Table 5-5. Well Driller and Commercial Farm Dose Fractions by Exposure Pathway

WMA	Source Location with Highest Dose	External	Soil Ingestion	Soil Inhalation
Well Driller Scenario				
A-AX	AX-102 (tank plus leak)	5.1%	43.5%	51.4%
B-BX-BY	B-101	0.3%	45.9%	53.8%
C	C-201 (tank plus leak)	0.8%	45.6%	53.5%
S-SX	SX-115 (tank plus leak)	1.7%	45.2%	53.1%
T	T-106 (tank plus leak)	38.0%	28.5%	33.5%

Table 5-5. Well Driller and Commercial Farm Dose Fractions by Exposure Pathway

WMA	Source Location with Highest Dose	External	Soil Ingestion	Soil Inhalation
TX-TY	TX-118	1.9%	45.1%	53.0%
U	U-106	3.4%	44.4%	52.3%
Commercial Farm Scenario				
A-AX	AX-102 (tank plus leak)	2.2%	30.8%	67.0%
B-BX-BY	B-101	0.1%	31.6%	68.3%
C	C-201 (tank plus leak)	0.3%	31.5%	68.1%
S-SX	SX-115 (tank plus leak)	0.7%	31.4%	67.9%
T	T-106 (tank plus leak)	24.5%	23.9%	51.6%
TX-TY	TX-118	0.7%	31.4%	67.9%
U	U-106	1.4%	31.1%	67.5%

Table 5-6. Suburban Garden and Rural Pasture Dose Fractions by Exposure Pathway (2 pages)

WMA	Source Location with Highest Dose	External	Soil Ingestion	Soil Inhalation	Food
Suburban Garden Scenario					
A-AX	AX-102 (tank plus leak)	0.7%	38.4%	22.6%	38.3%
B-BX-BY	B-101	0.0%	40.2%	23.5%	36.2%
C	C-201 (tank plus leak)	0.1%	40.1%	23.5%	36.3%
S-SX	SX-115 (tank plus leak)	0.2%	39.0%	22.9%	37.8%
T	T-106 (tank plus leak)	2.0%	8.0%	4.7%	85.3%
TX-TY	TX-118	0.2%	40.0%	23.5%	36.2%
U	U-106	0.4%	39.9%	23.4%	36.2%

Table 5-6. Suburban Garden and Rural Pasture Dose Fractions by Exposure Pathway (2 pages)

WMA	Source Location with Highest Dose	External	Soil Ingestion	Soil Inhalation	Food
Rural Pasture Scenario					
A-AX	AX-102 (tank plus leak)	1.6%	45.1%	51.6%	1.7%
B-BX-BY	B-101	0.1%	46.5%	52.9%	0.6%
C	C-201 (tank plus leak)	0.2%	46.5%	52.9%	0.4%
S-SX	SX-115 (tank plus leak)	0.5%	45.6%	52.0%	1.9%
T	T-106 (tank plus leak)	9.9%	19.4%	22.0%	48.7%
TX-TY	TX-118	0.5%	46.3%	52.8%	0.4%
U	U-106	1.0%	46.0%	52.5%	0.4%

5.6 SENSITIVITY AND UNCERTAINTY IN THE DOSE RESULTS

5.6.1 Introduction

The risk metric for waste intrusion is the EDE from radionuclides in the waste. The projected dose depends on the waste and borehole characteristics and the assumed exposure scenarios. The objective of this section is to quantify the likely range of each parameter (uncertainty) and indicate how changes to that one parameter would affect the intruder dose (sensitivity).

The process of driving a borehole brings a portion of the underground radioactivity to the surface. The dose to the individual who drives the borehole (acute case) is calculated as the curies exhumed divided by the mass of the drill cuttings and multiplied by the scenario dose factor for the well driller. This calculation is carried out for each radionuclide. The intruder dose is the sum of the dose from each radionuclide. The dose to an individual who lives near the well (chronic case) is calculated as the curies exhumed times the appropriate scenario dose factor. In all cases, the intruder dose depends on a few parameters whose importance can be determined by examining the equations used to calculate the dose. The parameters that significantly influence the intruder doses are shown in Table 5-7.

The first three parameter lines in Table 5-7 describe well characteristics. The next four parameter lines describe waste characteristics. The last two parameter lines describe the exhumed material. Each parameter has a range of possible values. The relationship between the parameter and the intruder dose is indicated in the last column. "Linear" means the dose is proportional to the value assigned the parameter. "Square" means the dose is proportional to the square of the parameter. "Varies" means that the effect of the parameter depends on the composition of the waste.

Each of the parameters listed in Table 5-7 is discussed below. The relative amount of the various radionuclides in the waste (i.e., waste composition) varies widely and has important effects on the intruder dose. It is assumed that the composition is fixed so that the uncertainties can be discussed for particular mixtures.

Table 5-7. Important Parameters and Estimated Ranges

Parameter [a]	Parameter Range [b]			How Parameter Changes Dose
	Low	Used	High	
Borehole depth – acute [c]	*0.8	Table 5-2	*1.2	Inverse [d]
Borehole diameter – chronic [e]	*0.8	Table 5-1	*1.2	Square [f]
Well location on the 200 Area plateau	0	Maximum	Maximum	Varies [g]
Decay time at intrusion	100 yr	500 yr	1,000 yr	Varies [g]
Waste thickness – tank residual	0	Table E-1	*4	Linear [h]
Waste thickness – unplanned releases	*0.25	Table E-2	*4	Linear [h]
Fraction available for internal dose (residual tank waste only) [i]	0.1	1	1	Linear [h]
Spreading area – chronic [e]	*0.8	Table 5-1	*1.2	Inverse [d]
Tilling depth – chronic [e]	0.1 m	0.15 m	0.20 m	Inverse [d]

[a] The important parameters are separated into three groups separated by double lines. The groups consider well characteristics, waste characteristics, and the fate of the drill cuttings.
[b] "Parameter Range" describes how much larger or smaller the parameter could be relative to the value used in the calculations of intruder dose.
[c] "Acute" refers to the well drilling scenario.
[d] "Inverse" means doubling the parameter halves the intruder dose.
[e] "Chronic" refers to the post-intrusion scenarios (i.e., rural pasture, suburban garden, and commercial farm).
[f] "Square" means the intruder dose is proportional to the square of the parameter.
[g] "Varies" means the effect of the parameter on intruder dose depends on waste composition.
[h] "Linear" means that the intruder dose is proportional to the parameter.
[i] The fraction available for internal dose from waste released to soil is 100%.
* Indicates multiply by the number.

5.6.2 Well Characteristics

The borehole depth is important only for the well driller scenario (acute). The ratio of waste thickness to borehole depth determines the waste dilution. The well driller dose is inversely proportional to the borehole depth. If the well depth decreases by 20%, the dose increases by 20%. The uncertainty in this parameter is small because the depth to groundwater is known and unlikely to change significantly in the future.

The borehole diameter is important for the chronic intruder scenarios. The volume of waste exhumed depends on the cross-sectional areas for the well. Therefore, the intruder dose varies with the square of the borehole diameter. The uncertainty in this parameter is small. The well diameter is based on current drilling practices near the Hanford Site, as discussed in Section A7.0 of Rittmann (2004).

The third parameter in Table 5-7 (well location) ranges from wells that encounter no radioactive waste to the wells that find the worst-case tanks. The waste composition is an important factor. Because waste composition has a log-normal distribution, the well location also is expected to have a log-normal distribution. In the present intruder analysis, the worst-case intruder location

was selected. Thus, the maximum dose is obtained. If a location with no waste is selected, the intruder dose is zero. This is the range shown in Table 5-7.

5.6.3 Waste Characteristics

The first waste characteristic in Table 5-7 (decay time) is the time between site closure and intrusion. The range shown comes from DOE (1999d) as the time period of interest for inadvertent intrusion. The effect on the intruder dose depends on the composition of the waste. Wastes rich in short half-life isotopes such as strontium-90 and cesium-137 will be very sensitive to the decay time. Typically, the short half-life isotopes are important during the first few hundred years. After that, the intruder dose hardly changes with intrusion time. The time chosen for intrusion is based on the assumed efficacy of institutional control and intrusion deterrents at the Hanford Site.

The next two items in Table 5-7 show how waste thickness affects intruder dose. Two rows are needed because residual waste and the UPRs to soil have different uncertainties. The residual waste in the tanks has an average thickness less than 1 in. Due to the shape of the bottom of the tank and the difficulty in removing some attached solids, the waste thickness will vary. Assuming most of the waste is located in 25% of the area, the average waste thickness and resulting intruder dose could be a factor of 4 or larger. This is the assumed upper bound shown in Table 5-7. The estimated residual waste inventory has been assumed to cover the bottom of the tank so that representative doses can be calculated for that tank. The intruder dose varies linearly with the thickness of the residual tank waste.

The shape of UPRs to soil is based on observed plumes near the underground tanks that have leaked in the past as discussed in Appendix E. The thickness of contaminated soil depends on the horizontal spread of the plume. In the absence of significant soil discontinuities, larger leaks migrate downward primarily and are more tall than wide. As the moisture content in the leak decreases, significant horizontal spreading has been observed to occur. The reference case assumes the plume has a diameter equal to its height. The relative height and width of the plume could vary by a factor of 5. Another consideration is the volume of the soil plume compared to the volume of liquid that entered the soil. The reference case assumes the contaminated soil has a volume 10 times the volume of the liquid. The likely range for the soil filling fraction is 5% to 15% based on soil porosity and residual moisture content. The combination of these ranges leads to a waste thickness that may vary by a factor of 4 from the reference case. The intruder dose varies linearly with the vertical thickness of the contaminated soil.

The fraction of the exhumed waste that is available for internal dose is assumed to be 100%. For the leaks and UPRs to soil, this value is reasonable. For residual tank waste, this value could be as low as 10% based on the fraction of the drill cuttings that has been ground to fine (i.e., respirable) particulate, in addition to the degree of chemical inertness. Because plutonium and americium give most of the dose, the internal component is much larger than the external component. Thus, the fraction available has a roughly linear effect on the intruder dose.

5.6.4 Characteristics of the Exhumed Material

The last two rows in Table 5-7 indicate the volume of soil that the exhumed waste is mixed with. The mixed volume is the product of the spreading area and the tilling depth. The intruder dose is inversely proportional to this volume. While the intruder dose is very sensitive to the values for spreading area and tilling depth, there is little room for variation in the values selected.

If the spreading area changes appreciably, other exposure parameters must also change. Smaller spreading areas lead to reduced contact with the contaminants. They require less attention, so the individual spends less time in the contaminated area and therefore receives smaller external doses. The individual also inhales and ingests less contaminated dust. For the garden scenario, if the garden area decreases, the produce is more contaminated and the gardener receives more dose. However, a smaller garden produces less food, and offsets the increase in concentration. For the rural pasture scenario, the spreading area is driven by the caloric intake for the cow. Reducing the area of the pasture means the higher radionuclide concentrations in the pasture grass, but the cow will be eating uncontaminated fodder grown elsewhere. Hence, the spreading area is assumed to vary by no more than 20%, as shown in Table 5-7.

The tilling depth is also related to the thickness of soil from which vegetables and grasses derive their nutrients. If the tilling depth is smaller, the soil concentration is larger, but the plants obtain a portion of their nutrients from uncontaminated depths of the soil. Hence, the tilling depth is assumed to vary by no more than the range shown in Table 5-7.

The spreading area and tilling depth are part of the exposure scenario unit dose factors. These two parameters are independent of the waste composition, and therefore were included in this discussion.

5.6.5 Summary of Intruder Dose Uncertainty

The calculation of intruder dose is carried out using representative values for most parameters, and bounding parameters for some (i.e., fraction available for internal dose and which tank is drilled through). The use of typical values is consistent with DOE (1999d), which specifies using representative or average values for the critical group. The use of "worst-case" assumptions is specifically rejected.

When a parameter value is replaced with a probability distribution, the intruder dose becomes a probability distribution. As each parameter is made into a distribution, there are two effects on the dose distribution. First, the range of possible doses expands. For example, combining the high end of the ranges in Table 5-7 gives a factor of 10 increase in the intruder dose. Second, the relative standard deviation of the dose distribution shrinks. This is illustrated with two simple distributions in Section 2.0 of *Evaluation of KE Basin Sludge Radioisotopics and Volumes in Support of the Sludge Water System Safety Analysis* (Rittman and Strom 2002). The combined effect is to create extremely large theoretical doses that have extremely low probabilities. Thus, DOE (1999d) recommends representative values rather than bounding values because the bounding cases are so unlikely to occur.

The fact that two parameters are "bounding" while the rest are "reasonably likely" gives assurance that the calculated doses are representative averages for the critical groups, with some conservatism included in the calculation.

5.7 CONCLUSIONS

One acute and three chronic exposure scenarios were analyzed. Calculated intruder doses were below the performance objective for the reference cases, namely the well driller and rural pasture scenarios. In the two alternative scenarios, the dose from the suburban garden exceeds the performance objective for three tanks, AX-102, SX-115, and TX-118, under the assumed suburban garden exposure scenario. The dose from the commercial farm is well below the performance objective.

The numbers used in the calculations are selected from observed or expected ranges to represent average cases. Two parameters were selected with maximum values: 1) the fraction available to give internal dose (100%) and 2) the borehole location in the tank with the highest dose.

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6.0 PERFORMANCE EVALUATION

6.1 INTRODUCTION

This chapter provides an evaluation of the SST PA results provided in Chapters 4.0 and 5.0 with respect to the performance objectives discussed in Section 1.5 for the reference case. A comparison of the performance objectives to the SST PA results for the reference case leads to the following conclusions:

- Estimated impacts from residual waste, following HFFACO (Ecology et al. 1989) prescribed levels of 99% retrieval, are below all groundwater performance objectives at the WMA fenceline over the period of simulation for the reference exposure scenarios.
- Past releases from all WMAs (except WMA C) result in some groundwater MCLs being exceeded at the fenceline.
- Past releases result in selected performance objectives (ILCR) being exceeded at the WMA fenceline in WMA S-SX and WMA T for the reference case exposure scenarios.
- Selected performance objectives associated with the protection of the general public are exceeded at the WMA fenceline in all WMAs for the residential exposure scenarios (radiological ILCR and HI) due to past releases.
- Estimated all-pathways farmer scenario doses are less than the performance objective (15 mrem/yr) at the WMA fenceline.
- Estimated intruder doses are less than the performance objectives for the protection of intruders for the reference case exposure scenarios (driller and rural farmer).
- Bounding estimates for the effects of releases to air are below the performance objectives for the protection of air resources.

The following sections compare the estimated impacts from WMA closure to the performance objectives for each area of protection cited in Section 1.5:

- Protection of groundwater resources (Section 6.2)
- Protection of the general public (i.e., human health risk impacts) (Section 6.3)
- Protection of the inadvertent intruder (Section 6.4)
- Protection of air resources (Section 6.5).

6.2 COMPARISON OF ESTIMATED GROUNDWATER CONCENTRATIONS TO GROUNDWATER RESOURCES PERFORMANCE OBJECTIVES

The protection of groundwater resources is expressed as limits on health-impacting contaminant concentrations, and as a limit on the beta-photon emitter dose (Section 1.5) expressed as performance objectives or MCLs. The reference case groundwater concentration estimates, presented in Sections 4.3 through 4.9, are compared to performance objectives for the protection of groundwater resources in this section. Also, the groundwater concentrations in Chapter 4.0 are used to calculate the beta-photon emitter doses (Section 3.2.2.6) that are presented in this chapter. The tank row within each WMA with the highest estimated values for health-impacting contaminant concentrations and beta-photon emitter dose over the assessment period (i.e., years 2000 through 12032) is used in Section 6.2.1 to compare to its performance objective (or MCL) summarized in Table 1-2. Details are given for the groundwater pathway for each of the waste sources (i.e., past releases and residual waste) and the composite (sum of all waste sources within a given tank row) at the fenceline of each WMA. This section presents the following:

- Reference case composite source (Section 6.2.1)
- Reference case past releases source (Section 6.2.2)
- Reference case residual waste source (Section 6.2.3)
- Conclusion (Section 6.2.4).

6.2.1 Reference Case Composite Source

This section compares the peak estimated concentrations and beta-photon doses for contaminants reaching the WMA fenceline for all combined source terms (e.g., past releases such as tank leaks and UPRs, and residual waste in SSTs, pipelines, and MUSTs) to the relevant performance objectives (MCLs) identified for each WMA in Table 1-2.

Table 6-1 presents the highest composite groundwater concentrations over the period of evaluation from years 2000 to 12032 and its associated peak tank row for each health-impacting contaminant that reached groundwater along with the associated dominant source component (e.g., past release or residual waste).

The other contaminants with associated performance objectives for the protection of groundwater that are not listed in Table 6-1 are not estimated to reach the groundwater within the 10,000-year simulation period (years 2000 through 12032); therefore, their estimated concentrations are zero. Specifically, the alpha emitters (excluding radium-226, radium-228, and uranium) and strontium-90 concentrations are estimated to be zero at the WMA fenceline (Appendix D). Similarly, the following chemicals are not estimated to reach the groundwater within the simulation period (years 2000 through 12032), and therefore, their estimated concentrations are zero at the WMA fenceline (Appendix D):

- Antimony
- Arsenic
- Barium
- Beryllium
- Cadmium
- Cyanide
- Iron
- Lead
- Mercury
- Nickel
- Selenium
- Silver
- Thallium
- Zinc

A total of six contaminants and the beta-photon dose exceed their performance objectives at the WMA fenceline for different WMAs. The six contaminants are:

- Tritium
- Carbon-14
- Technicium-99
- Chromium
- Nitrate
- Nitrite

Past releases result in selected groundwater MCLs for mobile contaminants being exceeded at all WMA fencelines (except WMA C). The technetium-99 MCL from past releases is significantly exceeded (greater than a factor of 10).

After 300 years (year 2332), groundwater concentrations at the WMA fenceline from past releases of mobile contaminants are below the groundwater MCLs for all WMAs except WMA S-SX and WMA T. For these two WMAs, the groundwater concentrations at the fenceline are below the MCLs after approximately year 2450.

All SST WMAs with the exception of WMA C have at least one health-impacting contaminant concentration or beta-photon emitter dose that exceeds its respective MCL value at the WMA fenceline over the period of simulation. WMA T has the highest estimated values for the beta-photon dose and two contaminants (carbon-14 and technetium-99), while WMA S-SX has the highest estimated values for the other four contaminants (tritium, chromium, nitrate, and nitrite). As indicated in Table 6-1, these peak values that exceed the performance objectives are associated with past releases. The estimated groundwater impacts are highest in the 200 West Area SST WMAs. This is not unexpected based on current groundwater measurements (Sections 2.6 and 2.7). For example, groundwater well measurements near tank SX-115 (well 299-W23-19) show technetium-99 groundwater concentrations of 188,000 pCi/L, which corresponds to approximately 210 times the MCL of 900 pCi/L.

The health-impacting contaminant concentration or beta-photon emitter dose values due to mobile contaminants, although decreasing with time in the analysis at evaluation times greater than year 2050, still exceed their performance objectives for technetium-99 concentration and beta-photon emitter dose (i.e., 900 pCi/L and 4 mrem/yr, respectively) at the end of institutional control (year 2332) for WMAs S-SX and T. Technetium-99 groundwater concentration and cumulative beta-photon emitter dose are estimated to be below their respective MCLs at the WMA fenceline in the year 2341 for WMA S-SX and year 2444 for WMA T.

Table 6-1. Reference Case Composite Groundwater Peak Values Compared to Performance Objectives (4 pages)

Contaminant	Peak Value at WMA Fenceline	Groundwater MCL	Dominant Component	Peak Row	Peak Year
Waste Management Area S-SX					
Radionuclides					
Beta particle and photon (mrem/yr)	**867**	4	Past releases	SX-107	2043
Tritium (pCi/L)	**38,000**	20,000	Past releases	SX-113	2040
Carbon-14 (pCi/L)	**5,500**	2,000 [a]	Past releases	SX-107	2043
Cobalt-60 (pCi/L)	0.036	100 [a]	Past releases	SX-113	2054
Technetium-99 (pCi/L)	**192,000**	900 [a]	Past releases	SX-107	2043
Iodine-129 (pCi/L)	0.92	1 [a]	Past releases	SX-107	12032
Radium-226 (pCi/L) [c]	0.00 [b]	3	Past releases	SX-107	12032
Nonradionuclides					
Ammonia (mg/L)	1.34	NA	Past releases	SX-107	2043
Chloride (mg/L)	12.9	250	Past releases	SX-107	2043
Chromium (mg/L)	**5.22**	0.1	Past releases	SX-107	2043
Fluoride (mg/L)	0.333	4	Past releases	SX-104	2043
Manganese (mg/L)	0.00 [b]	0.05	Past releases	SX-107	12032
Nitrate (mg/L)	**392**	45	Past releases	SX-107	2043
Nitrite (mg/L)	**189**	3.3	Past releases	SX-107	2043
Sulfate (mg/L)	9.67	250	Past releases	SX-107	2043
Uranium (mg/L)	0.00 [b]	0.03	Past releases	SX-107	12032
Waste Management Area T					
Radionuclides					
Beta particle and photon (mrem/yr)	**1,550**	4	Past releases	T-104	2043
Tritium (pCi/L)	14,700	20,000	Past releases	T-104	2040
Carbon-14 (pCi/L)	**9,660**	2,000 [a]	Past releases	T-104	2043
Cobalt-60 (pCi/L)	0.0771	100 [a]	Past releases	T-104	2054
Technetium-99 (pCi/L)	**344,000**	900 [a]	Past releases	T-104	2043
Iodine-129 (pCi/L)	0.702	1 [a]	Past releases	T-104	12032
Radium-226 (pCi/L) [c]	0.00 [b]	3	Past releases	T-104	12032
Nonradionuclides					
Ammonia (mg/L)	1.4	NA	Past releases	T-104	2043
Chloride (mg/L)	8.93	250	Past releases	T-104	2043
Chromium (mg/L)	**4.64**	0.1	Past releases	T-104	2043
Fluoride (mg/L)	0.287	4	Past releases	T-104	2043
Manganese (mg/L)	0.00 [b]	0.05	Past releases	T-104	12032
Nitrate (mg/L)	**272**	45	Past releases	T-104	2043
Nitrite (mg/L)	**123**	3.3	Past releases	T-104	2043
Sulfate (mg/L)	24.3	250	Past releases	T-104	2043
Uranium (mg/L)	0.00 [b]	0.03	Past releases	T-104	12032

Table 6-1. Reference Case Composite Groundwater Peak Values Compared to Performance Objectives (4 pages)

Contaminant	Peak Value at WMA Fenceline	Groundwater MCL	Dominant Component	Peak Row	Peak Year
Waste Management Area TX-TY					
Radionuclides					
Beta particle and photon (mrem/yr)	**182**	4	Past releases	TX-105	2043
Tritium (pCi/L)	1,220	20,000	Past releases	TY-105	2040
Carbon-14 (pCi/L)	1,370	2,000 [a]	Past releases	TX-105	2043
Cobalt-60 (pCi/L)	0.00 [b]	100 [a]	Past releases	TX-105	2054
Technetium-99 (pCi/L)	**40,300**	900 [a]	Past releases	TX-105	2043
Iodine-129 (pCi/L)	0.137	1 [a]	Past releases	TX-105	12032
Radium-226 (pCi/L) [c]	0.00 [b]	3	Past releases	TX-105	12032
Nonradionuclides					
Ammonia (mg/L)	0.566	NA	Past releases	TX-105	2043
Chloride (mg/L)	6.47	250	Past releases	TY-105	2043
Chromium (mg/L)	**0.796**	0.1	Past releases	TX-105	2043
Fluoride (mg/L)	0.699	4	Past releases	TX-105	2043
Manganese (mg/L)	0.00 [b]	0.05	Past releases	TX-105	12032
Nitrate (mg/L)	**349**	45	Past releases	TY-105	2043
Nitrite (mg/L)	**23.1**	3.3	Past releases	TX-105	2043
Sulfate (mg/L)	22.4	250	Past releases	TY-105	2043
Uranium (mg/L)	0.00 [b]	0.03	Past releases	TY-105	12032
Waste Management Area U					
Radionuclides					
Beta particle and photon (mrem/yr)	**89**	4	Past releases	U-104	2043
Tritium (pCi/L)	4,500	20,000	Past releases	U-104	2040
Carbon-14 (pCi/L)	732	2,000 [a]	Past releases	U-104	2043
Cobalt-60 (pCi/L)	0.00 [b]	100 [a]	Past releases	U-110	2054
Technetium-99 (pCi/L)	**19,500**	900 [a]	Past releases	U-104	2043
Iodine-129 (pCi/L)	0.0675	1 [a]	Past releases	U-104	12032
Radium-226 (pCi/L) [c]	0.00 [b]	3	Past releases	U-104	12032
Nonradionuclides					
Ammonia (mg/L)	0.132	NA	Past releases	U-110	2043
Chloride (mg/L)	0.977	250	Past releases	U-110	2043
Chromium (mg/L)	**0.7**	0.1	Past releases	U-110	2043
Fluoride (mg/L)	0.152	4	Past releases	U-104	2043
Manganese (mg/L)	0.00 [b]	0.05	Past releases	U-110	12032
Nitrate (mg/L)	39.4	45	Past releases	U-110	2043
Nitrite (mg/L)	**11.5**	3.3	Past releases	U-110	2043
Sulfate (mg/L)	20.7	250	Past releases	U-104	2043
Uranium (mg/L)	0.00 [b]	0.03	Past releases	U-104	12032

Table 6-1. Reference Case Composite Groundwater Peak Values Compared to Performance Objectives (4 pages)

Contaminant	Peak Value at WMA Fenceline	Groundwater MCL	Dominant Component	Peak Row	Peak Year
Waste Management Area C					
Radionuclides					
Beta particle and photon (mrem/yr)	2.64	4	Past releases	C-102	2051
Tritium (pCi/L)	241	20,000	Past releases	C-102	2044
Carbon-14 (pCi/L)	42.7	2,000 [a]	Past releases	C-102	2051
Cobalt-60 (pCi/L)	0.00 [b]	100 [a]	Past releases	C-102	2052
Technetium-99 (pCi/L)	565	900 [a]	Past releases	C-102	2051
Iodine-129 (pCi/L)	0.0309	1 [a]	Past releases	C-102	9621
Radium-226 (pCi/L) [c]	0.00 [b]	3	Past releases	C-102	12032
Nonradionuclides					
Ammonia (mg/L)	0.00538	NA	Past releases	C-101	2051
Chloride (mg/L)	0.0512	250	Past releases	C-101	2051
Chromium (mg/L)	0.0135	0.1	Past releases	C-102	2051
Fluoride (mg/L)	0.00837	4	Past releases	C-101	2051
Manganese (mg/L)	0.00 [b]	0.05	Past releases	C-102	12032
Nitrate (mg/L)	2.71	45	Past releases	C-101	2051
Nitrite (mg/L)	1.02	3.3	Past releases	C-102	2051
Sulfate (mg/L)	0.195	250	Past releases	C-101	2051
Uranium (mg/L)	0.00 [b]	0.03	Past releases	C-102	12032
1,1,1-Trichloroethane (mg/L)	0.00 [b]	0.2	Residual waste	C-103	12032
1,1,2-Trichloroethane (mg/L)	0.00 [b]	0.005	Residual waste	C-103	12032
1,1-Dichloroethene (mg/L)	0.00 [b]	0.007	Residual waste	C-103	12032
1,4-Dichlorobenzene (mg/L)	0.00 [b]	0.075	Residual waste	C-103	12032
Carbon tetrachloride (mg/L)	0.00 [b]	0.005	Residual waste	C-103	12032
Chloroform (mg/L)	0.00 [b]	0.08	Residual waste	C-103	12032
Dichloromethane (mg/L)	0.00 [b]	0.005	Residual waste	C-103	12032
Benzene (mg/L)	0.00 [b]	0.005	Residual waste	C-103	12032
Ethylbenzene (mg/L)	0.00 [b]	0.7	Residual waste	C-103	12032
Toluene (mg/L)	0.00 [b]	1	Residual waste	C-103	12032
Styrene (mg/L)	0.00 [b]	0.1	Residual waste	C-103	12032
Xylene (mg/L)	0.00 [b]	10	Residual waste	C-103	12032
Waste Management Area B-BX-BY					
Radionuclides					
Beta particle and photon (mrem/yr)	**40.9**	4	Past releases	B-103	2051
Tritium (pCi/L)	650	20,000	Past releases	B-103	2044
Carbon-14 (pCi/L)	327	2,000 [a]	Past releases	B-103	2051
Cobalt-60 (pCi/L)	0.0265	100 [a]	Past releases	B-103	2052

Table 6-1. Reference Case Composite Groundwater Peak Values Compared to Performance Objectives (4 pages)

Contaminant	Peak Value at WMA Fenceline	Groundwater MCL	Dominant Component	Peak Row	Peak Year
Technetium-99 (pCi/L)	**9,030**	900 [a]	Past releases	B-103	2051
Iodine-129 (pCi/L)	0.0982	1 [a]	Past releases	B-103	9621
Radium-226 (pCi/L) [c]	0.00 [b]	3	Past releases	B-103	12032
Nonradionuclides					
Ammonia (mg/L)	0.0143	NA	Past releases	B-103	2051
Chloride (mg/L)	0.162	250	Past releases	B-103	2051
Chromium (mg/L)	**0.17**	0.1	Past releases	B-103	2051
Fluoride (mg/L)	0.0462	4	Past releases	B-201	2051
Manganese (mg/L)	0.00 [b]	0.05	Past releases	B-103	12032
Nitrate (mg/L)	10.1	45	Past releases	B-103	2051
Nitrite (mg/L)	2.02	3.3	Past releases	B-101	2051
Sulfate (mg/L)	11.6	NA	Past releases	B-103	2051
Uranium (mg/L)	0.00394	0.03	Past releases	B-103	12032
Waste Management Area A-AX					
Radionuclides					
Beta particle and photon (mrem/yr)	**46.6**	4	Past releases	A-101	2051
Tritium (pCi/L)	94.4	20,000	Past releases	A-101	2044
Carbon-14 (pCi/L)	354	2,000 [a]	Past releases	A-101	2051
Cobalt-60 (pCi/L)	0.0145	100 [a]	Past releases	A-101	2052
Technetium-99 (pCi/L)	**10,300**	900 [a]	Past releases	A-101	2051
Iodine-129 (pCi/L)	0.06	1 [a]	Past releases	A-101	9621
Radium-226 (pCi/L) [c]	0.00 [b]	3	Past releases	A-101	12032
Nonradionuclides					
Ammonia (mg/L)	0.0654	NA	Past releases	A-101	2051
Chloride (mg/L)	0.43	250	Past releases	A-101	2051
Chromium (mg/L)	**0.121**	0.1	Past releases	A-101	2051
Fluoride (mg/L)	0.0771	4	Past releases	A-101	2051
Manganese (mg/L)	0.00 [b]	0.05	Past releases	A-101	12032
Nitrate (mg/L)	9.11	45	Past releases	A-101	2051
Nitrite (mg/L)	**5.22**	3.3	Past releases	A-101	2051
Sulfate (mg/L)	0.5	250	Past releases	A-101	2051
Uranium (mg/L)	0.00 [b]	0.03	Past releases	A-101	12032

Bold indicates the constituent exceeds the maximum contaminant level.

The peak row designation is the lowest numbered tank in the sequence (e.g., T-104 identifies the peak row consisting of tanks T-104, T-105, and T-106).

[a] *National Interim Primary Drinking Water Regulations* (EPA 1976), as applicable.

[b] Constituent was not above effective zero of 1.0 E-02 pCi/L for radionuclides or 1.0E-05 mg/L for chemicals.

[c] The performance measure, radium-226 plus radium-228, has a performance objective (MCL) of 5 pCi/L in groundwater. The estimated concentration for this performance measure for all WMAs is 0.00 at the WMA fenceline.

NA = not applicable

6.2.2 Reference Case Past Release Source

This section focuses on the past releases component of the source terms analyzed in Chapter 4.0. The past releases component includes both past releases from SSTs and UPRs that were evaluated in Chapter 4.0. As presented in Table 6-2, the performance objectives that are surpassed for past releases include the following:

- Beta-photon drinking water radiation dose
- Technetium-99 groundwater concentration
- Tritium groundwater concentration
- Carbon-14 groundwater concentration
- Nitrate groundwater concentration
- Nitrite groundwater concentration
- Chromium groundwater concentration.

Table 6-2 summarizes the number of tank rows within each WMA where the protection of groundwater resources performance objectives is exceeded due to past releases. The contaminant concentration data supporting this summary information are provided in Appendix D. Table 6-2 provides a measure of the pervasiveness of performance objective exceedances by WMA, and supports the claim that estimated impacts are higher in the 200 West Area when compared to the 200 East Area.

Table 6-2. Number of Tank Rows for Each Waste Management Area Exceeding the Performance Objective Due to the Past Releases Source Term

	200 West Area WMAs				200 East Area WMAs		
	S-SX	T	TX-TY	U	C	B-BX-BY	A-AX
Number of Tank Rows Simulated	**9**	**4**	**5**	**5**	**5**	**7**	**4**
Contaminant							
Beta-photon emitters	5	3	4	3	0	3	3
Technetium-99 concentration	4	3	4	3	0	3	3
Tritium concentration	2	0	0	0	0	0	0
Carbon-14 concentration	2	1	0	0	0	0	0
Nitrate concentration	3	1	3	0	0	0	0
Nitrite concentration	5	2	3	2	0	0	1
Chromium concentration	5	3	4	3	0	1	1

Based on Table 6-2, WMA S-SX contains the most tank rows that exceeded their MCLs, followed by WMA TX-TY, WMA T, and then WMA U. No past releases result in the MCLs being exceeded at the WMA C fenceline. The 200 West Area SST WMAs had more tank rows that exceeded the performance objectives than the 200 East Area SST WMAs. The tritium concentration at the WMA fenceline only exceeds its MCL in WMA S-SX for two tank rows. The carbon-14 and nitrate concentrations at the WMA fenceline only exceed their MCLs in the 200 West Area. WMAs in both 200 Areas have some tank rows where the MCLs are exceeded for nitrite and chromium concentrations.

It must be emphasized that these impacts assume that no engineered barrier is placed over the WMAs until the time of site closure, which in the simulations for the reference case was assumed to be at year 2032. Because the simulation began in the year 2000, rather than at the time of closure, contaminants from past releases were exposed to high recharge rates (100 mm/yr) during this time period. This high recharge rate resulted in elevated migration rates and fluxes into the unconfined aquifer from past releases.

Work from previous assessments of past releases (particularly the FIRs [Knepp 2002a, 2002b]) show that placing interim surface barriers earlier (i.e., year 2010) will reduce estimated impacts by shortening the exposure time of past release source contaminants to high recharge rates. In Section 4.11, analytical results are presented for earlier interim cover placement in year 2010 and the estimated groundwater concentrations for mobile contaminants were reduced at the WMA fenceline by a factor of approximately 2 with respect to the reference case results. The estimated impacts would still remain above performance objectives for most WMAs at the WMA fenceline.

6.2.3 Reference Case Residual Waste Source

Chapter 4.0 and Appendix D present estimated groundwater concentrations at the WMA boundary fenceline. Table 6-3 presents the highest groundwater concentrations and beta-photon dose over the period of evaluation (years 2000 to 12032) from residual waste in tanks and MUSTs. These peak values bound the residual waste contribution from plugged pipelines.

No chemical or radionuclide constituent performance objectives are exceeded during the first 10,000-year simulation period. In contrast to past releases, impacts from the waste residuals (whether in tanks or ancillary equipment) are much smaller, with only chromium approaching its MCL of 0.1 mg/L for WMA S-SX. Because of the smaller inventories (Appendix C) associated with ancillary equipment and the slower contaminant release rates and lower recharge rates associated with tank residual waste contaminant transport, impacts are below the performance objectives for both radionuclides and chemicals over the 10,000-year evaluation period at the WMA fenceline.

Peak groundwater concentrations for tank residuals are greater than a factor of 4 below groundwater MCLs at the WMA fencelines.

The inventory data in Appendix C assume that all 100-Series tanks meet the HFFACO residual waste goal of 360 ft^3 of residual waste, while the 200-Series tanks have 30 ft^3 of residual waste (Ecology et al. 1989). Impacts from a tank row (the row being defined by being parallel to the groundwater flow) are given because the groundwater will act to add the impacts from different contaminant sources within such a row.

The DOE performance objective for protection of the groundwater (beta-photon drinking water dose) is also met for all the residual waste in each WMA during the first 10,000 years at the WMA fenceline for the reference case.

Table 6-3. Reference Case Tank Residuals Groundwater Values Compared to Performance Objectives (2 pages)

Contaminant	Peak Value at WMA Fenceline	Groundwater MCL
Waste Management Area S-SX		
Beta particle and photon (mrem/yr)	0.158	4
Tritium (pCi/L)	0.00[b]	20,000
Carbon-14 (pCi/L)	0.522	2,000[a]
Technetium-99 (pCi/L)	35.5	900[a]
Iodine-129 (pCi/L)	0.00[b]	1[a]
Chromium (mg/L)	0.0249	0.1
Nitrate (mg/L)	0.0306	45
Nitrite (mg/L)	0.00578	3.3
Uranium (mg/L)	0.00[b]	0.03
Waste Management Area T		
Beta particle and photon (mrem/yr)	0.0337	4
Tritium (pCi/L)	0.00[b]	20,000
Carbon-14 (pCi/L)	0.183	2,000[a]
Technetium-99 (pCi/L)	7.58	900[a]
Iodine-129 (pCi/L)	0.00[b]	1[a]
Chromium (mg/L)	0.00208	0.1
Nitrate (mg/L)	0.0224	45
Nitrite (mg/L)	0.00608	3.3
Uranium (mg/L)	0.00[b]	0.03
Waste Management Area TX-TY		
Beta particle and photon (mrem/yr)	0.628	4
Tritium (pCi/L)	0.00[b]	20,000
Carbon-14 (pCi/L)	0.304	2,000[a]
Technetium-99 (pCi/L)	141	900[a]
Iodine-129 (pCi/L)	0.00[b]	1[a]
Chromium (mg/L)	0.00363	0.1
Nitrate (mg/L)	0.0456	45
Nitrite (mg/L)	0.00542	3.3
Uranium (mg/L)	0.00[b]	0.03
Waste Management Area U		
Beta particle and photon (mrem/yr)	0.895	4
Tritium (pCi/L)	0.00[b]	20,000
Carbon-14 (pCi/L)	0.403	2,000[a]
Technetium-99 (pCi/L)	201	900[a]
Iodine-129 (pCi/L)	0.00[b]	1[a]
Chromium (mg/L)	0.00884	0.1
Nitrate (mg/L)	0.0307	45
Nitrite (mg/L)	0.0049	3.3
Uranium (mg/L)	0.00[b]	0.03

Table 6-3. Reference Case Tank Residuals Groundwater Values Compared to Performance Objectives (2 pages)

Contaminant	Peak Value at WMA Fenceline	Groundwater MCL
Waste Management Area C		
Beta particle and photon (mrem/yr)	0.0262	4
Tritium (pCi/L)	0.00 [b]	20,000
Carbon-14 (pCi/L)	0.0547	2,000 [a]
Technetium-99 (pCi/L)	5.86	900 [a]
Iodine-129 (pCi/L)	0.00 [b]	1 [a]
Chromium (mg/L)	0.000171	0.1
Nitrate (mg/L)	0.00573	45
Nitrite (mg/L)	0.00157	3.3
Uranium (mg/L)	0.00 [b]	0.03
Waste Management Area B-BX-BY		
Beta particle and photon (mrem/yr)	0.291	4
Tritium (pCi/L)	0.00 [b]	20,000
Carbon-14 (pCi/L)	0.387	2,000 [a]
Technetium-99 (pCi/L)	65.4	900 [a]
Iodine-129 (pCi/L)	0.00 [b]	1 [a]
Chromium (mg/L)	0.00270	0.1
Nitrate (mg/L)	0.0192	45
Nitrite (mg/L)	0.00249	3.3
Uranium (mg/L)	0.00 [b]	0.03
Waste Management Area A-AX		
Beta particle and photon (mrem/yr)	0.0892	4
Tritium (pCi/L)	0.00 [b]	20,000
Carbon-14 (pCi/L)	0.0431	2,000 [a]
Technetium-99 (pCi/L)	20.0	900 [a]
Iodine-129 (pCi/L)	0.00 [b]	1 [a]
Chromium (mg/L)	0.00432	0.1
Nitrate (mg/L)	0.00410	45
Nitrite (mg/L)	0.00265	3.3
Uranium (mg/L)	0.00 [b]	0.03

[a] National Interim Primary Drinking Water Standards (EPA 1976), as applicable.

[b] Value was not above effective zero of 1.0E-02 pCi/L for radionuclides or 1.0E-05 mg/L for nonradionuclides.

6.2.4 Conclusion

Past releases from all WMAs (except WMA C) result in some protection of groundwater resources performance objectives being exceeded at the WMA fenceline. The performance objectives that are exceeded are dose from beta and photon emitters and the MCLs for technetium-99, tritium, carbon-14, nitrate, nitrite, and chromium concentrations. The estimated impacts from residual waste do not exceed protection of groundwater resources performance objectives.

6.3 COMPARISON OF ESTIMATED GROUNDWATER PATHWAY HUMAN HEALTH IMPACTS TO PERFORMANCE OBJECTIVES AT WASTE MANAGEMENT AREA FENCELINE

The estimated groundwater concentrations for the reference case (provided in Chapter 4.0 and Appendix D) have been used to estimate human health impacts associated with the use of groundwater. Human health impacts have been estimated for a reference land use exposure scenario (i.e., industrial land use on the Central Plateau as described in Section 1.9.1). The reference land use is supported by the Hanford Site comprehensive land-use EIS (DOE 1999b) and the "Risk Framework Description" (Klein et al. 2002). It is recognized that alternative land uses may occur over the period of assessment, and these alternative land use exposure scenarios include a residential land use and an all-pathways farmer as described in Section 1.9.2. These estimated human health impacts have been compared to the performance objectives for the protection of the general public provided in Table 1-1. Section 6.3.1 provides more detail on how the reference case in association with the land use exposure scenario will be compared to the performance objectives. A comparison of estimated groundwater pathway human health impacts to performance objectives at the WMA fenceline has led to the following conclusions:

- Estimated all-pathways farmer doses are less than the performance objective (15 mrem/yr) at the WMA fenceline.
- Past releases result in selected performance objectives (ILCR) being exceeded at the WMA fenceline in WMA S-SX and WMA T for the reference exposure scenarios.
- Estimated impacts from residual waste are below all groundwater performance objectives at the WMA fenceline over the period of simulation for the reference exposure scenarios.
- Selected performance objectives associated with the protection of the general public are exceeded at the WMA fenceline in all WMAs for the residential exposure scenarios (radiological ILCR and HI) due to past releases.

6.3.1 Introduction

This section evaluates the performance of the closed WMA system relative to the performance objectives for protection of the general public. Performance objectives considered in this SST PA are identified and discussed in Section 1.5 (Table 1-1). For convenience, the performance objectives for protection of the general public are repeated in Table 6-4. This portion of the analysis focused on the estimated long-term human health impacts associated with the groundwater contaminant migration pathway. The metrics (i.e., health effects quantifiers) used for the evaluation consisted of radiation dose and cancerous and non-cancerous (toxic) human health effects (Table 6-4).

Radiation dose was estimated in units of mrem per year. The calculated dose value represents the 50-year committed EDE that results from exposure during the first year of use of contaminated groundwater.

Table 6-4. Performance Objectives for Protection of the General Public

Performance Measure		Performance Objective
All-pathways dose (mrem/yr)		15
ILCR (radiological)	Industrial[a]	10^{-4} to 10^{-5}
	Residential	10^{-4} to 10^{-5}
ILCR (chemical carcinogen)	WAC 173-340 Method B[a]	10^{-5}
	WAC 173-340 Method C	10^{-5}
HI (chemical non-carcinogen)	WAC 173-340 Method B[a]	1
	WAC 173-340 Method C	1

[a] Reference case exposure scenario.

An incremental lifetime cancer risk (ILCR) has been estimated. The calculated ILCR value is a probability (unitless), representing the estimated lifetime increase in the risk of contracting some type of cancer, whether fatal or non-fatal, from using contaminated groundwater. The risk increase is considered incremental in that it represents an increase beyond that resulting from natural background exposure. Separate ILCR estimates are presented for radiological and nonradiological (i.e., carcinogenic chemical) contaminant exposures. Cancer risk metrics from radionuclides and from carcinogenic chemicals are typically reported separately because of differences in how risk is estimated for these two categories of contaminants.

Non-cancer toxic effects are presented as a hazard index (HI). The calculated HI value is a ratio (unitless) of the estimated toxic chemical intake (average daily dose from contaminated groundwater use) to a reference dose (daily dose that is likely to be without an appreciable risk of deleterious effects during a lifetime). An HI greater than one indicates adverse health effects would be expected. An HI less than one indicates adverse health effects would not be expected. A health effect could be fatal or it could be a minor, temporary effect on the human body, depending on the specific chemical and the amount of exposure involved.

Each evaluated metric required that an exposure scenario be specified in order to calculate values for comparison against the performance objectives. Exposure scenarios are collections of assumed human activities that are used to define the level of interaction of an individual with potentially contaminated environmental media (e.g., groundwater). The exposure scenarios used for this analysis (Table 6-4) were based on plausible future land uses involving groundwater that have been identified for the Central Plateau (Section 1.9).

For the reference case, radiological ILCR was estimated using an industrial worker scenario, while chemical health effects (ILCR and HI) were estimated using Method B (residential) from the Washington State groundwater cleanup regulations (WAC 173-340-720). For the alternative case, radiological ILCR was estimated using a residential scenario, chemical health effects (ILCR and HI) were estimated using Method C (industrial) from WAC 173-340-720, and all-pathways radiation dose was estimated using an irrigated farming scenario (all-pathways farmer). General descriptions of these scenarios are provided in Section 1.9.2. Detailed descriptions are given in Rittmann (2004).

Common to each exposure scenario was the assumption that a hypothetical individual located at the WMA fenceline withdraws and uses groundwater for drinking water and other uses after it has become contaminated by tank waste that remains in the WMA soil or infrastructure at closure. Groundwater withdrawal was assumed to occur from a well; however, exposure to contaminants from the well drilling activity itself was not included in any of the groundwater pathway scenarios. Impacts associated with a well drilling scenario were considered as part of the inadvertent intruder analysis described in Chapter 5.0. Section 6.4 provides a comparison of estimated intruder impacts with performance objectives.

Each metric was evaluated in each WMA from the end of institutional controls (assumed to occur 300 years after closure, or year 2332) to the end of the 10,000-year post-closure simulation period (year 12032) (Section 1.9.1). The underlying assumption is that the application of institutional controls will prevent chronic access to groundwater and associated exposure to contaminants at the WMA fencelines for 300 years after WMA closure. The metric values used for comparison against performance objectives were selected based on a specified point in time and space. The time of evaluation used for each metric was the projected time of peak for that metric in a given WMA within the 10,000-year post-closure simulation period. The point of evaluation was always the groundwater at the hydrologically downgradient WMA boundary.

Each section (Sections 6.3.2 through 6.3.8) begins with a summary of the overall performance of the WMA and then provides results for the individual metrics including tables of results by tank row, graphs showing variation over time, and tables identifying the driving contaminants. Waste component assignments for each tank row are described in the opening tables of Sections 4.3 through 4.9 (e.g., Table 4-1). As in Chapter 4.0, results are discussed in terms of the two primary types of waste sources: 1) the past releases component, which includes past tank leaks and UPRs, and 2) the residual waste component, which includes SST residuals and ancillary equipment residuals (MUSTs and plugged and blocked pipelines). Plugged and blocked pipelines inventory was included into tank rows that had the lowest groundwater impact. From Chapter 4.0, the plugged and blocked pipeline source is typically not aligned with a given tank row. Therefore, it would be inappropriate to capture the impacts from this source in the tank row having the highest estimated impacts. Presentation of the results is organized by waste sources because the severity and timing of health effects are caused primarily by differences in contaminant inventories and migration characteristics between the two waste source types. As in Chapter 4.0, the designation of each tank row is the lowest numbered tank in the sequence (e.g., S-101 identifies the tank row consisting of tanks S-101, S-102, and S-103). This designation method is used throughout Section 6.3.

6.3.2 Groundwater Pathway Human Health Risk at Waste Management Area S-SX

Table 6-5 compares the estimated human health impacts from WMA S-SX to the performance objectives for protecting the general public. The point of evaluation for these impact estimates is the WMA fenceline. The values shown are the peak values for the composite source term (i.e., sum of dose contributions from past releases and residual waste source components) from the tank row with the highest value. The peak values for each metric occur at the time of assumed loss of institutional controls (year 2332) and in each case are from tank row SX-107. For the reference land use case, the estimated HI (Method B) is above the performance objective by a small factor, while the radiological ILCR (industrial) is above the Washington State

standard of 10^{-5} by a small factor but below the federal standard of 10^{-4}. For the alternative land use case, the estimated all-pathways dose and HI (Method C) are below their respective performance objectives, while the radiological ILCR (residential) is above the performance objective. The chemical ILCR for both reference (Method B) and alternative (Method C) land use cases is 0. Section 6.3.2.3 contains additional information on chemical ILCR using Methods B and C. Each metric is discussed individually in the following sections.

Table 6-5. Comparison of Estimated Reference Case Impacts for Waste Management Area S-SX with Performance Objectives for Protecting the General Public

Performance Measure		Performance Objective	Peak Value [a]	Peak Year	Tank Row
All-pathways dose (mrem/yr)		15	1.75E+00	2332	SX-107
ILCR (radiological)	Industrial	10^{-4} to 10^{-5}	**1.30E-05**	2332	SX-107
	Residential	10^{-4} to 10^{-5}	**3.12E-04**	2332	SX-107
ILCR (chemical carcinogen)	WAC 173-340 Method B	10^{-5}	0 [b]	NA	NA
	WAC 173-340 Method C	10^{-5}	0 [b]	NA	NA
HI (chemical non-carcinogen)	WAC 173-340 Method B	1	**1.29E+00**	2332	SX-107
	WAC 173-340 Method C	1	5.54E-01	2332	SX-107

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Estimated from the groundwater concentrations from all sources within a given tank row at the WMA S-SX fenceline. Values shown are the maximum projected values over the first 10,000 years after closure.

[b] See Section 6.3.2.3 for additional information on chemical ILCR.

NA = not applicable

6.3.2.1 All-Pathways Dose at Waste Management Area S-SX

Table 6-6 shows the estimated peak all-pathways dose by source component (past release and residual waste) for each tank row in WMA S-SX. The composite dose does not exceed the performance objective (15 mrem/yr) in any tank row and is significantly below the performance objective for most tank rows. The tank row with the highest dose is tank row SX-107. The peak dose from that tank row is below the performance objective by a factor of approximately 9 and is driven by the past releases component. Peak doses from the residual waste component are below the performance objective by at least three orders of magnitude in all nine tank rows.

Estimated all-pathways farmer dose is below the performance objective of 15 mrem/yr at the WMA fenceline.

Technetium-99, carbon-14, and iodine-129 are the major contributors to the all-pathways farmer dose from past releases.

Technetium-99 and carbon-14 are the major contributors to the all-pathways farmer dose from tank residuals.

Table 6-6 shows that the estimated peak all-pathways farmer dose occurs at approximately year 8200 for tank rows S-101, S-104, S-107, S-110, and SX-101. These tank rows (except S-104) do not have past releases. Therefore, the peak dose is driven by the mobile

contaminants associated with the residual wastes (see Figure 4-1). For tank row S-104, a small tank leak (technetium-99 inventory = 0.04 Ci) source contributed to the residual waste source (sum of tank rows technetium-99 inventory = 2.9 Ci). For this case, the peak contribution to the all-pathways dose from the residual waste was a factor of approximately 1.6 times the peak contribution from the past release. Table 6-6 also shows the peak all-pathways farmer dose occurs at year 2332 (end of institutional controls) for tank rows SX-104, SX-107, SX-110, and SX-113. All these tank rows have associated past releases where the technetium-99 inventory in the past leak is greater than the technetium-99 inventory associated with the tank row residual waste (Appendix C). For these tank rows, the peak all-pathways dose is dominated by their corresponding past releases.

Table 6-6. Estimated Peak All-Pathways Dose by Tank Row in Waste Management Area S-SX [a]

All-Pathways Dose Performance Objective: 15 mrem/yr									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row
S-101	3.07E-02	8171	1.75%	NA	NA	NA	3.07E-02	8171	49.04%
S-104	6.31E-02	8191	3.61%	3.89E-02	2332	2.22%	6.26E-02	8191	100.00%
S-107	4.33E-02	8171	2.47%	NA	NA	NA	4.33E-02	8171	69.17%
S-110 [b]	1.44E-02	8061	0.82%	NA	NA	NA	1.44E-02	8121	23.00%
SX-101	3.02E-02	8181	1.73%	NA	NA	NA	3.02E-02	8181	48.24%
SX-104	3.82E-01	2332	21.83%	3.82E-01	2332	21.83%	2.90E-02	8171	46.33%
SX-107	1.75E+00	2332	100.00%	1.75E+00	2332	100.00%	3.34E-03	8161	5.34%
SX-110	8.08E-02	2332	4.62%	8.08E-02	2332	4.62%	2.13E-03	8171	3.40%
SX-113	5.52E-01	2332	31.54%	5.52E-01	2332	31.54%	2.27E-03	8171	3.63%

[a] Shading indicates maximum row all components all-pathways dose.
[b] Tank row S-110 contains plugged and blocked pipelines inventory.
NA = not applicable

Figure 6-1 shows temporal variations in all-pathways dose from tank row SX-107. The dominance of the past releases component is revealed by the overlap of the composite and past releases curves. The two curves are virtually indistinguishable over the entire assessment period. Residual wastes never make more than a minor contribution to the composite dose. Even late in the assessment period, doses are dominated by less mobile contaminants from past releases with mobile contaminants from residual wastes making only a minor contribution.

Figure 6-2 and Table 6-7 show the relative contaminant contributions to all-pathways dose from tank row SX-107 and further illustrate the dominance of the past releases component. Technetium-99 from past releases dominates the composite dose at the time of peak (year 2332) and remains dominant through the early part of the assessment period. Iodine-129 from past releases becomes dominant at about year 4500 and remains as such through the end of the evaluation period (Figure 6-2). At the time of peak from residual wastes (year 8161), iodine-129 from past releases contributes over 98% of the composite dose, whereas technetium-99 from

residual wastes contributes only 1%. In Table 6-7, results are presented for the composite all-pathways dose at calendar year 2332 (the peak year for the past release component dose) and at calendar year 8161 (the peak year for the residuals waste component dose).

Figure 6-1. All-Pathways Dose for Tank Row SX-107

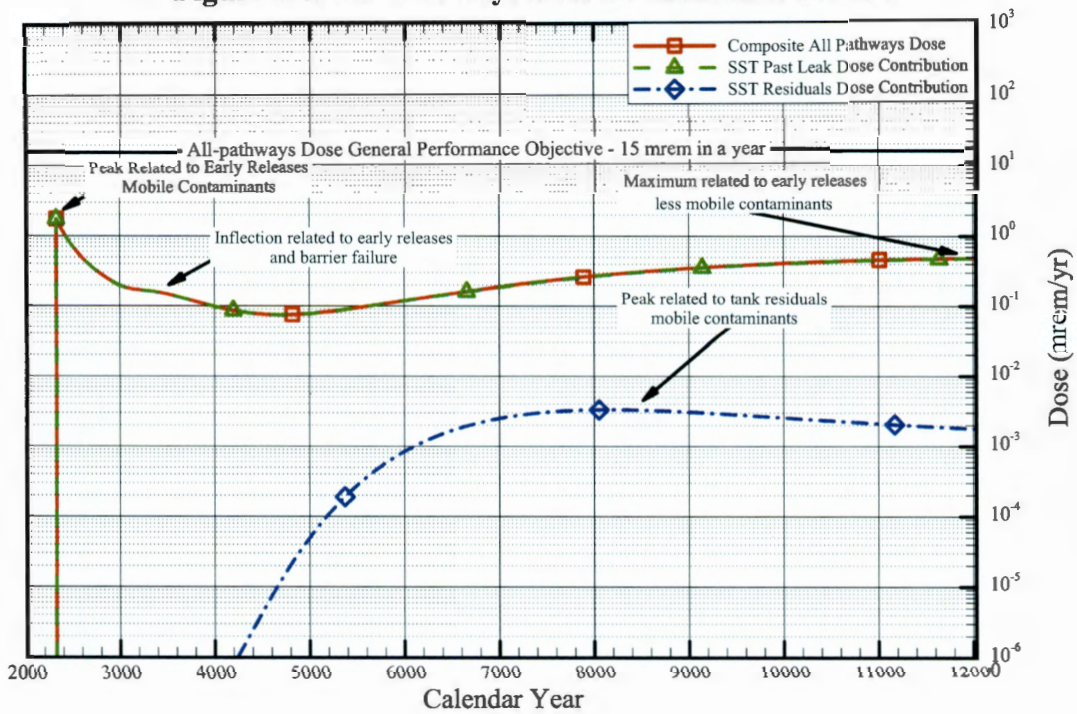


Figure 6-2. All-Pathways Dose for Tank Row SX-107 with Driving Contaminant Contributions

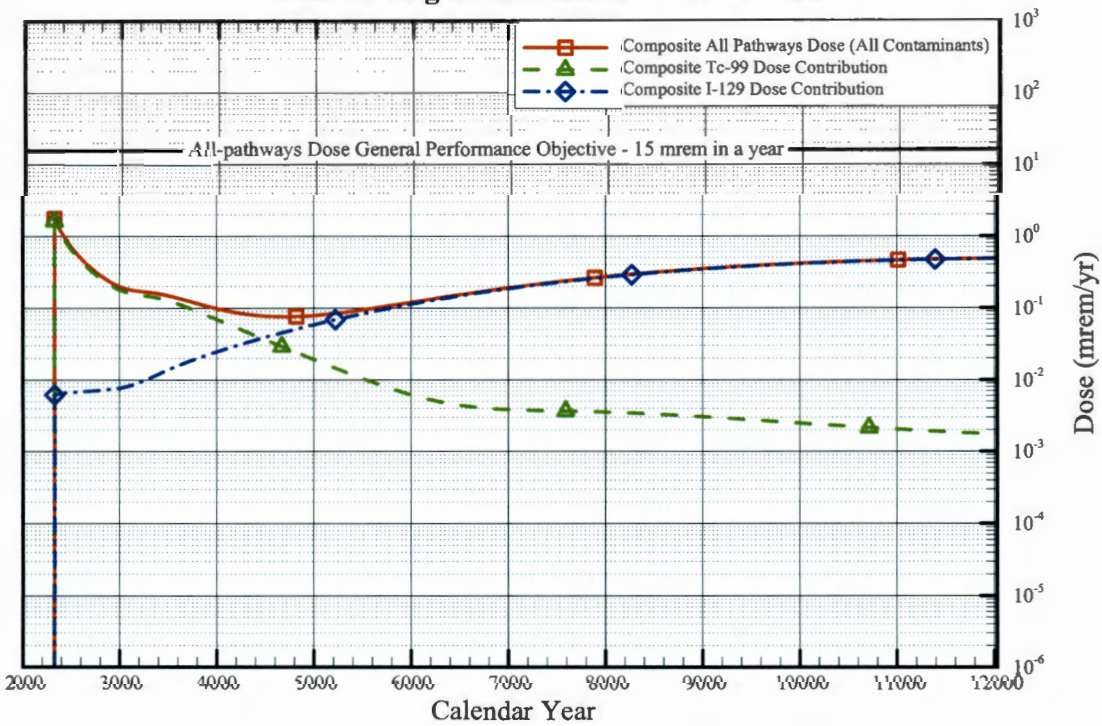


Table 6-7. Fractional Contributions to Composite All-Pathways Dose by Selected Contaminants in Tank Row SX-107-109, Reference Case

Contaminant	Calendar Year : 2332		Calendar Year: 8161 [a]	
	Dose mrem/yr	Contribution to Total Dose	Dose mrem/yr	Contribution to Total Dose
Technetium-99	1.62E+00	92.57%	3.48E-03	1.23%
Carbon-14	1.24E-01	7.08%	2.08E-04	0.07%
Iodine-129	6.18E-03	0.35%	2.79E-01	98.70%
Other	2.55E-10	<0.01%	9.03E-07	<0.01%
Total	1.75E+00	100%	2.83E-01	100%

[a] Iodine-129 originated from past release sources. Technetium-99 and carbon-14 originated predominantly from tank waste residual sources.

6.3.2.2 Radiological Cancer Risk at Waste Management Area S-SX

Tables 6-8 and 6-9 show the estimated peak radiological ILCR by source component for each tank row in WMA S-SX for the reference case (industrial scenario) and alternative land use case (residential scenario), respectively. For the reference land use case, the composite radiological ILCR does not exceed the performance objective in any tank row except SX-107 (Table 6-8). The peak ILCR for that tank row exceeds the Washington State standard (10^{-5}) by a factor of less than 2 and is driven by the past releases component. Under the industrial exposure scenario, the peak ILCR from the residual waste component is below the Washington State standard (10^{-5}) by at least two orders of magnitude in all nine tank rows.

Estimated ILCR from one tank row exceeded the performance objective of 10^{-5} at the WMA fenceline for the reference exposure scenario due to past releases.

Technetium-99 is the major contributor to the peak ILCR.

For the alternative land use case, the composite radiological ILCR exceeds the Washington State standard (10^{-5}) in five of the nine tank rows (Table 6-9). In tank row SX-107, the peak ILCR also exceeds the federal standard (10^{-4}) by a factor of 3. The peak ILCR for that tank row is driven by the past releases component. Under the residential exposure scenario, the peak ILCR from the residual waste component approaches the Washington State standard (10^{-5}) in several tank rows and slightly exceeds that standard in tank row S-104.

Note that the peak radiological ILCR for the residual waste component in tank row SX-107 occurs slightly earlier for the industrial scenario (year 8181) than the residential scenario (year 8191) (Tables 6-8 and 6-9). This difference is caused primarily by differences in the radiological half-lives for technetium-99 and carbon-14, the top two contributors to the peak ILCR from residual waste. Technetium-99 drives the peak ILCR under both the industrial and residential scenarios; however, carbon-14 also makes a minor but important contribution. Both technetium-99 and carbon-14 are highly mobile (K_d = 0 mL/g); however, because of half-life differences (5,730 and 211,097 years for carbon-14 and technetium-99, respectively), carbon-14 inventory decreases relative to technetium-99 inventory during the migration period such that their peak years of contamination (year 7831 versus year 8191 for carbon-14 and

technetium-99, respectively) and ILCR peak values diverge. The degree of this divergence depends on the recharge rate and contaminant release rate from the residual waste. When the contributions from these two contaminants are summed to generate a total residual waste ILCR curve, the peak for the industrial scenario occurs slightly earlier than the residential scenario, reflecting the influence of the earlier carbon-14 peak. For the residential scenario, however, the total ILCR peak coincides with the technetium-99 peak. This is because the increase in unit risk factors between the industrial and residential scenarios is greater for technetium-99 (factor of 24 increase) than for carbon-14 (factor of 7 increase) such that the technetium-99 contribution to the composite ILCR value overwhelms the effects of the earlier carbon-14 peak.

Table 6-8. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Reference Case: Industrial Exposure Scenario by Tank Row in Waste Management Area S-SX [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
S-101	2.32E-07	8181	1.78%	NA	NA	NA	2.32E-07	8181	47.35%
S-104	4.91E-07	8191	3.78%	8.16E-08	2332	0.63%	4.90E-07	8191	100.00%
S-107	3.28E-07	8181	2.52%	NA	NA	NA	3.28E-07	8181	66.94%
S-110 [b]	9.78E-08	8101	0.75%	NA	NA	NA	9.78E-08	8101	19.96%
SX-101	2.35E-07	8191	1.81%	NA	NA	NA	2.35E-07	8191	47.96%
SX-104	2.81E-06	2332	21.62%	2.81E-06	2332	21.62%	2.21E-07	8181	45.10%
SX-107	**1.30E-05**	2332	100.00%	**1.30E-05**	2332	100.00%	2.51E-08	8181	5.12%
SX-110	5.99E-07	2332	4.61%	5.99E-07	2332	4.61%	1.60E-08	8181	3.27%
SX-113	3.82E-06	2332	29.38%	3.82E-06	2332	29.38%	1.73E-08	8181	3.53%

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Shading indicates maximum row all components peak ILCR.

[b] Tank row S-110 contains plugged and blocked pipelines inventory.

NA = not applicable

Table 6-9. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Alternative Case: Residential Exposure Scenario by Tank Row in Waste Management Area S-SX [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
S-101	5.62E-06	8191	1.80%	NA	NA	NA	5.62E-06	8191	47.23%
S-104	**1.19E-05**	8191	3.81%	1.00E-06	2332	0.32%	**1.19E-05**	8191	100.00%
S-107	7.93E-06	8191	2.54%	NA	NA	NA	7.93E-06	8191	66.64%
S-110 [b]	2.31E-06	8111	0.74%	NA	NA	NA	2.31E-06	8111	19.41%
SX-101	5.70E-06	8191	1.83%	NA	NA	NA	5.70E-06	8191	47.90%
SX-104	**6.75E-05**	2332	21.63%	**6.75E-05**	2332	21.63%	5.34E-06	8191	44.87%
SX-107	**3.12E-04**	2332	100.00%	**3.12E-04**	2332	100.00%	6.05E-07	8191	5.08%
SX-110	**1.44E-05**	2332	4.62%	**1.44E-05**	2332	4.62%	3.87E-07	8191	3.25%
SX-113	**9.08E-05**	2332	29.10%	**9.08E-05**	2332	29.10%	4.20E-07	8191	3.53%

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Shading indicates maximum row all components peak ILCR.

[b] Tank row S-110 contains plugged and blocked pipelines inventory.

NA = not applicable

Figure 6-3 shows temporal variations in radionuclide ILCR from all sources in tank row SX-107 for the reference land use case. As noted for the all-pathways dose (Section 6.3.2.1), the dominance of the past releases component is revealed by the overlap of the composite and past releases curves. Here again, the two curves are virtually indistinguishable, with the residual waste component making no more than a minor contribution to the composite ILCR at any point in the assessment period. As with the all-pathways dose, composite ILCR values late in the assessment period are dominated by less mobile contaminants from past releases.

Figure 6-4 and Table 6-10 show the relative contaminant contributions to radiological ILCR from tank row SX-107 at two times: 1) the past releases ILCR peak year and 2) the residual waste peak year. As noted for the all-pathways dose (Section 6.3.2.1), this information further illustrates the dominance of the past releases component throughout the modeling time frame for tank rows with large past release inventories of mobile contaminants. Technetium-99 from past releases dominates the composite ILCR at the time of peak (year 2332) and remains dominant through the early part of the assessment period. Iodine-129 from past releases becomes dominant at about year 5300 and remains dominant through the end of the assessment period (Figure 6-4). Under the industrial exposure scenario, iodine-129 from past releases contributes over 93% of the composite ILCR at the time of peak from residual waste (year 8181), whereas technetium-99 from residual waste contributes about 6%. A small amount of technetium-99 from past releases is still present in groundwater at the fenceline in year 8181 but its contribution to the composite ILCR is quite minor (about 0.5%). Under the residential exposure scenario, the relative contribution from technetium-99 at the time of peak from residual waste is greater than for the industrial scenario because of the additional exposure pathways (e.g., garden vegetables) included in this scenario. In Table 6-10, results are present for the composite ILCR at calendar

year 2332 (the peak year for the past release component ILCR) and at calendar years 8181 and 8191 (the peak years for the tank residuals component industrial and residential ILCR, respectively).

Figure 6-3. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row SX-107

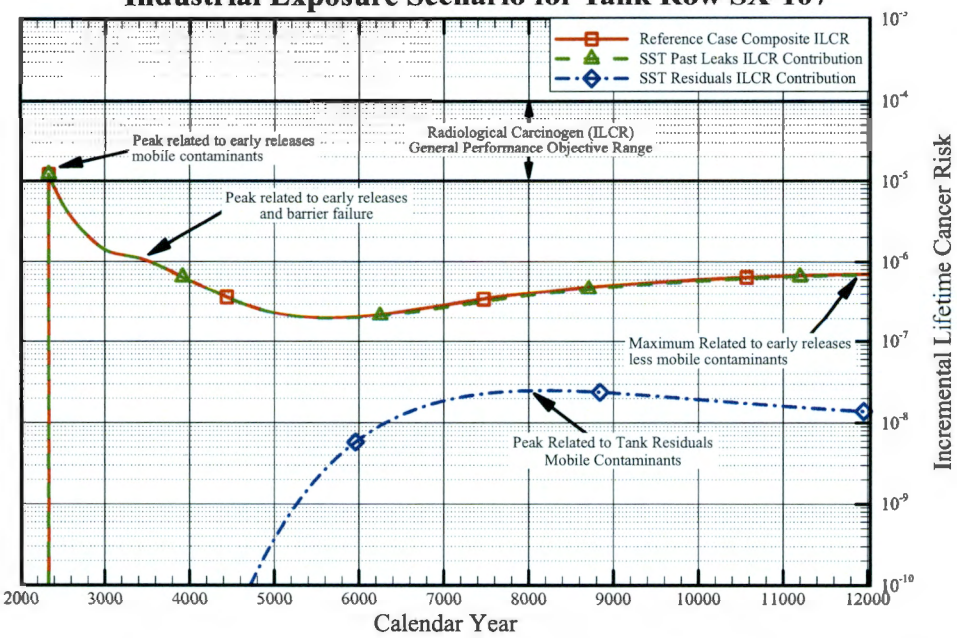


Figure 6-4. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row SX-107 with Driving Contaminant Contributions

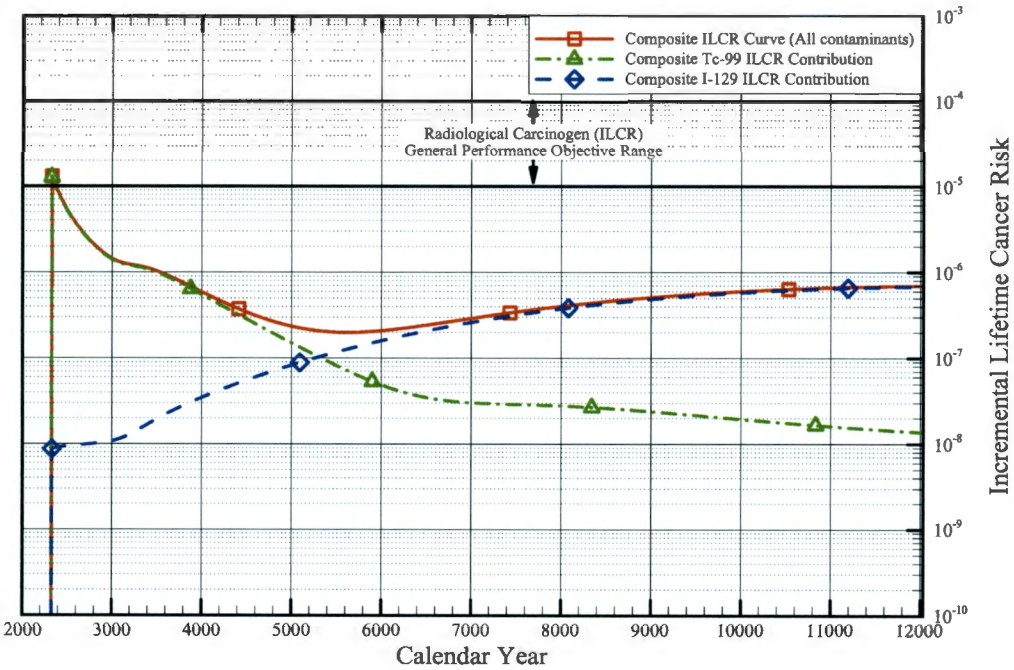


Table 6-10. Fractional Contributions to Composite Incremental Lifetime Cancer Risk by Selected Contaminants in Tank Row SX-107-109

Industrial Scenario (Reference Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8181**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	**1.28E-05**	98.40%	2.73E-08	6.44%
Carbon-14	1.99E-07	1.53%	3.32E-10	0.08%
Iodine-129	8.72E-09	0.07%	3.97E-07	93.49%
Other	3.63E-15	<0.01%	1.85E-12	<0.01%
Total	**1.30E-05**	100%	4.24E-07	100%
Residential Scenario (Alternative Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8191**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	**3.11E-04**	99.53%	6.65E-07	24.36%
Carbon-14	1.44E-06	0.46%	2.39E-09	0.09%
Iodine-129	4.52E-08	0.01%	2.06E-06	75.55%
Other	0.00E+00	<0.01%	9.77E-12	<0.01%
Total	**3.12E-04**	100%	2.73E-06	100%

Bold indicates the performance objective is exceeded.

[a] Iodine-129 originated from past release sources. Technetium-99 and carbon-14 originated predominantly from tank waste residual sources.

6.3.2.3 Chemical Cancer Risk at Waste Management Area S-SX

Two scenarios from the Washington State groundwater cleanup regulations (Method C and Method B from WAC 173-340) were used to assess reference case impacts from nonradiological carcinogenic chemicals (Section 1.9). Of the nonradiological chemicals for which tank waste inventories are currently reported in the BBI, the following five are classified as carcinogenic:

- Arsenic
- Beryllium
- Hexavalent chromium
- Cadmium
- Cobalt

All five are classified as carcinogenic via inhalation but only one, arsenic, is also classified as carcinogenic via ingestion. Because both of the WAC 173-340 groundwater scenarios are based solely on drinking water ingestion, arsenic was the only chemical considered in calculating the chemical ILCR. Arsenic has extremely low mobility in the vadose zone and was assigned a K_d of 39 mL/g (Spitz and Moreno 1996). For the contaminant fate and transport modeling (Chapter 3.0), a K_d of 5 mL/g was used. Results of that modeling for WMA S-SX (Section 4.2) indicated that arsenic would not reach groundwater at the fenceline within the 10,000-year simulation period. Thus, the calculated chemical ILCR for WMA S-SX was zero.

It is possible that more carcinogenic chemicals are present in tank waste than are currently reported in the BBI. Inventory data for additional chemicals, potentially including carcinogenic chemicals not analyzed in this SST PA (e.g., organic chemicals), will be generated following waste retrieval through post-retrieval sample analysis. As additional inventory information

becomes available, the data will be evaluated under the integrated regulatory closure process described in Chapter 1.0.

6.3.2.4 Non-Carcinogenic Chemical Hazard Index at Waste Management Area S-SX

Tables 6-11 and 6-12 show the estimated peak non-carcinogenic chemical HI by source component for each tank row in WMA S-SX for the reference case (WAC 173-340 Method B) and alterative land use case (Method C) exposure scenarios, respectively. For the reference land use case, the composite non-carcinogenic chemical HI approaches the performance objective in several tank rows but exceeds it only in tank row SX-107 (Table 6-11). In that tank row, the peak HI exceeds the performance objective by less than a factor of 2 and is driven by the past releases component. Under the WAC 173-340 Method B exposure scenario, the peak HI from the residual waste component approaches the performance objective in several tank rows but never exceeds it.

For the alternative land use case, the composite HI does not exceed the performance objective (HI = 1) in any tank row (Table 6-12). The tank row with the highest HI is tank row SX-107. The peak HI for that tank row is below the performance objective by nearly a factor of 2 and is driven by the past releases component. Under the WAC 173-340 Method C exposure scenario, the peak HI from the residual waste component is below the performance objective by approximately one or more orders of magnitude in all nine tank rows.

Estimated HI from one tank row exceeded the performance objective of 1 at the WMA fenceline due to past releases.

Chromium, nitrate, and nitrite are the major contributors to the chemical HI.

Table 6-11. Estimated Hazard Index for Reference Case: WAC 173-340 Method B Exposure Scenario by Tank Row in Waste Management Area S-SX [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
S-101	4.39E-01	8201	34.03%	NA	NA	NA	4.39E-01	8201	67.96%
S-104	3.42E-01	8201	26.51%	5.86E-02	2332	4.54%	3.42E-01	8201	52.94%
S-107	3.56E-01	8201	27.60%	NA	NA	NA	3.56E-01	8201	55.11%
S-110 [b]	9.02E-02	8201	6.99%	NA	NA	NA	9.02E-02	8201	13.96%
SX-101	6.46E-01	8201	50.08%	NA	NA	NA	6.46E-01	8201	100.00%
SX-104	2.94E-01	2332	22.79%	1.49E-01	2332	11.55%	2.94E-01	8201	45.51%
SX-107	**1.29E+00**	2332	100.00%	**1.29E+00**	2332	100.00%	3.80E-02	8201	5.88%
SX-110	3.92E-02	2332	3.04%	3.92E-02	2332	3.04%	1.26E-02	8201	1.95%
SX-113	7.19E-01	2332	55.74%	7.19E-01	2332	55.74%	9.95E-02	8201	15.40%

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Shading indicates maximum row all components all-pathways dose.

[b] Tank row S-110 contains plugged and blocked pipelines inventory.

NA = not applicable

Table 6-12. Estimated Hazard Index for Alternative Case: WAC 173-340 Method C Exposure Scenario by Tank Row in Waste Management Area S-SX [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
S-101	1.76E-01	8201	31.77%	NA	NA	NA	1.76E-01	8201	67.95%
S-104	1.37E-01	8201	24.73%	2.58E-02	2332	4.66%	1.37E-01	8201	52.90%
S-107	1.43E-01	8201	25.81%	NA	NA	NA	1.43E-01	8201	55.21%
S-110 [b]	3.62E-02	8201	6.53%	NA	NA	NA	3.62E-02	8201	13.98%
SX-101	2.59E-01	8201	46.75%	NA	NA	NA	2.59E-01	8201	100.00%
SX-104	1.18E-01	2332	21.30%	6.42E-02	2332	11.59%	1.18E-01	8201	45.56%
SX-107	5.54E-01	2332	100.00%	5.54E-01	2332	100.00%	1.53E-02	8201	5.91%
SX-110	1.68E-02	2332	3.03%	1.68E-02	2332	3.03%	5.06E-03	8201	1.95%
SX-113	3.02E-01	2332	54.51%	3.02E-01	2332	54.51%	3.98E-02	8201	15.37%

[a] Shading indicates maximum row all components all-pathways dose.
[b] Tank row S-110 contains plugged and blocked pipelines inventory.
NA = not applicable

Figure 6-5 shows temporal variations in non-carcinogenic chemical HI from tank row SX-107 for the reference land use case. The component contributions for this metric differ from those for the all-pathways dose (Section 6.3.2.1) and radiological ILCR (Section 6.3.2.2). For the latter two metrics, the past releases component dominates the cumulative curve for the entire assessment period, owing largely to the inventory of semi-mobile (K_d = 0.2 mL/g) iodine-129 in the past releases. In contrast, the inventory of less-mobile chemicals (e.g., uranium) in the past releases is very minor. As a result, the composite HI values are driven almost entirely by the mobile (K_d = 0 mL/g) chemical species and the residual waste component becomes dominant over the last half of the assessment period. The mobile chemicals in past releases dominate the composite HI curve from the time of peak (year 2332) to about the year 5800, at which point the mobile chemicals in residual waste take over and dominate through the end of the assessment period.

Figure 6-6 and Table 6-13 show the relative contaminant contributions to non-carcinogenic chemical HI from tank row SX-107. The combined contributions from hexavalent chromium and nitrite in past releases dominate the composite HI from the time of peak (year 2332) to about year 5800 when residual waste become dominant (Figure 6-6). From that point to the end of the assessment period, the composite HI is driven almost entirely by hexavalent chromium. The significant drop-off in the nitrite contribution reflects the much lower nitrite inventory in residual waste compared with past releases. At the time of peak from residual waste (year 8201), hexavalent chromium from the residual waste component contributes over 95% of the composite HI under both the WAC 173-340 Method C and Method B exposure scenarios. In Table 6-13, results are presented for the composite HI at calendar year 2332 (the peak year for the past release component HI) and at calendar year 8201 (the peak year for the residuals component HI).

Figure 6-5. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row SX-107

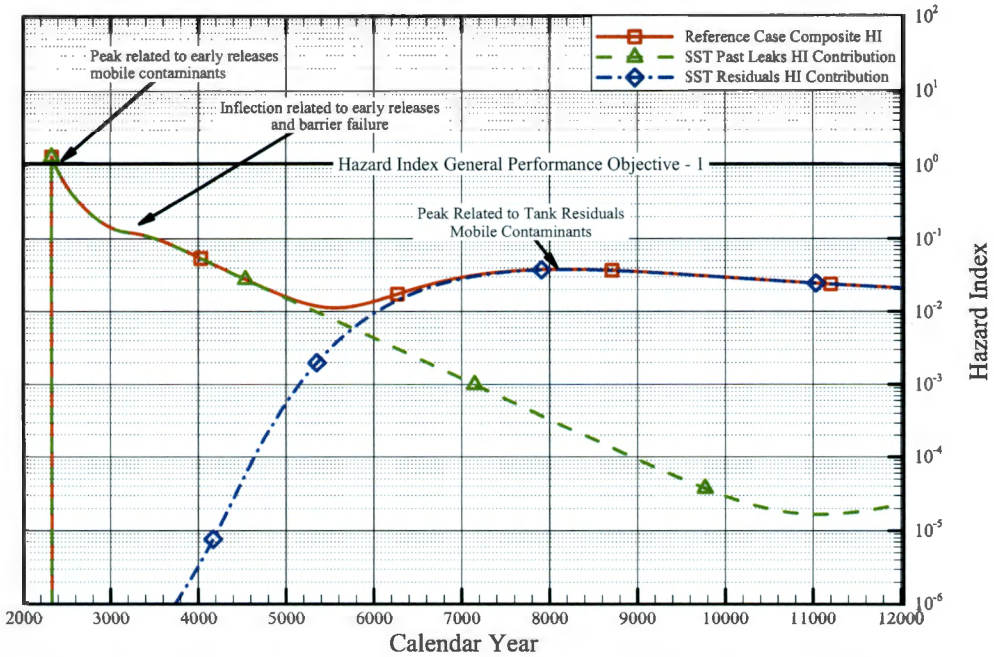


Figure 6-6. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row SX-107 with Driving Contaminant Contributions

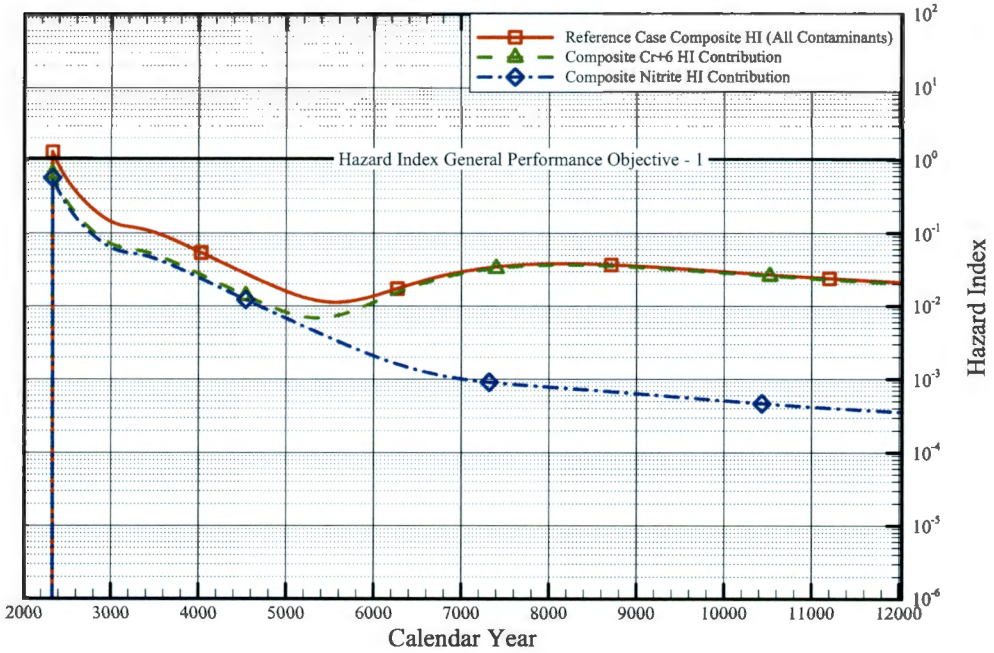


Table 6-13. Fractional Contributions to Composite Hazard Index by Selected Contaminants in Tank Row SX-107-109

WAC 173-340 Method B (Reference Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8201**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Chromium	6.48E-01	50.10%	3.67E-02	95.95%
Nitrite	5.71E-01	44.13%	7.55E-04	1.97%
Nitrate	7.42E-02	5.73%	7.75E-04	2.02%
Other	1.87E-04	0.03%	9.32E-06	0.06%
Total	**1.29E+00**	100%	3.83E-02	100%
WAC 173-340 Method C (Alternative Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8201**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Chromium	2.59E-01	46.77%	1.47E-02	95.40%
Nitrite	2.61E-01	47.08%	3.45E-04	2.24%
Nitrate	3.39E-02	6.12%	3.54E-04	2.30%
Other	4.08E-04	0.03%	2.04E-05	0.05%
Total	5.54E-01	100%	1.54E-02	100%

Bold indicates the performance objective is exceeded.

[a] Chromium, nitrite, and nitrate originated from predominantly residual waste sources.

6.3.3 Groundwater Pathway Human Health Risk at Waste Management Area T

Table 6-14 compares the estimated impacts for WMA T to the performance objectives for protecting the general public. The values shown are the peak values for the composite source term (i.e., sum of dose contributions from past releases and residual waste source components) from the tank row with the highest value. The peak values for each metric occur at the time of assumed loss of institutional controls (year 2332) and in each case are from tank row T-104. For the reference case, the estimated HI (Method B) is approximately the performance objective. The radiological ILCR (industrial) is approximately twice the Washington State standard of 10^{-5}, but below the federal standard of 10^{-4}. For the alternative land use case, the estimated all-pathways dose and HI (Method C) are below their respective performance objectives, while the radiological ILCR (residential) is above (ILCR) the respective performance objective. The chemical ILCR for both reference (Method C) and alternative (Method B) land use case is 0 (see Section 6.3.3.3 for additional information on chemical ILCR using Methods B and C). Each metric is discussed individually in the following sections.

Table 6-14. Comparison of Estimated Reference Case Impacts for Waste Management Area T with Performance Objectives for Protecting the General Public

Performance Measure		Performance Objective	Peak Value [a]	Peak Year	Tank Row
All-pathways dose (mrem/yr)		15	3.13E+00	2332	T-104
ILCR (radiological)	Industrial	10^{-4} to 10^{-5}	**2.32E-05**	2332	T-104
	Residential	10^{-4} to 10^{-5}	**5.60E-04**	2332	T-104
ILCR (chemical carcinogen)	WAC 173-340 Method B	10^{-5}	0 [b]	NA	NA
	WAC 173-340 Method C	10^{-5}	0 [b]	NA	NA
HI (chemical non-carcinogen)	WAC 173-340 Method B	1	**9.99E-01**	2332	T-104
	WAC 173-340 Method C	1	4.24E-01	2332	T-104

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Calculated in groundwater at the WMA T fenceline. Values shown are the maximum projected values over the first 10,000 years after closure (year 2032).

[b] See Section 6.3.3.3 for additional information on chemical ILCR.

NA = not applicable

6.3.3.1 All-Pathways Dose at Waste Management Area T

Table 6-15 shows the estimated peak all-pathways dose by source component for each tank row in WMA T. The composite dose does not exceed the performance objective (15 mrem/yr) in any tank row and is significantly below the performance objective for most tank rows. The tank row with the highest dose is T-104. The peak dose from that tank row is below the performance objective by a factor of approximately 5 and is driven by the past leak at T-106. Peak doses from the residual waste component are below the performance objective by at least three orders of magnitude in all four tank rows.

Table 6-15 shows the peak all-pathways farmer dose from all components occurs at year 2332 (except from tank row T-110). Each tank row has at least one past release assigned. For tank row T-110, a small tank leak (technetium-99 inventory = 7.4×10^{-6} Ci) is included with a larger technetium inventory associated with residual waste (tank residual technetium-99 inventory = 0.11 Ci plus MUST inventory = 0.0066 Ci). For tank row T-110, the contribution to the all-pathways farmer dose from residual waste provides the highest impact. Therefore, tank row T-110 peak all-pathways farmer dose is at approximately year 8190.

Estimated all-pathways farmer dose is below the performance objective of 15 mrem/yr at the WMA fenceline.

Technetium-99, carbon-14, and iodine-129 are the major contributors to the all-pathways farmer dose from past releases.

Technetium-99 and carbon-14 are the major contributors to the all-pathways farmer dose from tank residuals.

Table 6-15. Estimated Peak All-Pathways Dose by Tank Row in Waste Management Area T [a]

All-Pathways Dose Performance Objective: 15 mrem/yr									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row
T-101	1.14E-01	2332	3.64%	1.14E-01	2332	3.64%	1.00E-02	8151	74.63%
T-104	3.13E+00	2332	100.00%	3.13E+00	2332	100.00%	1.34E-02	8191	100.00%
T-107	2.68E-02	2332	0.86%	2.68E-02	2332	0.86%	7.29E-03	8191	54.40%
T-110	2.43E-03	8191	0.08%	3.40E-06	2332	<0.01%	2.43E-03	8191	18.13%

[a] Shading indicates maximum row all components all-pathways dose.

Figure 6-7 shows temporal variations in all-pathways dose from tank row T-104. The dominance of the past releases component is revealed by the overlap of the composite and past releases curves. The two curves are virtually indistinguishable over the entire assessment period. Residual wastes never make more than minor contributions to the composite dose. Even late in the assessment period, doses are dominated by less mobile contaminants from past releases with mobile contaminants from residual waste making only a minor contribution.

Figure 6-8 and Table 6-16 show the relative contaminant contributions to all-pathways dose from tank row T-104. Technetium-99 from past releases dominates the composite dose at the time of peak (year 2332) and remains dominant through the early part of the assessment period. Iodine-129 from past releases becomes dominant at about year 4800 and remains as such through the end of the assessment period (Figure 6-8). At the time of peak from residual wastes (year 8181), iodine-129 from past releases contributes over 93% of the composite dose, whereas technetium-99 from residual wastes contributes only about 6%. In Table 6-16, results are presented for the composite all-pathways dose at calendar year 2332 (the peak year for the past release component dose) and at calendar year 8181 (the peak year for the residuals component dose).

Figure 6-7. All-Pathways Dose for Tank Row T-104

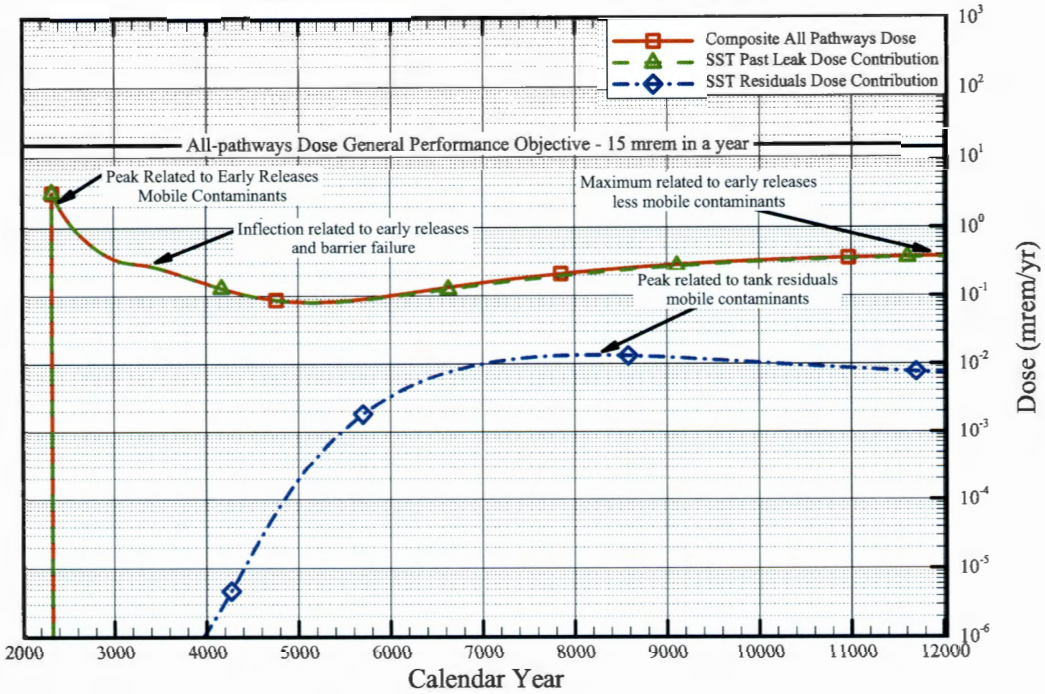


Figure 6-8. All-Pathways Dose for Tank Row T-104 with Driving Contaminant Contributions

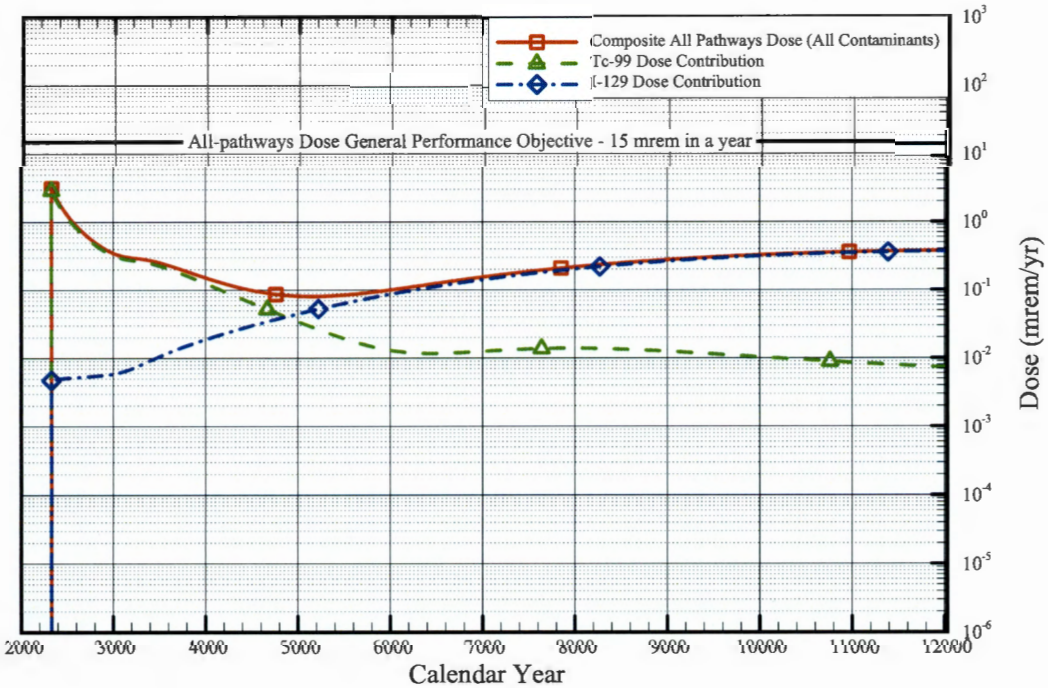


Table 6-16. Fractional Contributions to Composite All-Pathways Dose by Selected Contaminants in Tank Row T-104, Reference Case

Contaminant	Calendar Year: 2332		Calendar Year: 8181	
	Dose mrem/yr	Contribution to Total Dose	Dose mrem/yr	Contribution to Total Dose [a]
Technetium-99	2.91E+00	92.89%	1.39E-02	6.05%
Carbon-14	2.18E-01	6.96%	1.37E-04	0.06%
Iodine-129	4.72E-03	0.15%	2.15E-01	93.89%
Other	2.69E-10	<0.01%	2.10E-06	<0.01%
Total	3.13E+00	100%	2.29E-01	100%

[a] Iodine-129 originated from past release sources. Technetium-99 and carbon-14 originated from predominantly tank waste residual sources.

6.3.3.2 Radiological Cancer Risk at Waste Management Area T

Tables 6-17 and 6-18 show the estimated peak radiological ILCR by source component for each tank row in WMA T for the reference case (industrial scenario) and alternative land use case (residential scenario), respectively. For the reference land use case, the composite radiological ILCR does not exceed the performance objective in any tank row except T-104 (Table 6-17). The peak ILCR for that tank row exceeds the Washington State standard (10^{-5}) by a factor of a little over 2 and is driven by the past releases component. Under the industrial exposure scenario, the peak ILCR from the residual waste component is below the Washington State standard (10^{-5}) by well over two orders of magnitude in three of the four tank rows and a little less than two orders of magnitude for tank row T-104.

Estimated ILCR from one tank row exceeded the performance objective of 10^{-5} at the WMA fenceline for the reference exposure scenario due to past releases.

Technetium-99 is the major contributor to the peak ILCR.

For the alternative land use case (residential), the composite radiological ILCR exceeds the Washington State standard (10^{-5}) in two of the four tank rows (Table 6-18). In tank row T-104, the peak ILCR also exceeds the federal standard (10^{-4}) by a factor of close to 6. The peak ILCR for that tank row is driven by the past releases component. Under the residential exposure scenario, the peak ILCR from the residual waste component is well below the Washington State standard (10^{-5}) in all four tank rows.

Note that the peak radiological ILCR for the residual waste component in tank row T-101 occurs slightly earlier for the industrial scenario (year 8181) than the residential scenario (year 8191) (Tables 6-17 and 6-18). This difference is caused primarily by differences in the radiological half-lives for technetium-99 and carbon-14, the top two contributors to the peak ILCR from residual waste, and the fact that the ratio of carbon-14 to technetium-99 is almost an order of magnitude higher than the other tank rows. See discussion in Section 6.3.2.2 for the detailed explanation for this observation.

Table 6-17. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Reference Case: Industrial Exposure Scenario by Tank Row in Waste Management Area T [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
T-101	7.89E-07	2332	3.40%	7.89E-07	2332	3.40%	7.34E-08	8181	69.90%
T-104	**2.32E-05**	2332	100.00%	**2.32E-05**	2332	100.00%	1.05E-07	8191	100.00%
T-107	1.98E-07	2332	0.85%	1.98E-07	2332	0.85%	5.70E-08	8191	54.29%
T-110	1.91E-08	8191	0.08%	9.06E-12	2332	<0.01%	1.91E-08	8191	18.19%

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Shading indicates maximum row all components peak ILCR.

Table 6-18. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Alternative Case: Residential Exposure Scenario by Tank Row in Waste Management Area T [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
T-101	**1.87E-05**	2332	3.34%	**1.87E-05**	2332	3.34%	1.76E-06	8191	69.29%
T-104	**5.60E-04**	2332	100.00%	**5.60E-04**	2332	100.00%	2.54E-06	8191	100.00%
T-107	4.77E-06	2332	0.85%	4.77E-06	2332	0.85%	1.39E-06	8191	54.72%
T-110	4.65E-07	8191	0.08%	1.43E-10	2332	<0.01%	4.65E-07	8191	18.31%

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Shading indicates maximum row all components peak ILCR.

Figure 6-9 shows temporal variations in radionuclide ILCR from tank row T-104 for the reference land use case. As noted for the all-pathways dose (Section 6.3.3.1), the dominance of the past releases component is revealed by the overlap of the composite and past releases curves. Here again, the two curves are virtually indistinguishable, with the residual waste component making no more than a minor contribution to the composite ILCR at any point in the assessment period. As with the all-pathways dose, composite ILCR values late in the assessment period are dominated by less mobile contaminants from past releases.

Figure 6-9. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row T-104

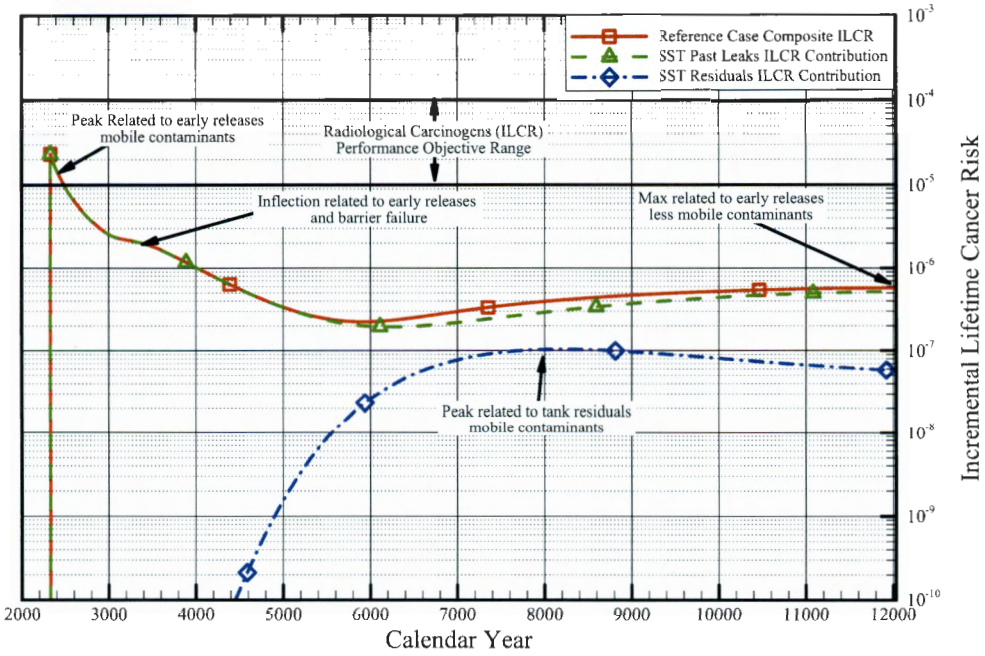


Figure 6-10 and Table 6-19 show the relative contaminant contributions to radiological ILCR from tank row T-104. Technetium-99 from past releases dominates the composite ILCR at the time of peak (year 2332) and remains dominant through the early part of the assessment period. Iodine-129 from past releases becomes dominant at about year 5300 and remains dominant through the end of the assessment period (Figure 6-10). Under the industrial exposure scenario, iodine-129 from past releases contributes over 74% of the composite ILCR at the time of peak from residual waste (year 8191), whereas technetium-99 from residual waste contributes about 26% (Table 6-19). A small amount of technetium-99 from past releases is still present in groundwater at the fenceline in year 8181 but its contribution to the composite ILCR is quite minor (about 0.5%). Under the residential exposure scenario, the relative contribution from technetium-99 at the time of peak from residual waste is greater than for the industrial scenario (63%) because of the additional exposure pathways (e.g., garden vegetables) included in this scenario (Table 6-19). In Table 6-19, results are present for the composite ILCR at calendar year 2332 (the peak year for the past release component ILCR) and at calendar year 8191 (the peak year for the tank residuals component ILCR).

Figure 6-10. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row T-104 with Driving Contaminant Contributions

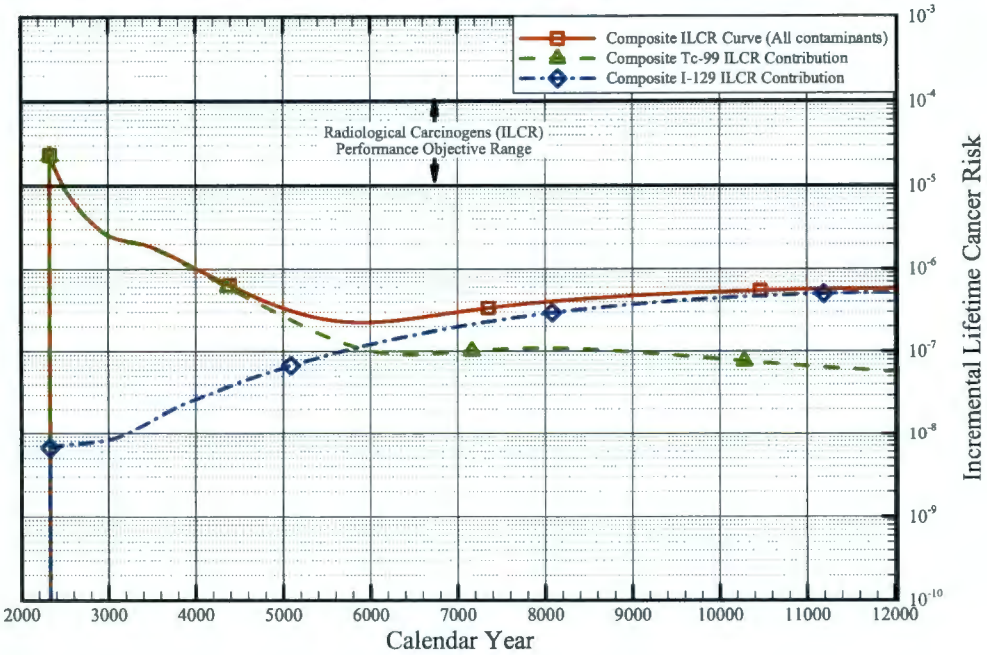


Table 6-19. Fractional Contributions to Composite Incremental Lifetime Cancer Risk by Selected Contaminants in Tank Row T-104

Industrial Scenario (Reference Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8191**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	**2.29E-05**	98.47%	1.09E-07	26.34%
Carbon-14	3.50E-07	1.50%	2.19E-10	0.05%
Iodine-129	6.67E-09	0.03%	3.04E-07	73.61%
Other	3.83E-15	<0.01%	4.18E-12	<0.01%
Total	**2.32E-05**	100%	4.13E-07	100%
Residential Scenario (Alternative Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8191**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	**5.58E-04**	99.54%	2.65E-06	62.71%
Carbon-14	2.53E-06	0.45%	1.59E-09	0.04%
Iodine-129	3.45E-08	0.01%	1.58E-06	37.25%
Other	1.59E-14	<0.01%	2.18E-11	<0.01%
Total	**5.60E-04**	100%	4.23E-06	100%

Bold indicates the performance objective is exceeded.

[a] Iodine-129 originated from past release sources. Technetium-99 and carbon-14 originated from predominantly tank waste residual sources.

6.3.3.3 Chemical Cancer Risk at Waste Management Area T

Two scenarios from the Washington State groundwater cleanup regulations (Method C and Method B from WAC 173-340) were used to assess reference case impacts from nonradiological carcinogenic chemicals (Section 1.9). Of the nonradiological chemicals for which tank waste inventories are currently reported in the BBI, the following five are classified as carcinogenic:

- Arsenic
- Beryllium
- Hexavalent chromium
- Cadmium
- Cobalt

All five are classified as carcinogenic via inhalation but only one, arsenic, is also classified as carcinogenic via ingestion. Because both of the WAC 173-340 groundwater scenarios are based solely on drinking water ingestion, arsenic was the only chemical considered in calculating the chemical ILCR. Arsenic has extremely low near-field (i.e., vadose zone) mobility and was assigned a K_d of 39 mL/g (Spitz and Moreno 1996) for the contaminant fate and transport modeling (Chapter 3.0). Results of that modeling for WMA T (Section 4.3) indicated that arsenic would not reach groundwater at the fenceline within the 10,000-year simulation period. Thus, the calculated chemical ILCR for WMA T was zero.

It is possible that more carcinogenic chemicals are present in tank waste than are currently reported in the BBI. Inventory data for additional chemicals, potentially including carcinogenic chemicals not analyzed in this SST PA (e.g., organic chemicals), will be generated following waste retrieval through post-retrieval sample analysis. As additional inventory information becomes available, the data will be evaluated under the integrated regulatory closure process described in Chapter 1.0.

6.3.3.4 Non-Carcinogenic Chemical Hazard Index at Waste Management Area T

Tables 6-20 and 6-21 show the estimated peak non-carcinogenic chemical HI by source component for each tank row in WMA T for the WAC 173-340 Method B and Method C exposure scenarios, respectively. For the reference land use case (Method B), the composite non-carcinogenic chemical HI is at the performance objective in tank row T-104 (Table 6-20), but at least an order of magnitude below the performance objective in the other three tank rows. Under the WAC 173-340 Method B exposure scenario, the peak HI from the residual waste component is an order of magnitude below the performance objective for all four tank rows.

For the alternative land use case, the composite HI (Method C) does not exceed the performance objective (HI = 1) in any tank row (Table 6-21). The tank row with the highest HI is tank row T-104. The peak HI for that tank row is approximately one-half the performance objective and is driven by the past releases component. Under the WAC 173-340 Method C exposure scenario, the peak HI from the residual waste component is below the performance objective by a factor of between 40 (tank row T-110) and 400 (tank row T-101).

Estimated HI from one tank row exceeded the performance objective of 1 at the WMA fenceline due to past releases.

Chromium, nitrate, and nitrite are the major contributors to the chemical HI.

Table 6-20. Estimated Hazard Index for Reference Case: WAC 173-340 Method B Exposure Scenario by Tank Row in Waste Management Area T [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
T-101	8.35E-02	2332	8.36%	8.35E-02	2332	8.36%	5.52E-03	8201	9.26%
T-104	**9.99E-01**	2332	100.00%	**9.99E-01**	2332	100.00%	1.95E-02	8201	32.72%
T-107	1.67E-02	8201	1.67%	1.34E-02	2332	1.34%	1.67E-02	8201	28.02%
T-110	5.96E-02	8201	5.97%	1.19E-03	2332	0.12%	5.96E-02	8201	100.00%

Bold indicates the performance objective is exceeded.

[a] Shading indicates maximum row all components peak HI.

Table 6-21. Estimated Hazard Index for Alternative Case: WAC 173-340 Method C Exposure Scenario by Tank Row in Waste Management Area T [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
T-101	3.65E-02	2332	8.61%	3.65E-02	2332	8.61%	2.30E-03	8201	9.50%
T-104	4.24E-01	2332	100.00%	4.24E-01	2332	100.00%	8.03E-03	8201	33.18%
T-107	7.27E-03	8201	1.71%	5.74E-03	2332	1.35%	7.27E-03	8201	30.04%
T-110	2.42E-02	8201	5.71%	5.05E-04	2332	0.12%	2.42E-02	8201	100.00%

[a] Shading indicates maximum row all components peak HI.

Figure 6-11 shows temporal variations in non-carcinogenic chemical HI from tank row T-104 to T-106 for the reference land use case. The component contributions for this metric differ from those for the all-pathways dose (Section 6.3.3.1) and radiological ILCR (Section 6.3.3.2). For the latter two metrics, the past releases component dominates the cumulative curve for the entire assessment period, owing largely to the inventory of semi-mobile (K_d = 0.2 mL/g) iodine-129 in the past releases. In contrast, the inventory of less-mobile chemicals (e.g., uranium) in the past releases is very minor. As a result, the composite HI values are driven almost entirely by the mobile (K_d = 0 mL/g) chemical species and the residual waste component becomes dominant over the last half of the assessment period. The mobile chemicals in past releases dominate the composite HI curve from the time of peak (year 2332) to about the year 5800, at which point the mobile chemicals in residual waste take over and dominate through the end of the assessment period.

Figure 6-11. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row T-104

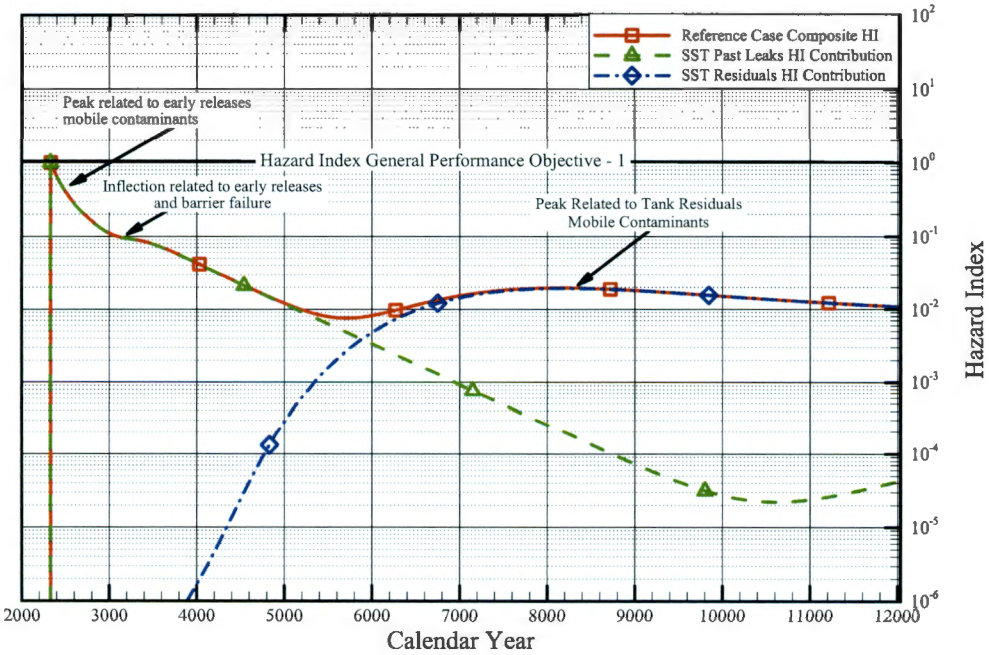


Figure 6-12 and Table 6-22 show the relative contaminant contributions to non-carcinogenic chemical HI from tank row T-104. The combined contributions from hexavalent chromium and nitrite in past releases dominate the composite HI from the time of peak (year 2332) to about year 5800 when residual wastes become dominant (Figure 6-12). From that point to the end of the assessment period, the composite HI is driven almost entirely by hexavalent chromium. The significant drop-off in the nitrite contribution reflects the much lower nitrite inventory in residual waste compared with past releases. At the time of peak from residual waste (year 8201), hexavalent chromium and fluoride from the residual waste component contribute over 93% of the composite HI under both the WAC 173-340 Method C and Method B exposure scenarios (Table 6-22). In Table 6-22, results are presented for the composite HI at calendar year 2332 (the peak year for the past release component HI) and at calendar year 8201 (the peak year for the residuals component HI).

Figure 6-12. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row T-104 with Driving Contaminant Contributions

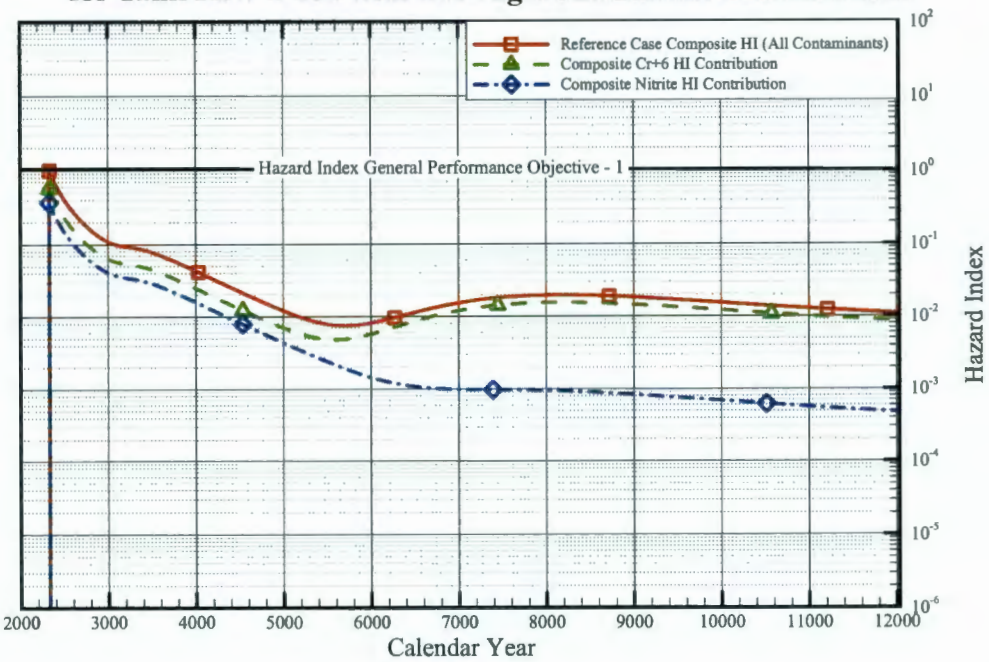


Table 6-22. Fractional Contributions to Composite Hazard Index by Selected Contaminants in Tank Row T-104

WAC 173-340 Method B (Reference Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8201**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Chromium	5.76E-01	57.68%	1.56E-02	79.29%
Nitrite	3.70E-01	37.04%	9.41E-04	4.78%
Nitrate	5.13E-02	5.13%	3.71E-04	1.88%
Fluoride	1.44E-03	0.14%	2.77E-03	14.05%
Uranium	0.00E+00	<0.01%	1.07E-06	0.01%
Other	9.63E-05	0.01%	1.96E-08	<0.01%
Total	**9.99E-01**	100%	1.97E-02	100%
WAC 173-340 Method C (Alternative Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8201**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Chromium	2.31E-01	54.39%	6.25E-03	77.01%
Nitrite	1.69E-01	39.92%	4.30E-04	5.30%
Nitrate	2.34E-02	5.53%	1.69E-04	2.09%
Fluoride	6.60E-04	0.16%	1.27E-03	15.60%
Uranium	0.00E+00	<0.01%	4.91E-07	0.01%
Other	4.40E-05	0.01%	8.95E-09	<0.01%
Total	4.24E-01	100%	8.11E-03	100%

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.
[a] Chromium, fluoride, nitrite, and nitrate originated from predominantly residual waste sources.

6.3.4 Groundwater Pathway Human Health Risk at Waste Management Area TX-TY

Table 6-23 compares the estimated impacts for WMA TX-TY to the performance objectives for protecting the general public. The values shown are the peak values for the composite source term (i.e., sum of dose contributions from past releases and residual waste source components) from the tank row with the highest value. The peak values for each metric occur at the time of assumed loss of institutional controls (year 2332) and in each case are from tank row TX-105. For the reference land use case, the estimated all-pathways dose is well below the performance objective. The radiological ILCR (industrial) is below the federal standard of 10^{-4} and Washington State standard of 10^{-5}. The estimated HI (Method B) is below the performance objective. For the alternative land use case, the radiological ILCR (residential) is below the federal standard of 10^{-4} but above the Washington State standard of 10^{-5}. The HI (Method C) is well below the performance objective. The chemical ILCR for both reference (Method B) and alternative (Method C) land use cases is 0 (see Section 6.3.4.3 for additional information on chemical ILCR using Methods B and C). Each metric is discussed individually in the following sections.

Table 6-23. Comparison of Estimated Reference Case Impacts for Waste Management Area TX-TY with Performance Objectives for Protecting the General Public

Performance Measure		Performance Objective	Peak Value [a]	Peak Year	Tank Row
All-pathways dose (mrem/yr)		15	3.73E-01	2332	TX-105
ILCR (radiological)	Industrial	10^{-4} to 10^{-5}	2.73E-06	2332	TX-105
	Residential	10^{-4} to 10^{-5}	**6.56E-05**	2332	TX-105
ILCR (chemical carcinogen)	WAC 173-340 Method B	10^{-5}	0 [b]	NA	NA
	WAC 173-340 Method C	10^{-5}	0 [b]	NA	NA
HI (chemical non-carcinogen)	WAC 173-340 Method B	1	2.09E-01	2332	TX-105
	WAC 173-340 Method C	1	8.94E-02	2332	TX-105

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Calculated in groundwater at the WMA TX-TY fenceline. Values shown are the maximum projected values over the first 10,000 years after closure.

[b] See Section 6.3.4.3 for additional information on chemical ILCR.

NA = not applicable

6.3.4.1 All-Pathways Dose at Waste Management Area TX-TY

Table 6-24 shows the estimated peak all-pathways dose by source component for each tank row in WMA TX-TY. The composite dose does not exceed the performance objective (15 mrem/yr) in any tank row and is significantly below the performance objective for most tank rows. The tank row with the highest dose is TX-105. The peak dose from that tank row is below the performance objective by a factor of approximately 40. Both the past release and tank residual components from that tank row contribute similar peak doses, but the peaks occur about 5,800 years apart.

Estimated all-pathways farmer dose is below the performance objective of 15 mrem/yr at the WMA fenceline.

Technetium-99, carbon-14, and iodine-129 are the major contributors to the all-pathways farmer dose from past releases.

Technetium-99 and carbon-14 are the major contributors to the all-pathways farmer dose from tank residuals.

Table 6-24 shows the peak all-pathways farmer dose from all components occurs at approximately year 8200 for tank rows TX-101, TX-109, TX-113, TX-116, and TXR vault. All these tank rows do not have past releases associated with them. Therefore, the peak dose is driven by the mobile contaminants in the residual waste (predominantly, technetium-99). Table 6-24 shows the peak all-pathways farmer doses from all components occurs at year 2332 for those tank rows having associated past releases, namely TX-105, TY-101, TY-103, and TY-105. All these tank rows have past releases where the technetium-99 inventory in the past releases is greater than the technetium-99 inventory in the residual waste (Appendix C). For these tank rows, the peak all-pathways farmer doses are dominated by the past releases.

Table 6-24. Estimated Peak All-Pathways Dose by Tank Row in Waste Management Area TX-TY [a]

All-Pathways Dose Performance Objective: 15 mrem/yr									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row
TX-101	1.83E-01	8191	49.06%	NA	NA	NA	1.83E-01	8191	73.49%
TX-105	3.73E-01	2332	100.00%	3.73E-01	2332	100.00%	2.49E-01	8191	100.00%
TX-109	2.19E-01	8191	58.71%	NA	NA	NA	2.19E-01	8191	87.95%
TX-113	2.25E-01	8191	60.32%	NA	NA	NA	2.25E-01	8191	90.36%
TX-116	1.30E-01	8191	34.85%	NA	NA	NA	1.30E-01	8191	52.21%
TXR vault	8.21E-03	8191	2.20%	NA	NA	NA	8.21E-03	8191	3.30%
TY-101	3.78E-02	2332	10.13%	3.78E-02	2332	10.13%	2.84E-03	8161	1.14%
TY-103	1.40E-01	2332	37.53%	1.40E-01	2332	37.53%	7.39E-03	8151	2.97%
TY-105	7.09E-02	2332	19.01%	7.09E-02	2332	19.01%	1.43E-03	8191	0.57%

[a] Shading indicates maximum row all components all-pathways dose.
NA = not applicable

Figure 6-13 shows temporal variations in all-pathways dose from tank row TX-105. The dominance of the past releases component up to almost year 5000 is revealed by the overlap of the composite and past releases curves. After about year 5500, tank residuals become the major contributor to the composite dose, and that contribution dominates the composite through the remainder of the simulation period, although the contribution by less mobile contaminants from past releases is increasing at the end of the simulation period.

Figure 6-13. All-Pathways Dose for Tank Row TX-105

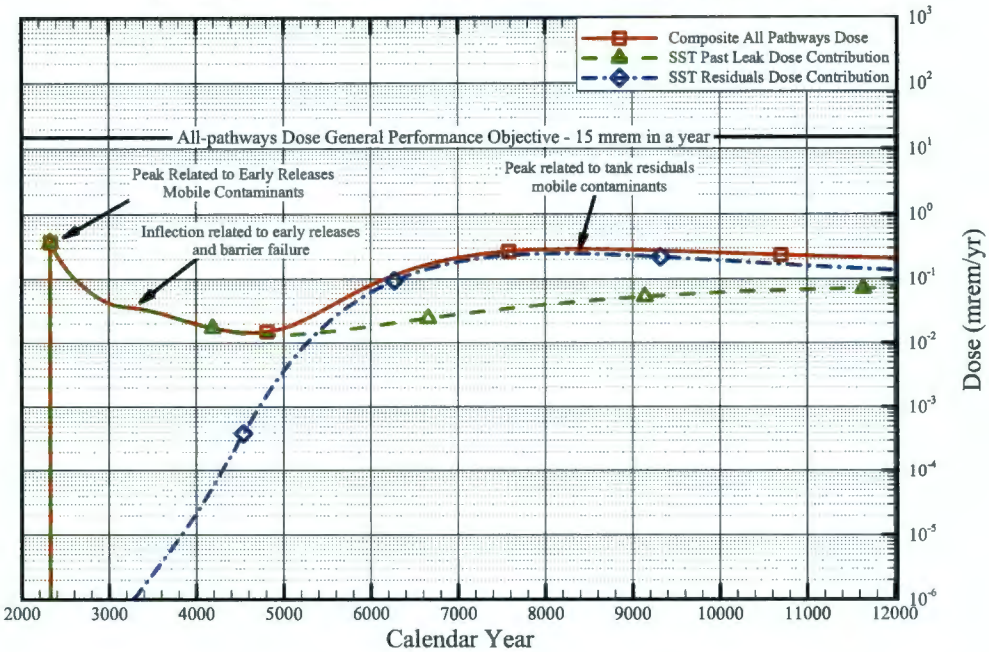


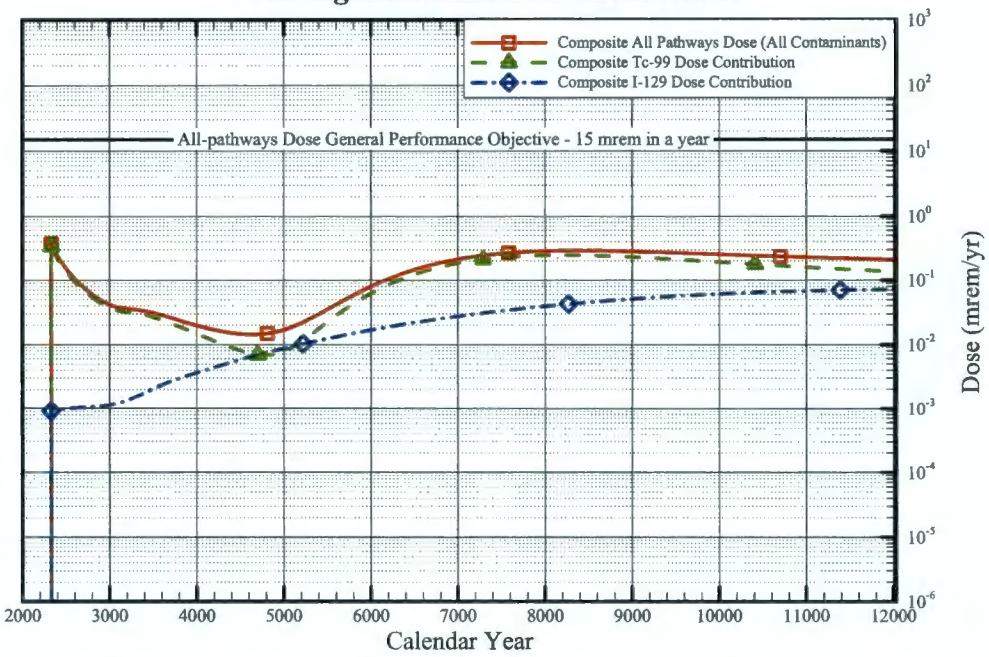
Table 6-25 and Figure 6-14 show the relative contaminant contributions to all-pathways dose from tank row TX-105. Technetium-99 from past releases dominates the composite dose at the time of peak (year 2332) and during the early part of the assessment period up to about year 4600. From years 4600 to 5200, technetium-99 from tank residuals and iodine-129 from past releases contribute almost equal amounts to the all-pathways dose. After year 5200, technetium-99 from tank residuals again becomes dominant and remains dominant through the end of the assessment period (Figure 6-14). At the time of peak from past releases, technetium-99 contributes 91% of the all-pathways dose. At the time of peak from tank residuals (year 8191), technetium-99 from tank residuals contributes over 85% of the composite dose, whereas iodine-129 from past releases contributes only about 14% (Table 6-25). In Table 6-25, results are presented for the composite all-pathways dose at calendar year 2332 (the peak year for the past release component dose) and at calendar year 8191 (the peak year for the residuals component dose).

Table 6-25. Fractional Contributions to Composite All-Pathways Dose by Selected Contaminants in Tank Row TX-105, Reference Case

Contaminant	Calendar Year: 2332		Calendar Year: 8191	
	Dose mrem/yr	Contribution to Total Dose	Dose mrem/yr	Contribution to Total Dose [a]
Technetium-99	3.41E-01	91.34%	2.47E-01	85.02%
Carbon-14	3.14E-02	8.42%	1.46E-03	0.50%
Iodine-129	9.23E-04	0.25%	4.21E-02	14.48%
Other	2.29E-11	<0.01%	2.85E-07	<0.01%
Total	3.73E-01	100%	2.91E-01	100%

[a] Iodine-129 originated from past release sources. Technetium-99 and carbon-14 originated predominantly from tank waste residual sources.

Figure 6-14. All-Pathways Dose for Tank Row TX-105 with Driving Contaminant Contributions



6.3.4.2 Radiological Cancer Risk at Waste Management Area TX-TY

Tables 6-26 and 6-27 show the estimated peak radionuclide ILCR by source component for each tank row in WMA TX-TY for the reference case (industrial scenario) and alternative land use case (residential scenario), respectively. For the reference case, the peak ILCR does not exceed the reference case performance objective in any tank row and is significantly below the performance objective for most tank rows (Table 6-26). The peak ILCR for the residential scenario is below the federal standard of 10^{-4} but above the Washington State standard of 10^{-5} for most tank rows (Table 6-27). The tank row with the highest ILCR for either case is TX-105. The peak ILCR from that tank row is below the reference performance objective (as described by the industrial exposure scenario) by a factor of almost 4, and below the federal standard for the residential scenario by nearly a factor of 2. The peak ILCR from that tank row is above the Washington State standard for the residential scenario by a factor of about 5. Both the past release and tank residual components from that tank row contribute similar peak ILCR, but the peaks occur about 5,800 years apart.

Estimated ILCR from each tank row is below the performance objective of 10^{-5} at the WMA fenceline for the reference exposure scenario.

Technetium-99 is the major contributor to the peak ILCR.

Table 6-26. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Reference Case: Industrial Exposure Scenario by Tank Row in Waste Management Area TX-TY [a]

Radiological Cancer Risk Performance Objective: $10^{-4} – 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
TX-101	1.43E-06	8191	52.38%	NA	NA	NA	1.43E-06	8191	73.33%
TX-105	2.73E-06	2332	100.00%	2.73E-06	2332	100.00%	1.95E-06	8191	100.00%
TX-109	1.72E-06	8191	63.00%	NA	NA	NA	1.72E-06	8191	88.21%
TX-113	1.76E-06	8191	64.47%	NA	NA	NA	1.76E-06	8191	90.26%
TX-116	1.02E-06	8191	37.36%	NA	NA	NA	1.02E-06	8191	52.31%
TXR vault	6.43E-08	8191	2.36%	NA	NA	NA	6.43E-08	8191	3.30%
TY-101	2.77E-07	2332	10.15%	2.77E-07	2332	10.15%	2.12E-08	8181	1.09%
TY-103	1.03E-06	2332	37.73%	1.03E-06	2332	37.73%	5.38E-08	8181	2.76%
TY-105	4.92E-07	2332	18.02%	4.92E-07	2332	18.02%	1.12E-08	8191	0.57%

[a] Shading indicates maximum row all components peak ILCR.

NA = not applicable

Table 6-27. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Alternative Case: Residential Exposure Scenario by Tank Row in Waste Management Area TX-TY [a]

Radiological Cancer Risk Performance Objective: $10^{-4} – 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
TX-101	**3.49E-05**	8191	53.20%	NA	NA	NA	**3.49E-05**	8191	73.63%
TX-105	**6.56E-05**	2332	100.00%	**6.56E-05**	2332	100.00%	**4.74E-05**	8191	100.00%
TX-109	**4.18E-05**	8191	63.72%	NA	NA	NA	**4.18E-05**	8191	88.19%
TX-113	**4.28E-05**	8191	65.24%	NA	NA	NA	**4.28E-05**	8191	90.30%
TX-116	**2.47E-05**	8191	37.65%	NA	NA	NA	**2.47E-05**	8191	52.11%
TXR vault	1.56E-06	8191	2.38%	NA	NA	NA	1.56E-06	8191	3.29%
TY-101	6.67E-06	2332	10.17%	6.67E-06	2332	10.17%	5.11E-07	8191	1.08%
TY-103	**2.47E-05**	2332	37.65%	**2.47E-05**	2332	37.65%	1.29E-06	8191	2.72%
TY-105	**1.17E-05**	2332	17.84%	**1.17E-05**	2332	17.84%	2.72E-07	8191	0.57%

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Shading indicates maximum row all components peak ILCR.

NA = not applicable

Figure 6-15 shows temporal variations in ILCR from tank row TX-105. The past releases component dominates the composite ILCR up to almost year 4500, as evidenced by the overlapping of the past release component and composite ILCR curves during this time. After about year 5200, tank residuals become the major contributor to the composite ILCR, such that after about year 5500 and through the remainder of the simulation period, the composite and tank residuals ILCR curves overlap each other, indicating that the tank residuals contribution dominates the ILCR.

Figure 6-15. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row TX-105

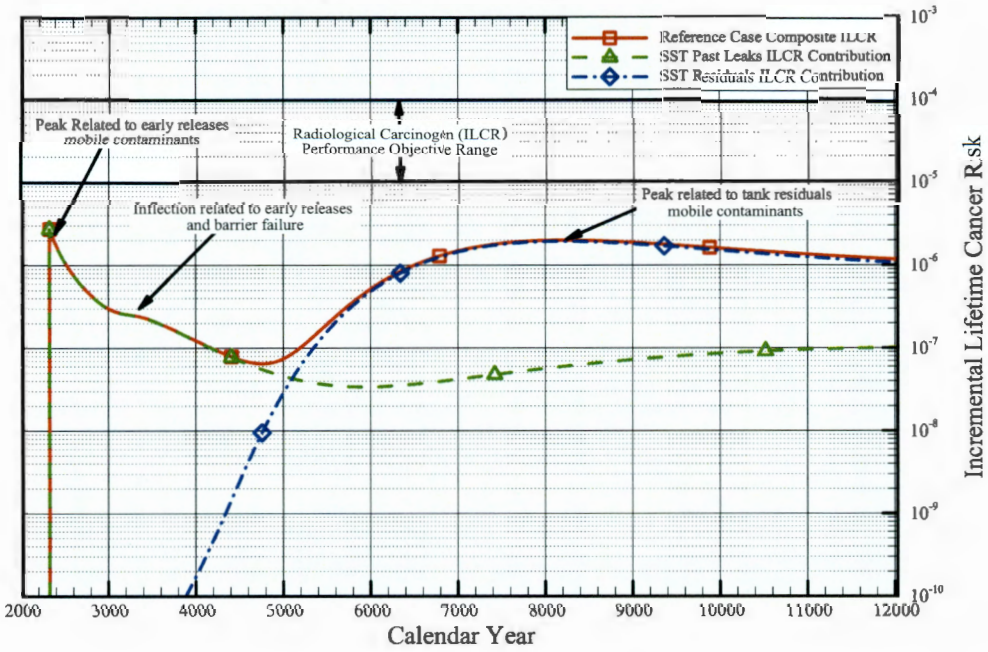


Figure 6-16 and Table 6-28 show the relative contaminant contributions to the reference case ILCR from tank row TX-105. The technetium-99 contribution dominates the composite ILCR during the entire simulation period, as evidenced by the overlapping of the two curves in Figure 6-16. At the time of peak from past releases, technetium-99 contributes 98% and 97% of the total industrial scenario ILCR (reference case) and residential scenario ILCR (alternative land use case), respectively. At the time of peak from tank residuals (year 8191), technetium-99 from tank residuals contributes over 99% of both the industrial scenario and residential scenario ILCR. Under the residential exposure scenario, the relative contribution from technetium-99 at the time of peak from residual waste is greater than for the industrial scenario because of the additional exposure pathways (e.g., garden vegetables) included in this scenario. In Table 6-28, results are present for the composite ILCR at calendar year 2332 (the peak year for the past release component ILCR) and at calendar year 8191 (the peak year for the tank residuals component ILCR).

Figure 6-16. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row TX-105 with Driving Contaminant Contributions

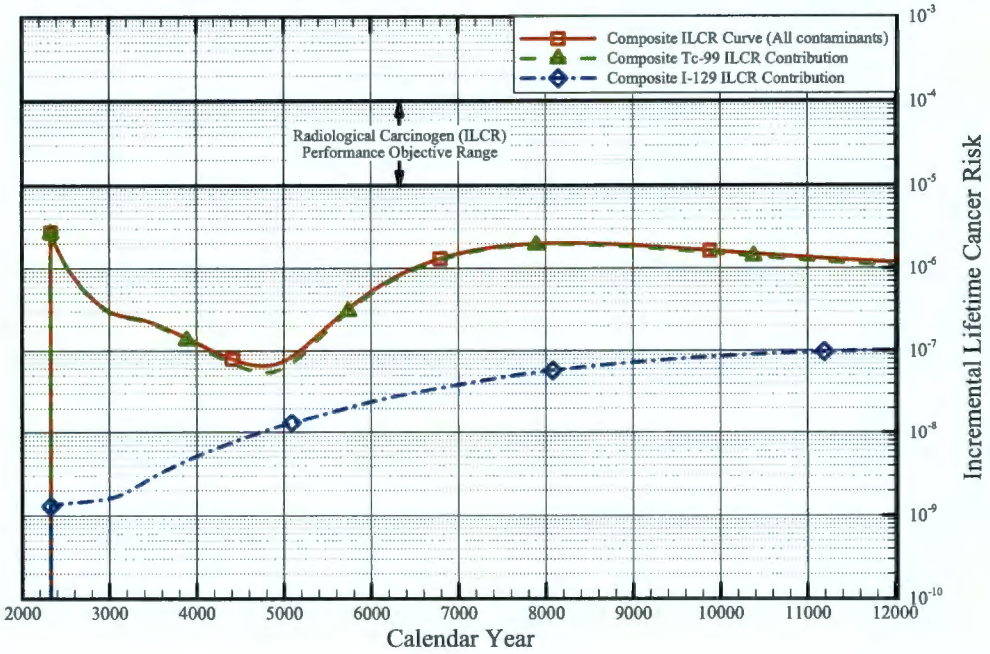


Table 6-28. Fractional Contributions to Composite Incremental Lifetime Cancer Risk by Selected Contaminants in Tank Row TX-105

Industrial Scenario (Reference Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8191**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	2.68E-06	98.11%	1.94E-06	96.92%
Carbon-14	5.03E-08	1.84%	2.34E-09	0.12%
Iodine-129	1.30E-09	0.05%	5.94E-08	2.96%
Other	3.26E-16	<0.01%	5.40E-13	<0.01%
Total	2.73E-06	100%	2.01E-06	100%
Residential Scenario (Alternative Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8191**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	**6.53E-05**	99.44%	**4.74E-05**	99.32%
Carbon-14	3.64E-07	0.55%	1.69E-08	0.04%
Iodine-129	6.75E-09	0.01%	3.08E-07	0.65%
Other	1.36E-15	<0.01%	2.80E-12	<0.01%
Total	**6.56E-05**	100%	**4.77E-05**	100%

Bold indicates the performance objective is exceeded.

[a] Iodine-129 originated from past release sources. Technetium-99 and carbon-14 originated predominantly from tank waste residual sources.

6.3.4.3 Chemical Cancer Risk at Waste Management Area TX-TY

Two scenarios from the Washington State groundwater cleanup regulations (Method B and Method C from WAC 173-340) were used to assess reference case impacts from nonradiological carcinogenic chemicals (Section 1.9). Of the nonradiological chemicals for which tank waste inventories are currently reported in the BBI, the following five are classified as carcinogenic:

- Arsenic
- Hexavalent chromium
- Cobalt
- Beryllium
- Cadmium

All five are classified as carcinogenic via inhalation but only one, arsenic, is also classified as carcinogenic via ingestion. Because both of the WAC 173-340 groundwater scenarios are based solely on drinking water ingestion, arsenic was the only chemical considered in calculating the chemical ILCR. Arsenic has extremely low near-field (i.e., vadose zone) mobility and was assigned a K_d of 39 mL/g (Spitz and Moreno 1996) for the contaminant fate and transport modeling (Chapter 3.0). Results of that modeling for WMA TX-TY (Section 4.4) indicated that arsenic would not reach groundwater at the fenceline within the 10,000-year simulation period. Thus, the calculated chemical ILCR for WMA TX-TY was zero.

It is possible that more carcinogenic chemicals are present in tank waste than are currently reported in the BBI. Inventory data for additional chemicals, potentially including carcinogenic chemicals not analyzed in this SST PA (e.g., organic chemicals), will be generated following waste retrieval through post-retrieval sample analysis. As additional inventory information becomes available, the data will be evaluated under the integrated regulatory closure process described in Chapter 1.0.

6.3.4.4 Non-Carcinogenic Chemical Hazard Index at Waste Management Area TX-TY

Tables 6-29 and 6-30 show the estimated peak HI by source component for each tank row in WMA TX-TY for the reference case (WAC 173-340 Method B) and alterative land use case (Method C) exposure scenarios, respectively. For the reference land use case, the composite non-carcinogenic chemical HI does not exceed the performance objective in any tank row (Table 6-29). The tank row with the maximum HI (Method B) from the past releases component is TX-105 with an HI that is almost a factor of 5 lower than the performance objective. Under the WAC 173-340 Method B exposure scenario, the peak HI from the residual waste component is at least two orders of magnitude below the performance objective in all nine tank rows.

For the alternative land use case (Method C), the HI does not exceed the performance objective (HI = 1) in any tank row, and is significantly below the performance objective for most tank rows (Table 6-30). The tank row with the highest HI is TX-105. The peak HI from that tank row is below the performance objective by a factor of approximately 10 and driven by the past releases. Under the WAC 173-340 Method C exposure scenario, the peak HI from the residual waste component is below the performance objective by approximately two or more orders of magnitude in all nine tank rows.

Estimated HI from each tank row is below the performance objective of 1 at the WMA fenceline.

Chromium, nitrate, and nitrite are the major contributors to the chemical HI.

Table 6-29. Estimated Hazard Index for Reference Case: WAC 173-340 Method B Exposure Scenario by Tank Row in Waste Management Area TX-TY [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
TX-101	7.29E-02	8201	34.88%	NA	NA	NA	7.29E-02	8201	74.31%
TX-105	2.09E-01	2332	100.00%	2.09E-01	2332	100.00%	9.81E-02	8201	100.00%
TX-109	5.92E-02	8201	28.33%	NA	NA	NA	5.92E-02	8201	60.35%
TX-113	3.02E-02	8201	14.45%	NA	NA	NA	3.02E-02	8201	30.78%
TX-116	4.90E-02	8201	23.44%	NA	NA	NA	4.90E-02	8201	49.95%
TXR vault	2.53E-03	8201	1.21%	NA	NA	NA	2.53E-03	8201	2.58%
TY-101	1.99E-02	2332	9.52%	1.99E-02	2332	9.52%	9.99E-03	8201	10.18%
TY-103	6.90E-02	2332	33.01%	6.90E-02	2332	33.01%	7.37E-03	8201	7.51%
TY-105	1.48E-01	2332	70.81%	1.48E-01	2332	70.81%	1.72E-03	8201	1.75%

[a] Shading indicates maximum row all components peak HI.
NA = not applicable

Table 6-30. Estimated Hazard Index for Alternative Case: WAC 173-340 Method C Exposure Scenario by Tank Row in Waste Management Area TX-TY [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
TX-101	2.95E-02	8201	33.00%	NA	NA	NA	2.95E-02	8201	74.68%
TX-105	8.94E-02	2332	100.00%	8.94E-02	2332	100.00%	3.95E-02	8201	100.00%
TX-109	2.40E-02	8201	26.85%	NA	NA	NA	2.40E-02	8201	60.76%
TX-113	1.22E-02	8201	13.65%	NA	NA	NA	1.22E-02	8201	30.89%
TX-116	1.98E-02	8201	22.15%	NA	NA	NA	1.98E-02	8201	50.13%
TXR vault	1.02E-03	8201	1.14%	NA	NA	NA	1.02E-03	8201	2.58%
TY-101	8.47E-03	2332	9.47%	8.47E-03	2332	9.47%	4.10E-03	8201	10.38%
TY-103	2.94E-02	2332	32.89%	2.94E-02	2332	32.89%	2.98E-03	8201	7.54%
TY-105	6.53E-02	2332	73.04%	6.53E-02	2332	73.04%	7.18E-04	8201	1.82%

[a] Shading indicates maximum row all components peak HI.
NA = not applicable

Figure 6-17 shows temporal variations in non-carcinogenic chemical HI from tank row TX-105 for the reference land use case. The dominance of the past releases component up to almost year 5600 is revealed by the overlap of the composite and past releases curves. After about year 5600, tank residuals become the larger contributor to the total HI, and by year 6400, the tank residuals are the dominant contributor.

Figure 6-18 and Table 6-31 show the relative contaminant contributions to non-carcinogenic chemical HI from tank row TX-105. The combined contributions of hexavalent chromium and nitrite from past releases dominate the composite HI from the time of peak (year 2332) to about year 5000, when residual wastes become dominant (Figure 6-18). From that point to the end of the assessment period, the composite HI is driven almost entirely by hexavalent chromium. The significant drop-off in the nitrate contribution reflects the much lower inventory in residual waste compared with past releases. At the time of peak from residual waste (year 8201), hexavalent chromium from the residual waste component contributes over 93% of the composite HI under both the WAC 173-340 Method C and Method B exposure scenarios. In Table 6-31, results are presented for the composite HI at calendar year 2332 (the peak year for the past release component HI) and at calendar year 8201 (the peak year for the residuals component HI).

Figure 6-17. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row TX-105

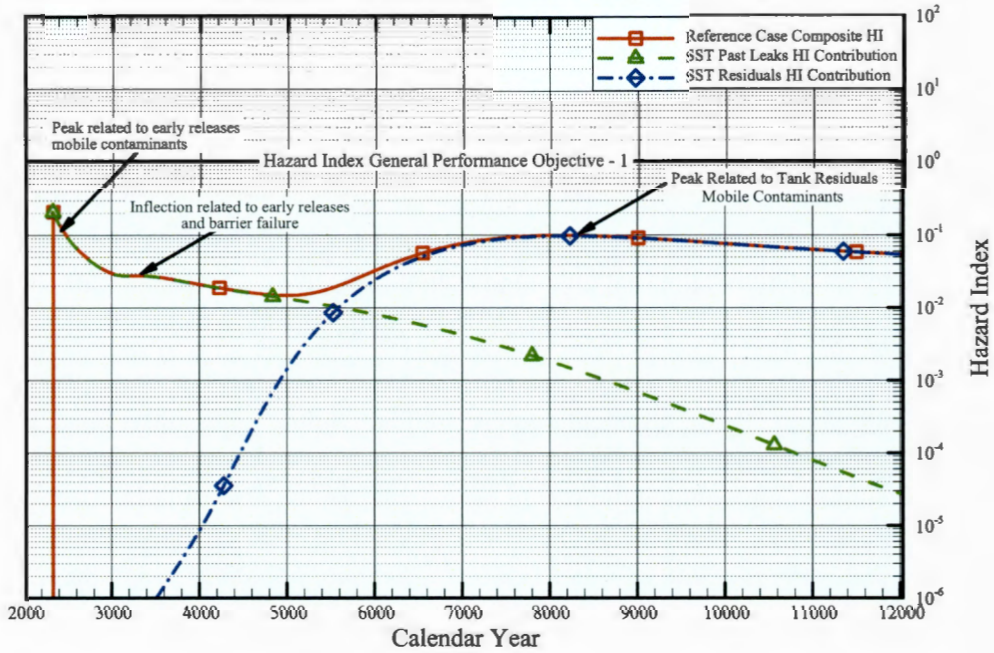


Figure 6-18. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row TX-105 with Driving Contaminant Contributions

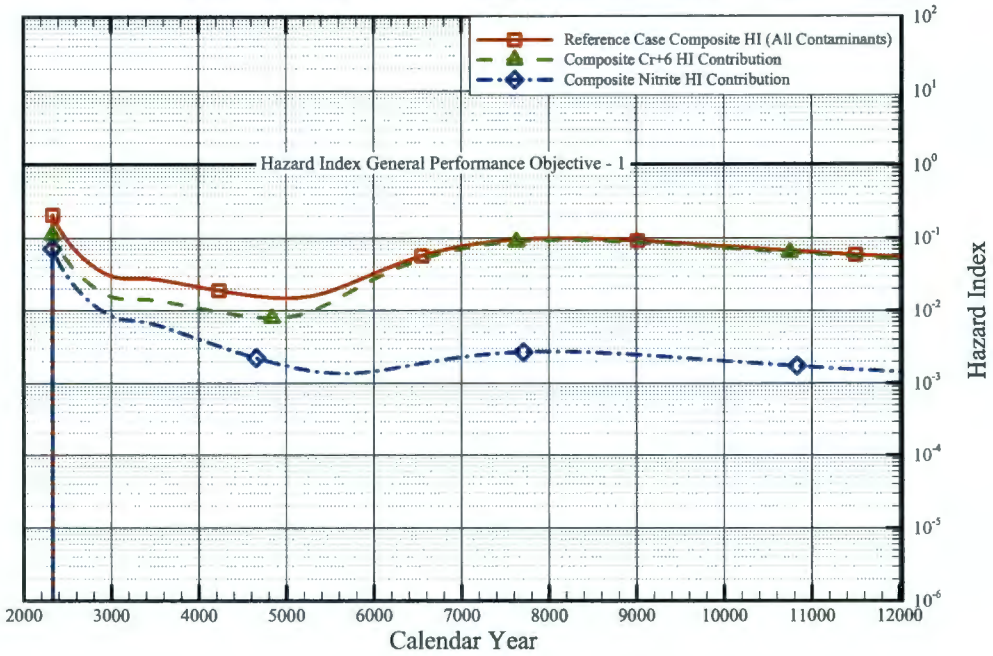


Table 6-31. Fractional Contributions to Composite Hazard Index by Selected Contaminants in Tank Row TX-105

WAC 173-340 Method B (Reference Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8201**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Chromium	1.11E-01	53.20%	9.42E-02	94.53%
Nitrite	7.16E-02	34.17%	2.71E-03	2.72%
Nitrate	1.70E-02	8.13%	2.12E-03	2.13%
Fluoride	8.84E-03	4.22%	6.22E-04	0.62%
n-Butyl alcohol	5.89E-04	0.28%	1.17E-07	<0.01%
Other	0.00E+00	<0.01%	8.43E-08	<0.01%
Total	2.09E-01	100%	9.96E-02	100%
WAC 173-340 Method C (Alternative Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8201**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Chromium	4.46E-02	49.87%	3.77E-02	93.80%
Nitrite	3.27E-02	36.60%	1.24E-03	3.09%
Nitrate	7.78E-03	8.70%	9.68E-04	2.41%
Fluoride	4.04E-03	4.52%	2.84E-04	0.71%
n-Butyl alcohol	2.69E-04	0.30%	5.35E-08	<0.01%
Other	0.00E+00	<0.01%	3.85E-08	<0.01%
Total	8.94E-02	100%	4.02E-02	100%

[a] Chromium, fluoride, nitrite, and nitrate originated from predominantly residual waste sources.

6.3.5 Groundwater Pathway Human Health Risk at Waste Management Area U

Table 6-32 compares the estimated impacts for WMA U to the performance objectives for protecting the general public. The values shown are the peak values for the composite source term (i.e., sum of dose contributions from past releases and residual waste source components) from the tank row with the highest value. Table 6-32 shows that tank row U-107 provides the largest impacts for each metric, and for this reason, tank row U-107 will be used throughout this section to illustrate the groundwater pathway human health risks at WMA U.

No past releases occur in tank row U-107, so the composite for each metric is identical to the contribution to each metric from residual waste in this WMA. The peak values for each metric occur at the residual waste component contribution peak year, which can vary between metrics because of differences in relative weighting for contributing contaminants. In all cases however, the peak occurs around the year 8200. For the reference land use case, the estimated HI (Method B) is below the performance objective and the radiological ILCR (industrial) is below the Washington State standard of 10^{-5} by about an order of magnitude and below the federal standard of 10^{-4} by two orders of magnitude. For the alternative land use case, the estimated all-pathways dose and chemical HI (Method C) are below their respective performance objectives, while the radiological ILCR (residential) is above the performance objective. The chemical ILCR for both reference (Method B) and alternative (Method C) land use cases is 0 (see Section 6.3.5.3 for additional information on chemical ILCR using Methods B and C). Each metric is discussed individually in the following sections.

Table 6-32. Comparison of Estimated Reference Case Impacts for Waste Management Area U with Performance Objectives for Protecting the General Public

Performance Measure		Performance Objective	Peak Value [a]	Peak Year	Tank Row
All-pathways dose (mrem/yr)		15	3.54E-01	8191	U-107
ILCR (radiological)	Industrial	10^{-4} to 10^{-5}	2.77E-06	8191	U-107
	Residential	10^{-4} to 10^{-5}	**6.75E-05**	8191	U-107
ILCR (chemical carcinogen)	WAC 173-340 Method B	10^{-5}	0 [b]	NA	NA
	WAC 173-340 Method C	10^{-5}	0 [b]	NA	NA
HI (chemical non-carcinogen)	WAC 173-340 Method B	1	2.32E-01	8201	U-107
	WAC 173-340 Method C	1	9.30E-02	8201	U-107

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Calculated in groundwater at the WMA U fenceline. Values shown are the maximum projected values over the first 10,000 years after closure.

[b] See Section 6.3.5.3 for additional information on chemical ILCR.

NA = not applicable

WMA U is unique in the SST system in that it is the only WMA where the tank row providing the greatest human health risk does not contain past releases. Typically, the past releases component drives risk results in a WMA; however in WMA U, the tank residual component is the primary risk driving component. This is because WMA U has the lowest inventory of

technetium-99 from the past release source component in the SST system. Technetium-99 is the predominant radionuclide risk driver in the past release source component. The complete past release component in WMA U comprises four past tank leaks, three of which are under 8,500 gal, and two negligible UPRs (36 and 500 gal). Two of the tank leaks occur in the same tank row, and the remaining two leaks are in separate tank rows, leaving one tank row in WMA U without a past tank leak. The tank row without a past tank leak (tank row U-107) has a technetium-99 inventory greater than that of the other tank rows containing past releases, and thus is the tank row driving human health risk.

6.3.5.1 All-Pathways Dose at Waste Management Area U

Table 6-33 shows the estimated peak all-pathways dose by source component for each tank row in WMA U. The composite dose does not exceed the performance objective (15 mrem/yr) in any tank row and is significantly below the performance objective for most tank rows. The tank row with the highest dose is U-107. The peak dose from that tank row is below the performance objective by a factor of approximately 40 and is driven by the residual waste component, because no past releases occur in tank row U-107. Tank rows containing past releases do not exceed the performance objective and are between one and three orders of magnitude below it.

Estimated all-pathways farmer dose is below the performance objective of 15 mrem/yr at the WMA fenceline.

Technetium-99, carbon-14, and iodine-129 are the major contributors to the all-pathways farmer dose from past releases.

Technetium-99 and carbon-14 are the major contributors to the all-pathways farmer dose from tank residuals.

Table 6-33 shows the peak all-pathways farmer dose from all components occurs at approximately year 8200 for tank rows U-101, U-107, and U-110. These three tank rows have past releases associated with them. However, the technetium-99 past release inventories for these tank rows are significantly less than the technetium-99 inventories associated with residual wastes. Since technetium-99 is the major contributor to the all-pathways farmer dose, the residual wastes for these tank rows dominate the all-pathways doses. Table 6-33 shows the peak all-pathways dose from all sources occurs at year 2332 for tank rows U-104 and UR vault. Tank row U-104 technetium-99 past release inventory (2.1 Ci) is slightly higher than the technetium-99 residual waste inventory (1.3 Ci). Therefore, the past release source term is the dominant source contribution for this tank row. Tank row CR vault includes the pipeline inventory (technetium-99 inventory = 0.10 Ci) and MUST inventory (technetium-99 residual waste inventory [MUST] = 0.4 Ci). Since the pipeline source is assumed to be readily available for transport, its contribution to the all-pathways farmer dose peaks at approximately year 2100. The slower release of grouted residual waste contaminants from the MUSTs and the assumption that the MUST residual waste is not exposed to the operational recharge offset the higher technetium-99 inventory in the MUST and results in the pipeline technetium-99 inventory dominating the all-pathways farmer dose for tank row CR vault.

Table 6-33. Estimated Peak All-Pathways Dose by Tank Row in Waste Management Area U [a]

All-Pathways Dose Performance Objective: 15 mrem/yr									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row
U-101	1.15E-01	8251 [b]	32.49%	4.13E-02	2332	22.69%	1.08E-01	8191	30.51%
U-104	1.82E-01	2332	51.41%	1.82E-01	2332	100.00%	2.81E-02	8181	7.94%
U-107	3.54E-01	8191	100.00%	NA	NA	NA	3.54E-01	8191	100.00%
U-110	1.49E-01	8281	42.09%	8.85E-02	2332	48.63%	1.37E-01	8191	38.70%
U vault [c]	3.74E-02	2332	10.56%	6.21E-03	2332	3.41%	3.11E-02	2332	8.79%

[a] Shading indicates maximum row all components all-pathways dose.

[b] The all components peak year and residual waste component peak year do not match in some U tank rows because the past release component contribution from iodine-129 is large enough to make the all components peak year occur later.

[c] Tank row UR vault contains plugged and blocked pipelines inventory.

NA = not applicable

Figure 6-19 shows temporal variations in all-pathways dose from tank row U-107. Because only the residual waste component occurs in this tank row, the composite and residual waste component curves overlap exactly. The all-pathways dose curve from the residual waste component rapidly increases during the first half of the simulation period, to peak in the year 8191, and then gradually declines throughout the remainder of the model time frame.

Figure 6-19. All-Pathways Dose for Tank Row U-107

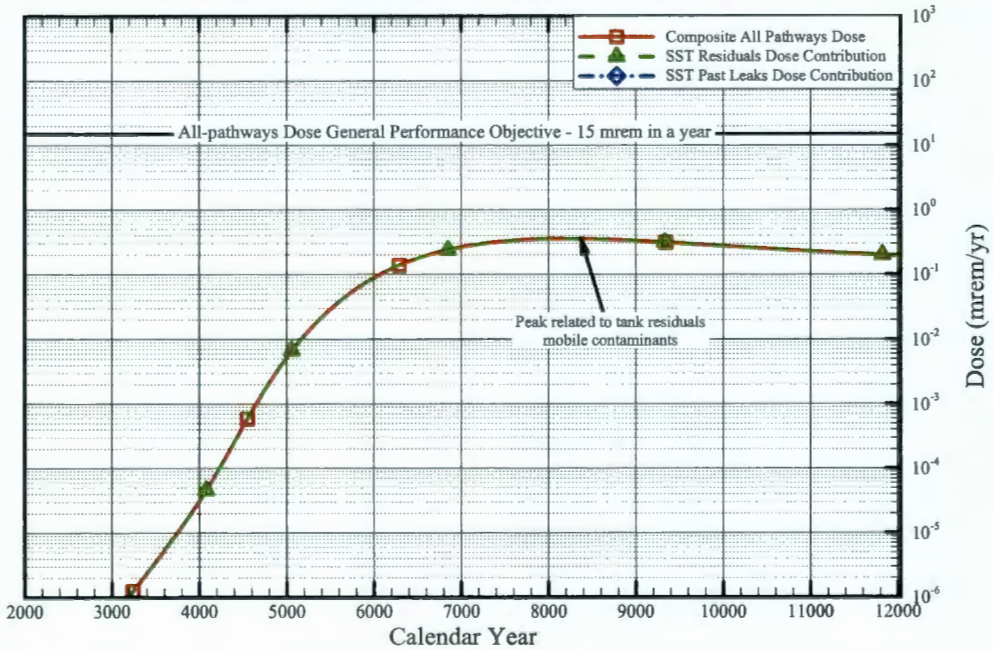


Figure 6-20 and Table 6-34 show the relative contaminant contributions to all-pathways dose from tank row U-107. Technetium-99 dominates the composite dose for the entire simulation period, because of its high mobility. Carbon-14 provides minimal contribution to the total all-pathways dose (0.54%). Iodine-129 does not appear in the simulation time frame because it is not mobile enough to reach groundwater from tank residual wastes, which are shallowly placed in the vadose zone in the model. Typically, iodine-129 only reaches groundwater in WMAs having past releases, which were placed in the vadose zone relatively close to the water table in the model. As no past releases occur in tank row U-107, iodine-129 is not close enough to the water table in the vadose zone to have a projected fenceline concentration during the simulation. In Table 6-20, results are presented for the composite all-pathways dose at calendar year 2332 (typically the peak year for the past release component dose in the 200 West Area WMAs) and at calendar year 8191 (the peak year for the residuals component dose).

Figure 6-20. All-Pathways Dose for Tank Row U-107 with Driving Contaminant Contributions

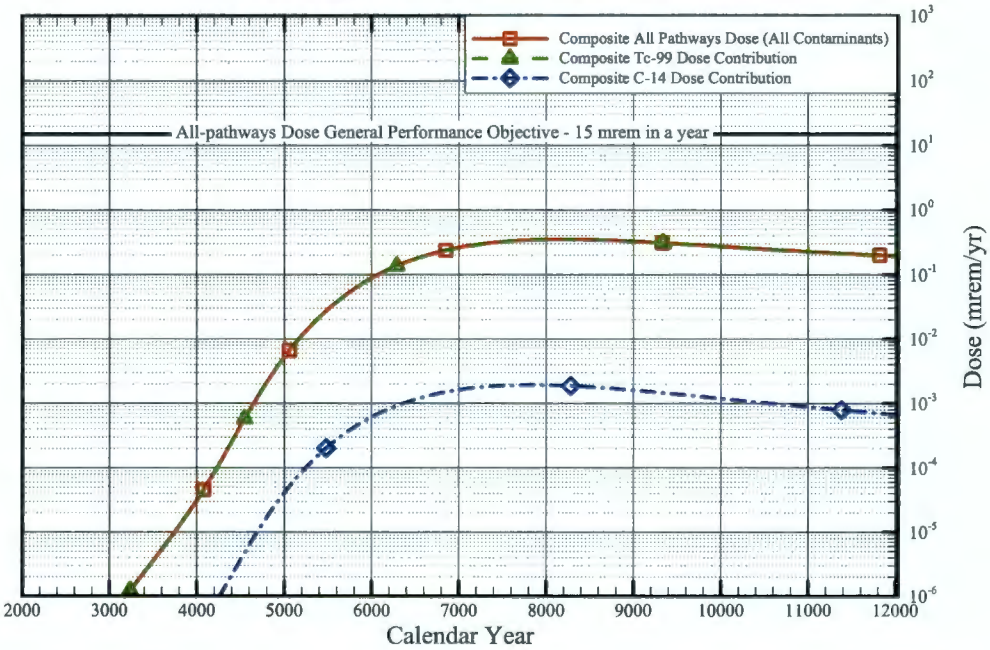


Table 6-34. Fractional Contributions to Composite All-Pathways Dose by Selected Contaminants in Tank Row U-107, Reference Case

Contaminant	Calendar Year: 2332		Calendar Year: 8191	
	Dose mrem/yr	Contribution to Total Dose	Dose mrem/yr	Contribution to Total Dose
Technetium-99	NA	NA	3.52E-01	99.46%
Carbon-14	NA	NA	1.91E-03	0.54%
Total	NA	NA	3.54E-01	100%

NA = not applicable

In tank rows where dose is dominated by the residual waste component (i.e., tank rows U-101, U-107, and U-110), the composite all-pathways dose peak year is sometimes later than the calculated peak year, which occurs when the dose contributions from only the tank residual wastes are assumed. Usually, the composite dose peak year is the same as the peak year for the component that dominates dose (i.e., the residual waste component). However, in these instances, the contributions to overall dose from past release components, although small, continue to increase as contributions from the tank residual component contributions decrease. This combination of dose changes over time is sufficient to shift the composite dose peak to a slightly later time.

In tank row U-101, the residual waste component all-pathways dose (driven by technetium-99) declines after a peak year of 8191. During the same period, the past releases component dose (driven by iodine-129) is exhibiting an increase in the same tank row. The rate of past release contribution increase is greater than the rate of residual waste contribution decrease between the years 8191 and 8251. When the two contributions are added together to form the composite dose, the magnitude of the past releases component dose contribution (approximately 6% of the composite dose) coupled with the increasing contribution of that component causes the composite dose to increase to a peak year of 8251. After year 8251, the rate of decrease for the residual waste contribution is so rapid that the overall composite dose decreases as well. This effect is also observed in the ILCR metric.

6.3.5.2 Radiological Cancer Risk at Waste Management Area U

Tables 6-35 and 6-36 show the estimated peak radiological ILCR by source component for each tank row in WMA U for the reference case (industrial scenario) and alternative land use case (residential scenario), respectively. For the reference land use case, the composite radiological ILCR does not exceed the performance objective in any tank row (Table 6-35). The peak ILCR occurs in tank row U-107, is an order of magnitude under the Washington State standard (10^{-5}), and is driven by the residual waste component. Although no past releases occur in tank row U-107, the other four tank rows in the WMA contain the past release component. In these tank rows, under the industrial exposure scenario, the peak ILCR from the past release component is below the Washington State standard (10^{-5}) by at least a factor of 3.

For the alternative land use case, the composite radiological ILCR exceeds the Washington State standard (10^{-5}) in all tank rows but the UR vault row (Table 6-36). Under the residential exposure scenario, the peak ILCR from the past releases component approaches the Washington State standard (10^{-5}) in tank rows U-101 and UR vault and slightly exceeds that standard in tank rows U-104 and U-110.

Estimated ILCR from each tank row is below the performance objective of 10^{-5} at the WMA fenceline for the reference exposure scenario.

Technetium-99 is the major contributor to the peak ILCR.

Table 6-35. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Reference Case: Industrial Exposure Scenario by Tank Row in Waste Management Area U [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
U-101	8.55E-07	8201	30.87%	2.90E-07	2332	21.97%	8.46E-07	8191	30.54%
U-104	1.32E-06	2332	47.65%	1.32E-06	2332	100.00%	2.18E-07	8191	7.87%
U-107	2.77E-06	8191	100.00%	NA	NA	NA	2.77E-06	8191	100.00%
U-110	1.09E-06	8201	39.35%	6.25E-07	2332	47.35%	1.07E-06	8191	38.63%
UR vault [b]	2.53E-07	2332	9.13%	4.53E-08	2332	3.43%	2.08E-07	2332	7.51%

[a] Shading indicates maximum row all components peak ILCR.

[b] Tank row UR vault contains plugged and blocked pipelines inventory.

NA = not applicable

Table 6-36. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Alternative Case: Residential Exposure Scenario by Tank Row in Waste Management Area U [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
U-101	**2.06E-05**	8191	30.52%	6.92E-06	2332	21.76%	**2.06E 05**	8191	30.52%
U-104	**3.18E-05**	2332	47.11%	**3.18E-05**	2332	100.00%	5.30E-06	8191	7.85%
U-107	**6.75E-05**	8191	100.00%	NA	NA	NA	**6.75E-05**	8191	100.00%
U-110	**2.62E-05**	8191	38.81%	**1.49E-05**	2332	46.86%	**2.61E-05**	8191	38.67%
UR vault [b]	5.99E-06	2332	8.87%	1.09E-06	2332	3.43%	4.91E-06	2332	7.27%

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Shading indicates maximum row all components peak ILCR.

[b] Tank row UR vault contains plugged and blocked pipelines inventory.

NA = not applicable

Figure 6-21 shows temporal variations in radionuclide ILCR from tank row U-107 for the expected industrial land use case. Again, as with the all-pathways dose (Section 6.3.5.1), the tank residual component and composite ILCR curves are identical as there is no past release component in tank row U-107.

Figure 6-21. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row U-107

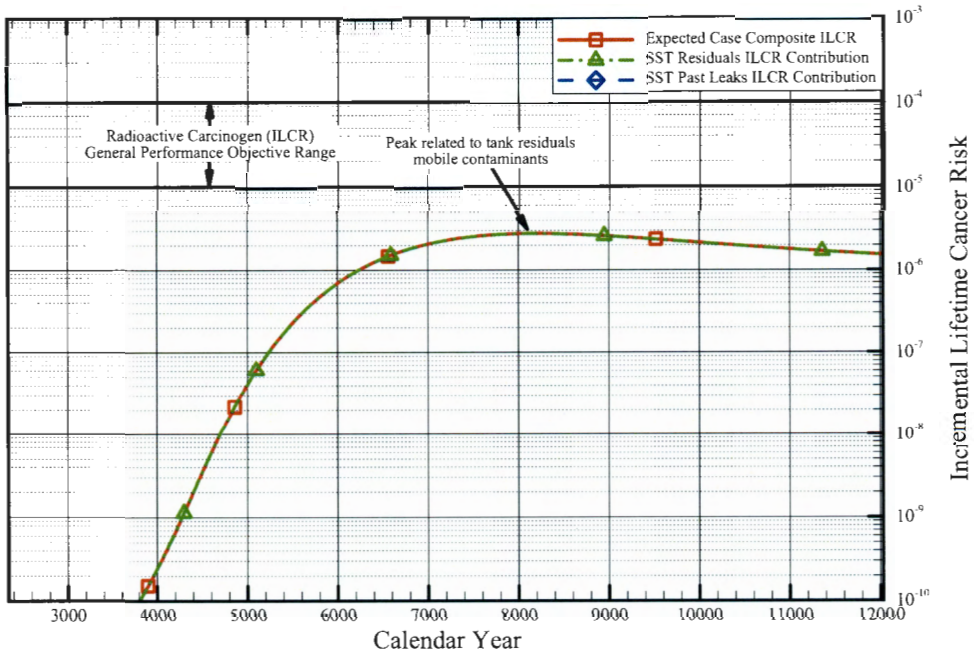


Figure 6-22 and Table 6-37 show relative contaminant contributions to radiological ILCR from tank row U-107. Technetium-99 dominates the radiological ILCR from tank row U-107 because it is mobile. Carbon-14 is also projected to make a negligible contribution to total radiological ILCR (0.11%). As described in Section 6.3.5.1 (all-pathways dose), the absence of a past releases component in tank row U-107 precludes iodine-129 from reaching the water table within the model time frame. Iodine-129 is less-mobile and therefore only reaches the water table during the simulation period when it is released from the past releases component, which is placed in closer proximity to the water table in the model.

Under the residential exposure scenario, the relative contribution from technetium-99 at the time of peak from residual waste is slightly higher (99.97%) because of the additional exposure pathways (e.g., garden vegetables) included in this scenario (Table 6-37). In Table 6-37, results are presented for the composite all-pathways dose at calendar year 2332 (typically the peak year for the past release component dose in West Area WMAs) and at calendar year 8191 (the peak year for the residuals component dose).

Figure 6-22. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row U-107 with Driving Contaminant Contributions

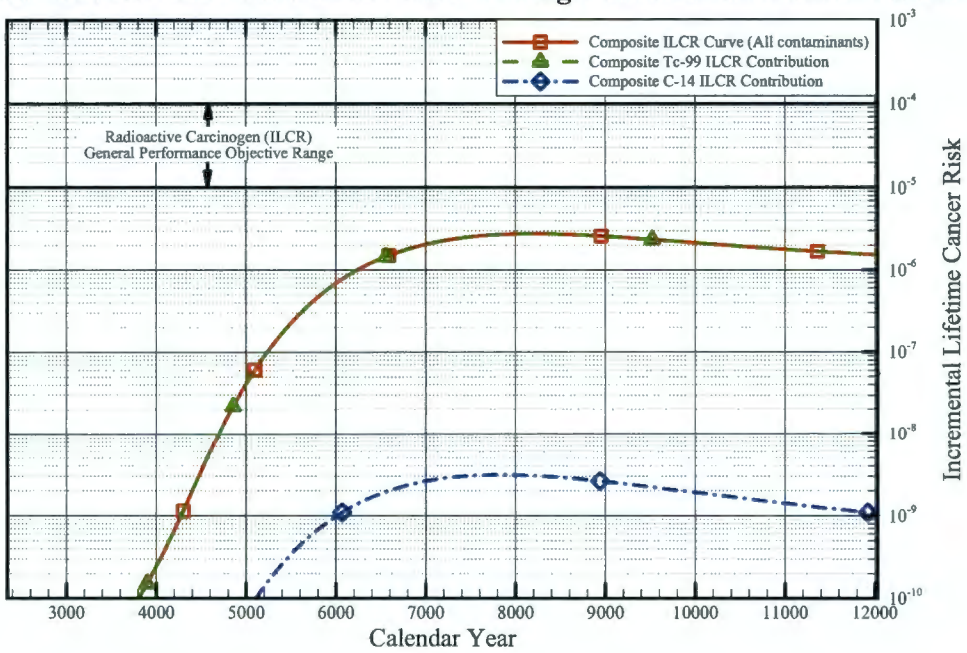


Table 6-37. Fractional Contributions to Composite Incremental Lifetime Cancer Risk by Selected Contaminants in Tank Row U-107

Industrial Scenario (Reference Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8191**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR**
Technetium-99	NA	NA	2.77E-06	99.89%
Carbon-14	NA	NA	3.06E-09	0.11%
Total	NA	NA	2.77E-06	100%
Residential Scenario (Alternative Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8191**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR**
Technetium-99	NA	NA	**6.75E-05**	99.97%
Carbon-14	NA	NA	2.21E-08	0.03%
Total	NA	NA	**6.75E-05**	100%

Bold indicates the performance objective is exceeded.
NA = not applicable

6.3.5.3 Chemical Cancer Risk at Waste Management Area U

Two scenarios from the Washington State groundwater cleanup regulations (Method C and Method B from WAC 173-340) were used to assess reference case impacts from nonradiological carcinogenic chemicals (Section 1.9). Of the nonradiological chemicals for which tank waste inventories are currently reported in the BBI, the following five are classified as carcinogenic:

- Arsenic
- Hexavalent chromium
- Cobalt
- Beryllium
- Cadmium

All five are classified as carcinogenic via inhalation but only one, arsenic, is also classified as carcinogenic via ingestion. Because both of the WAC 173-340 groundwater scenarios are based solely on drinking water ingestion, arsenic was the only chemical considered in calculating the chemical ILCR. Arsenic has extremely low near-field (i.e., vadose zone) mobility and was assigned a K_d of 39 mL/g (Spitz and Moreno 1996) for the contaminant fate and transport modeling (Chapter 3.0). Results of that modeling for WMA U (Section 4.5) indicated that arsenic would not reach groundwater at the fenceline within the 10,000-year simulation period. Thus, the calculated chemical ILCR for WMA U was zero.

It is possible that more carcinogenic chemicals are present in tank waste than are currently reported in the BBI. Inventory data for additional chemicals, potentially including carcinogenic chemicals not analyzed in this SST PA (e.g., organic chemicals), will be generated following waste retrieval through post-retrieval sample analysis. As additional inventory information becomes available, the data will be evaluated under the integrated regulatory closure process described in Chapter 1.0.

6.3.5.4 Non-Carcinogenic Chemical Hazard Index at Waste Management Area U

Tables 6-38 and 6-39 show the estimated peak non-carcinogenic chemical HI by source component for each tank row in WMA U for the WAC 173-340 Method B and Method C exposure scenarios, respectively. For the reference residential land use case, the composite non-carcinogenic chemical HI approaches the performance objective in several tank rows but does not exceeds it in any tank row in WMA U (Table 6-38). The tank row projected to provide the greatest composite non-carcinogenic chemical HI is tank row U-107. In that tank row, the peak HI is below the performance objective by a little more than a factor of 4 and is driven by the residual waste component. Tank rows including the past releases component have peak HI below the performance objective, using the WAC 173-340 Method B exposure scenario.

For the alternative industrial land use case, the composite HI does not exceed the performance objective (HI = 1) in any tank row (Table 6-39). The tank row with the highest HI is U-107. The peak HI for that tank row is below the performance objective by two orders of magnitude and is driven by the residual waste component, since there are no past releases in tank row U-107. In tank rows that include the past releases component, the peak HI from past releases is two or more orders of magnitude below the performance objective, using the WAC 173-340 Method C exposure scenario.

Estimated HI from each tank row is below the performance objective of 1 at the WMA fenceline.

Chromium, nitrate, and nitrite are the major contributors to the chemical HI.

Table 6-38. Estimated Hazard Index for Reference Case: WAC 173-340 Method B Exposure Scenario by Tank Row in Waste Management Area U [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
U-101	1.95E-01	8201	84.05%	7.83E-02	2332	60.23%	1.95E-01	8201	84.05%
U-104	1.61E-01	8201	69.40%	4.91E-02	2332	37.77%	1.61E-01	8201	69.40%
U-107	2.32E-01	8201	100.00%	NA	NA	NA	2.32E-01	8201	100.00%
U-110	1.36E-01	8201	58.62%	1.30E-01	2332	100.00%	1.36E-01	8201	58.62%
UR vault [b]	1.60E-02	2332	6.90%	1.69E-03	2332	1.30%	1.43E-02	2332	6.16%

[a] Shading indicates maximum row all components peak HI.
[b] Tank row UR vault contains plugged and blocked pipelines inventory.
NA = not applicable

Table 6-39. Estimated Hazard Index for Alternative Case: WAC 173-340 Method C Exposure Scenario by Tank Row in Waste Management Area U [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
U-101	7.81E-02	8201	83.98%	3.26E-02	2332	59.82%	7.81E-02	8201	83.98%
U-104	6.48E-02	8201	69.68%	2.02E-02	2332	37.06%	6.48E-02	8201	69.68%
U-107	9.30E-02	8201	100.00%	NA	NA	NA	9.30E-02	8201	100.00%
U-110	5.47E-02	8201	58.82%	5.45E-02	2332	100.00%	5.47E-02	8201	58.82%
UR vault [b]	6.74E-03	2332	7.25%	6.92E-04	2332	1.27%	6.05E-03	2332	6.51%

[a] Shading indicates maximum row all components peak HI.
[b] Tank row UR vault contains plugged and blocked pipelines inventory.
NA = not applicable

Figure 6-23 shows temporal variations in non-carcinogenic chemical HI from tank row U-107 for the reference land use case. As with the all-pathways dose (Section 6.3.5.1) and radiological ILCR (Section 6.3.5.2), the tank residual component and composite HI curves are identical as there is no past release component in tank row U-107.

Figure 6-24 and Table 6-40 show the relative contaminant contributions to non-carcinogenic chemical HI from tank row U-107. Under the WAC 173-340 Method B exposure scenario, hexavalent chromium is the dominant contributor to the composite HI during the simulation period, nitrite contributes a little more than 1% of the total composite HI at the peak year 8201, while nitrate and fluoride together comprise less than 1% of the total composite HI at the peak year 8201. These contaminant contribution ratios are approximately the same under the WAC 173-340 Method C exposure scenario as well (Table 6-40). In Table 6-40, results are

presented for the composite HI at calendar year 2332 (the typical peak year for the past release component HI in the 200 West Area WMAs) and at calendar year 8201 (the peak year for the residuals component HI).

Figure 6-23. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row U-107

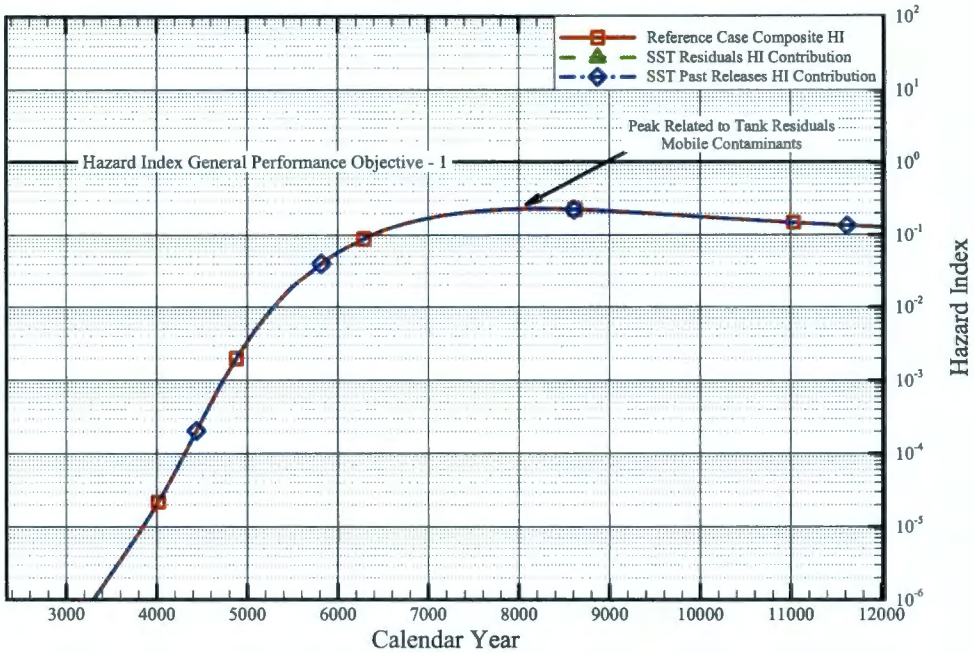


Figure 6-24. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row U-107 with Driving Contaminant Contributions

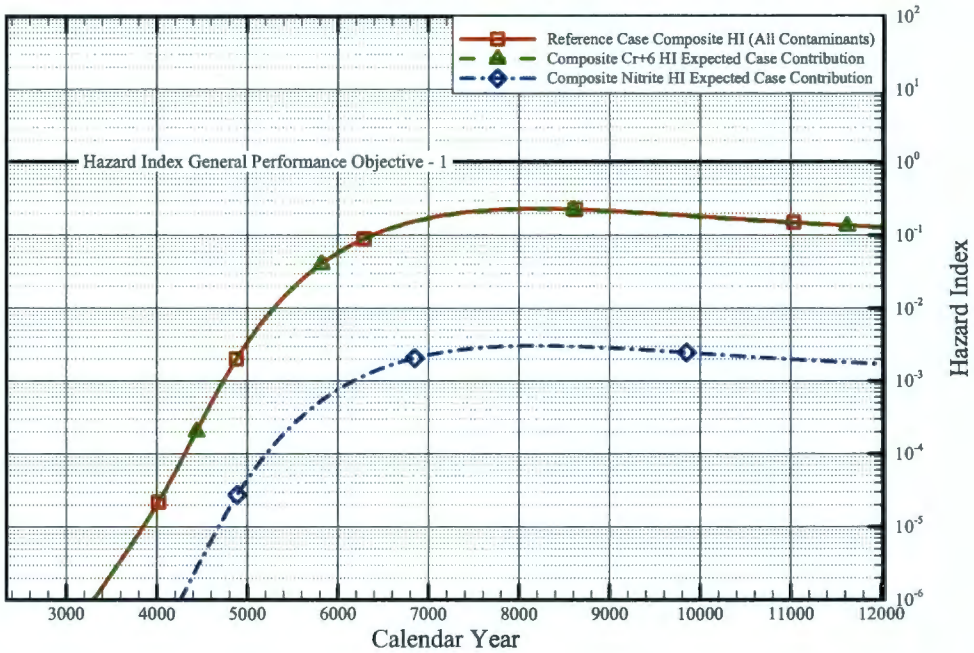


Table 6-40. Fractional Contributions to Composite Hazard Index by Selected Contaminants in Tank Row U-107

WAC 173-340 Method B (Reference Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8201**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI**
Chromium	NA	NA	2.27E-01	98.02%
Nitrite	NA	NA	3.05E-03	1.32%
Nitrate	NA	NA	1.20E-03	0.52%
Fluoride	NA	NA	3.51E-04	0.15%
Other	NA	NA	3.27E-09	<0.01%
Total	NA	NA	2.32E-01	100%
WAC 173-340 Method C (Alternative Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 8201**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI**
Chromium	NA	NA	9.09E-02	97.74%
Nitrite	NA	NA	1.40E-03	1.50%
Nitrate	NA	NA	5.48E-04	0.59%
Fluoride	NA	NA	1.61E-04	0.17%
Other	NA	NA	1.31E-09	<0.01%
Total	NA	NA	9.30E-02	100%

NA = not applicable

6.3.6 Groundwater Human Health Risk at Waste Management Area C

Table 6-41 compares the estimated impacts for WMA C to the performance objectives for protecting the general public. The values shown are the peak values for the composite source term (i.e., sum of contributions from past releases and residual waste source components) from the tank row with the highest value. The peak values for each metric occur about 3300 yr after assumed loss of institutional controls (year 2332) and in each case are from tank row CR vault. As provided in Section 4.6, the inventories associated with the three UPRs in the CR vault row are the main contributors. For the reference land use case, the estimated HI (Method B) is below the performance objective by one order of magnitude, while the radiological ILCR (industrial) is below the Washington State standard of 10^{-5} and the federal standard of 10^{-4}. For the alternative land use case, the estimated all-pathways dose and HI (Method C) is below their respective performance objectives, while the radiological ILCR (residential) is a factor of 5 above the Washington State standard of 10^{-5} but below the federal standard of 10^{-4}. The chemical ILCR for both reference (Method B) and alternative (Method C) land use cases is 0 (see Section 6.3.6.3 for additional information on chemical ILCR using Methods B and C). Each metric is discussed individually in the following sections.

Table 6-41. Comparison of Estimated Reference Case Impacts for Waste Management Area C with Performance Objectives for Protecting the General Public

Performance Measure		Performance Objective	Peak Value [a]	Peak Year	Tank Row
All-pathways dose (mrem/yr)		15	3.09E-01	5651	CR vault
ILCR (radiological)	Industrial	10^{-4} to 10^{-5}	2.27E-06	5691	CR vault
	Residential	10^{-4} to 10^{-5}	**5.46E-05**	5701	CR vault
ILCR (chemical carcinogen)	WAC 173-340 Method B	10^{-5}	0 [b]	NA	NA
	WAC 173-340 Method C	10^{-5}	0 [b]	NA	NA
HI (chemical non-carcinogen)	WAC 173-340 Method B	1	1.32E-01	5711	CR vault
	WAC 173-340 Method C	1	5.66E-02	5711	CR vault

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Calculated in groundwater at the WMA C fenceline. Values shown are the maximum projected values over the first 10,000 years after closure.

[b] See Section 6.3.6.3 for additional information on chemical ILCR.

NA = not applicable

6.3.6.1 All-Pathways Dose at Waste Management Area C

Table 6-42 shows the estimated peak all-pathways dose by source component for each tank row in WMA C. The composite dose does not exceed the performance objective (15 mrem/yr) in any tank row and is significantly below the performance objective for all tank rows. The tank row with the highest dose is CR vault. The peak dose from that tank row is below the performance objective by a factor of approximately 49 and is driven by the past releases component. Peak doses from the residual waste component are below the performance objective by at least four orders of magnitude in all five tank rows.

Estimated all-pathways farmer dose is below the performance objective of 15 mrem/yr at the WMA fenceline.

Technetium-99, carbon-14, and iodine-129 are the major contributors to the all-pathways farmer dose from past releases.

Technetium-99 and carbon-14 are the major contributors to the all-pathways farmer dose from tank residuals.

Table 6-42 shows the peak all-pathways farmer dose from all components occurs at approximately year 10430 for tank row C-103. The estimated all-pathways farmer dose for tank row C-103 is dominated by the residual waste mobile contaminants (predominantly technetium-99 = 1.5 Ci). Tank row C-103 is assumed to include the contribution from pipelines. The technetium inventory in the WMA C pipelines is significantly smaller (3.6×10^{-5} Ci) than in the other grouted residual waste; and therefore, does not contribute appreciably to the all-pathways dose from all components. Table 6-42 shows the peak all-pathways dose from all components peaks at year 2332 for tank rows C-101, C-102, and C-201. These tank rows have

associated past releases with technetium-99 inventories larger than the technetium-99 inventories associated with the residual wastes in each tank row (Appendix C). Finally, the CR vault tank row peak all-pathways farmer dose from all source components occurs at approximately year 5650 and is attributed to technetium-99 inventory (6.4 Ci) in the UPRs assigned to this tank row. The contribution to the all-pathways farmer dose from the residual waste in the CR vault tank row is small (0.046 Ci) relative to the UPR inventory.

Table 6-42. Estimated Peak All-Pathways Dose by Tank Row in Waste Management Area C [a]

All-Pathways Dose Performance Objective: 15 mrem/yr									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row
C-101	2.28E-02	2332	7.38%	2.28E-02	2332	7.38%	4.43E-03	10431	42.19%
C-102	3.24E-02	2332	10.49%	3.24E-02	2332	10.49%	4.38E-03	10441	41.71%
C-103 [b]	1.05E-02	10431	3.40%	NA	NA	NA	1.05E-02	10431	100.00%
C-201	3.07E-03	2332	0.99%	3.07E-03	2332	0.99%	2.32E-04	10411	2.21%
CR vault	3.09E-01	5651	100.00%	3.09E-01	5651	100.00%	3.30E-04	10441	3.14%

[a] Shading indicates maximum row all components all-pathways dose.
[b] Tank row C-103 contains plugged and blocked pipelines inventory.
NA = not applicable

Figure 6-25 shows temporal variations in all-pathways dose from tank row CR vault. The dominance of the past releases component is revealed by the overlap of the composite and past releases curves. The two curves are virtually indistinguishable over the entire assessment period. Residual wastes never make more than minor contribution to the composite dose. Even late in the assessment period, doses are dominated by mobile contaminants from past releases with mobile contaminants from residual wastes making only a minor contribution.

Figure 6-26 and Table 6-43 show the relative contaminant contributions to all-pathways dose from tank row CR vault and further illustrate the dominance of the past releases component. Technetium-99 from past releases dominates the composite dose at the time of peak (year 5651) and remains dominant through the assessment period. At the time of peak from residual waste (year 10441), technetium-99 from past releases contributes over 94% of the composite dose, whereas iodine-129 from past releases contributes only 0.55% (Table 6-43). In Table 6-43, results are presented for the composite all-pathways dose at calendar year 5651 (the peak year for the past releases component dose) and at calendar year 10441 (the peak year for the residuals component dose).

Figure 6-25. All-Pathways Dose for Tank Row CR Vault

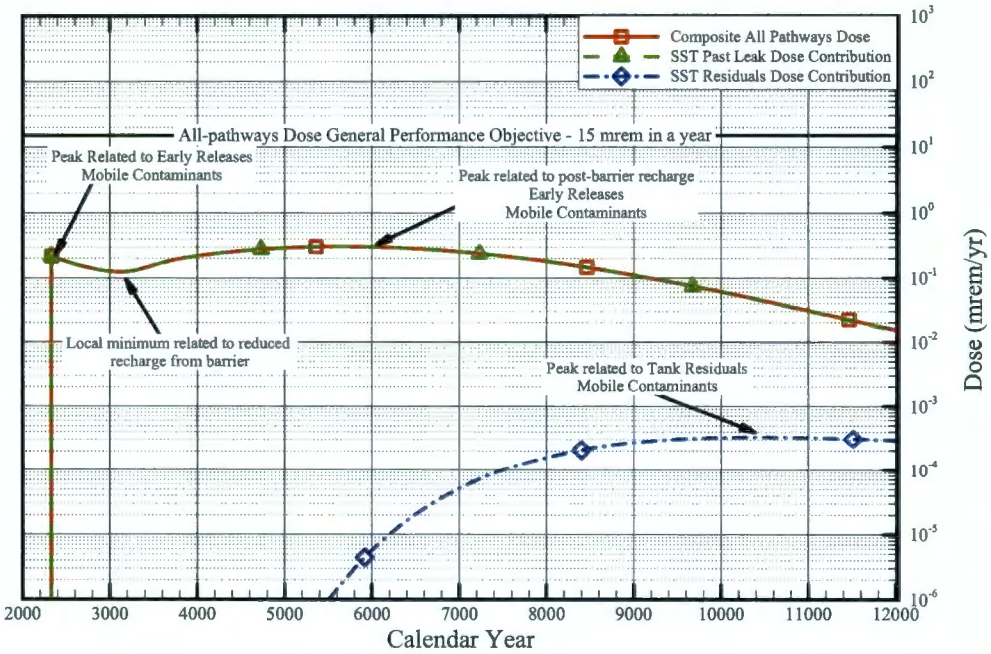


Figure 6-26. All-Pathways Dose for Tank Row CR Vault with Driving Contaminant Contributions

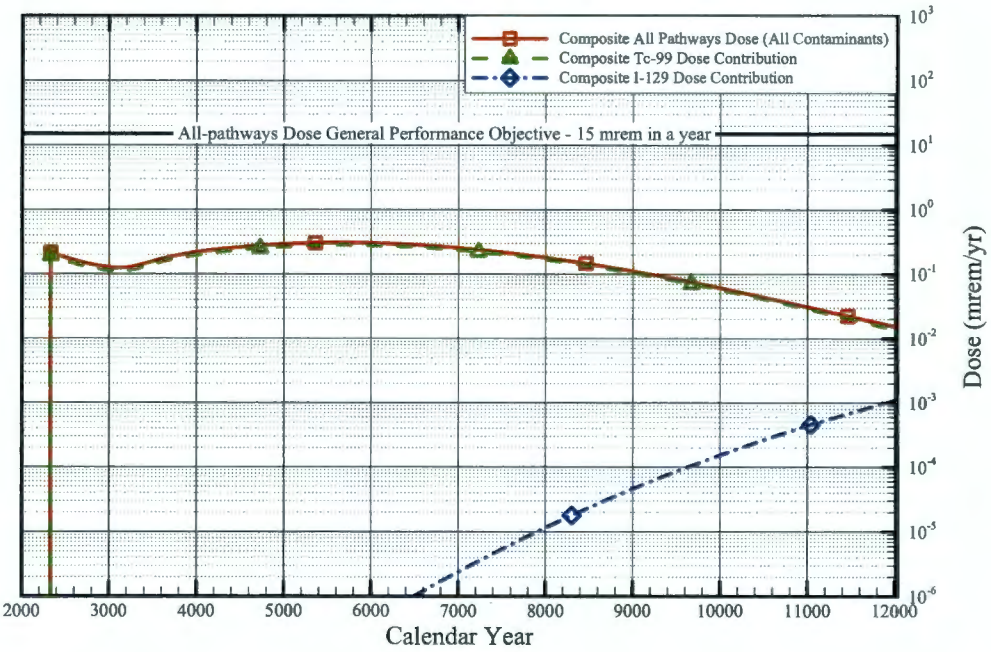


Table 6-43. Fractional Contributions to Composite All-Pathways Dose by Selected Contaminants in Tank Row CR Vault, Reference Case

Contaminant	Calendar Year: 5651		Calendar Year: 10441	
	Dose mrem/yr	Contribution to Total Dose	Dose mrem/yr	Contribution to Total Dose [a]
Technetium-99	2.83E-01	91.84%	4.30E-02	94.68%
Carbon-14	2.52E-02	8.16%	2.17E-03	4.77%
Iodine-129	2.12E-07	<0.01%	2.49E-04	0.55%
Other	0.00E+00	<0.01%	0.00E+00	<0.01%
Total	3.09E-01	100%	4.54E-02	100%

[a] Iodine-129 originated from past release sources. Technetium-99 and carbon-14 originated from predominantly past release sources.

6.3.6.2 Radiological Cancer Risk at Waste Management Area C

Tables 6-44 and 6-45 show the estimated peak radiological ILCR by source component for each tank row in WMA C for the reference case (industrial scenario) and alternative land use case (residential scenario), respectively. For the reference land use case, the composite radiological ILCR does not exceed the performance objective in any tank row (Table 6-44). The peak ILCR for that tank row is driven by the past releases component over the entire period of assessment. Under the industrial exposure scenario, the peak ILCR from the residual waste component is below the Washington State standard (10^{-5}) by at least three orders of magnitude in all five tank rows.

For the alternative land use case, the peak composite radiological ILCR in tank row CR vault exceeds the Washington State standard (10^{-5}), but is less than the federal standard (10^{-4}) (Table 6-45). The peak ILCR for that tank row is driven by the past releases component. Peak composite radiological ILCR values for the other four rows are below both Washington State and federal standards. Under the residential exposure scenario, the peak ILCR from the residual waste component is below the Washington State standard (10^{-5}) in all tank rows by one order of magnitude.

Estimated ILCR from each tank row is below the performance objective of 10^{-5} at the WMA fenceline for the reference exposure scenario.

Technetium-99 is the major contributor to the peak ILCR.

Note that the peak radiological ILCR for the residual waste component in tank row CR vault occurs slightly earlier for the industrial scenario (year10451) than the residential scenario (year 10461) (Tables 6-44 and 6-45, respectively). This difference is caused primarily by differences in the radiological half-lives for technetium-99 and carbon-14, the top two contributors to the peak ILCR from residual waste. Technetium-99 drives the peak ILCR under both the industrial and residential scenarios; however, carbon-14 also makes a minor but important contribution. Both technetium-99 and carbon-14 are highly mobile (K_d = 0 mL/g); however, because of half-life differences (5,730 and 211,097 years for carbon-14 and technetium-99, respectively), carbon-14 inventory decreases relative to technetium-99 inventory

during the migration period such that their peak years of contamination and ILCR peak values diverge (year 9781 versus year 10461 for carbon-14 and technetium-99, respectively). When the contributions from these two contaminants are summed to generate a total residual waste ILCR curve, the peak for the industrial scenario occurs slightly earlier than the residential scenario, reflecting the influence of the earlier carbon-14 peak. For the residential scenario, however, the total ILCR peak coincides with the technetium-99 peak. This is because the increase in unit risk factors between the industrial and residential scenarios is greater for technetium-99 (factor of 24 increase) than for carbon-14 (factor of 7 increase), thus allowing the technetium-99 ILCR to overwhelm the effects of the earlier carbon-14 peak.

Table 6-44. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Reference Case: Industrial Exposure Scenario by Tank Row in Waste Management Area C [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
C-101	1.65E-07	2332	7.27%	1.65E-07	2332	7.27%	3.42E-08	10451	42.12%
C-102	1.95E-07	2332	8.59%	1.95E-07	2332	8.59%	3.40E-08	10451	41.87%
C-103 [b]	8.12E-08	10451	3.58%	NA	NA	NA	8.12E-08	10451	100.00%
C-201	2.29E-08	2332	1.01%	2.29E-08	2332	1.01%	1.74E-09	10451	2.14%
CR vault	2.27E-06	5691	100.00%	2.27E-06	5691	100.00%	2.54E-09	10451	3.13%

[a] Shading indicates maximum row all components peak ILCR.

[b] Tank row C-103 contains plugged and blocked pipelines inventory.

NA = not applicable

Table 6-45. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Alternative Case: Residential Exposure Scenario by Tank Row in Waste Management Area C [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
C-101	3.95E-06	2332	7.23%	3.95E-06	2332	7.23%	8.29E-07	10461	42.08%
C-102	4.50E-06	2332	8.24%	4.50E-06	2332	8.24%	8.26E-07	10461	41.93%
C-103 [b]	1.97E-06	10451	3.61%	NA	NA	NA	1.97E-06	10451	100.00%
C-201	5.51E-07	2332	1.01%	5.51E-07	2332	1.01%	4.21E-08	10451	2.14%
CR vault	**5.46E-05**	5701	100.00%	**5.46E-05**	5701	100.00%	6.18E-08	10461	3.14%

Bold indicates the performance objective is exceeded.

[a] Shading indicates maximum row all components peak ILCR.

[b] Tank row C-103 contains plugged and blocked pipelines inventory.

NA = not applicable

Figure 6-27 shows temporal variations in radionuclide ILCR from tank row CR vault for the reference land use case. As noted for the all-pathways dose (Section 6.3.6.1), the dominance of the past releases component is revealed by the overlap of the composite and past releases curves. Here again, the two curves are virtually indistinguishable, with the residual waste component making no more than a minor contribution to the composite ILCR at any point in the assessment period. As with the all-pathways dose, composite ILCR values late in the assessment period are dominated by mobile contaminants from past releases.

Figure 6-27. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row CR Vault

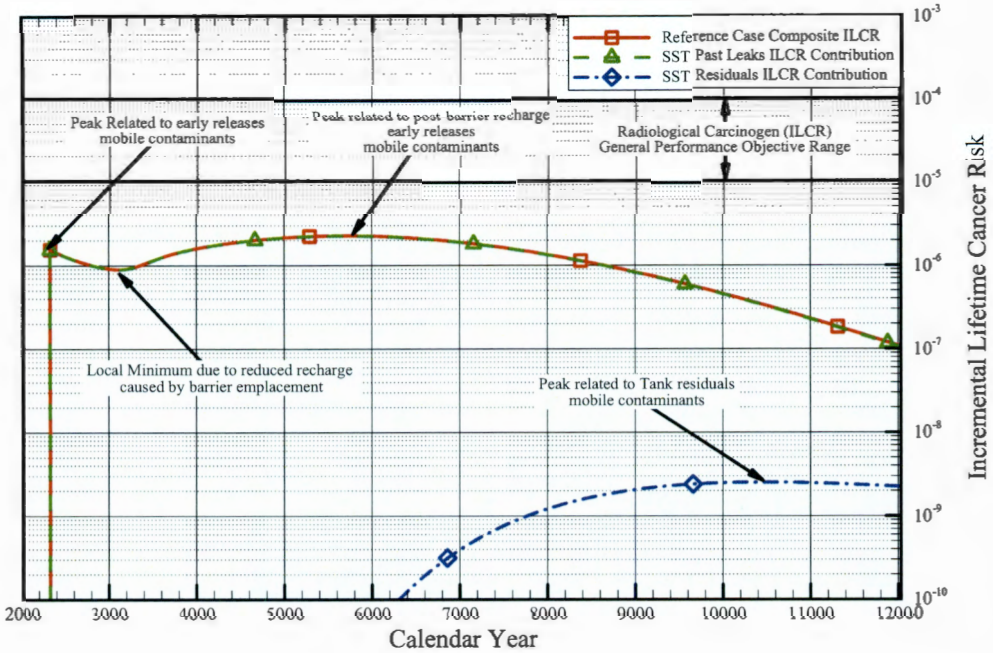


Figure 6-28 and Table 6-46 show the relative contaminant contributions to radiological ILCR from tank row CR vault. As noted for the all-pathways dose (Section 6.3.2.1), this information further illustrates the dominance of the past releases component. Technetium-99 from past releases dominates the composite ILCR at the time of peak (year 5691) and remains dominant through the assessment period. Under the industrial exposure scenario, technetium-99 from past releases contributes over 98% of the composite ILCR at the time of peak from residual waste (year 10451), whereas iodine-129 from past releases contributes about 0.1% (Table 6-46). Under the residential exposure scenario, the relative contribution from technetium-99 at the time of peak (year 6701) is greater than for the industrial scenario because of the additional exposure pathways (e.g., garden vegetables) included in this scenario (Table 6-46). In Table 6-46, results are presented for the composite ILCR at calendar year 5691 or 5701 (the peak years for the past releases industrial and residential components ILCR, respectively) and at calendar years 10451 or 10461 (the peak years for the tank residuals component industrial and residential ILCR, respectively).

Figure 6-28. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row CR Vault with Driving Contaminant Contributions

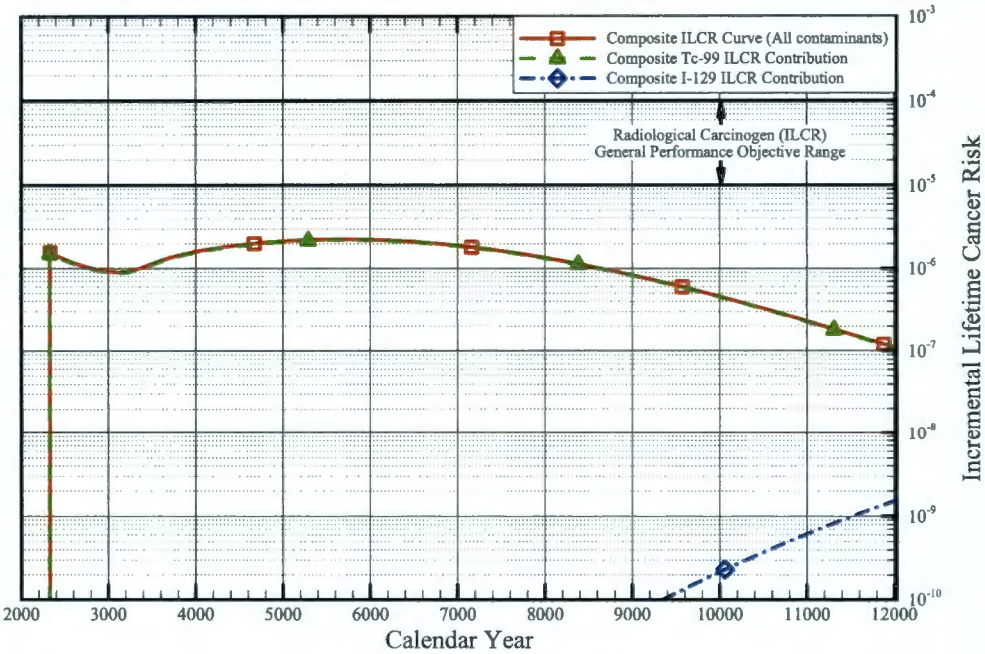


Table 6-46. Fractional Contributions to Composite Incremental Lifetime Cancer Risk by Selected Contaminants in Tank Row CR Vault

Industrial Scenario (Reference Case)				
Contaminant	**Calendar Year: 5691**		**Calendar Year: 10451**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	2.23E-06	98.23%	3.36E-07	98.88%
Carbon-14	4.02E-08	1.77%	3.45E-09	1.01%
Iodine-129	3.23E-13	<0.01%	3.55E-10	0.10%
Other [b]	0.00E+00	<0.01%	0.00E+00	<0.01%
Total	2.27E-06	100%	3.40E-07	100%
Residential Scenario (Alternative Case)				
Contaminant	**Calendar Year: 5701**		**Calendar Year: 10461**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	**5.43E-05**	99.47%	8.13E-06	99.67%
Carbon-14	2.90E-07	0.53%	2.47E-08	0.30%
Iodine-129	1.70E-12	<0.01%	1.86E-09	0.02%
Other [c]	0.00E+00	<0.01%	0.00E+00	<0.01%
Total	**5.46E-05**	100.00%	8.16E-06	100.00%

Bold indicates the performance objective is exceeded.

[a] Iodine-129 originated from past release sources. Technetium-99 and carbon-14 originated from predominantly past release sources.

[b] No additional contaminants are projected to contribute to the total ILCR at year 5691 or year 10451.

[c] No additional contaminants are projected to contribute to the total ILCR at year 5701 or year 10461.

6.3.6.3 Chemical Cancer Risk at Waste Management Area C

Two scenarios from the Washington State groundwater cleanup regulations (Method C and Method B from WAC 173-340) were used to assess reference case impacts from nonradiological carcinogenic chemicals (Section 1.9). Of the nonradiological chemicals for which tank waste inventories are currently reported in the BBI, the following five are classified as carcinogenic:

- Arsenic
- Hexavalent chromium
- Cobalt
- Beryllium
- Cadmium

All five are classified as carcinogenic via inhalation but only one, arsenic, is also classified as carcinogenic via ingestion. Because both of the WAC 173-340 groundwater scenarios are based solely on drinking water ingestion, arsenic was the only chemical considered in calculating the chemical ILCR. Arsenic has extremely low near-field (i.e., vadose zone) mobility and was assigned a K_d of 39 mL/g (Spitz and Moreno 1996) for the contaminant fate and transport modeling (Chapter 3.0). Results of that modeling for WMA C (Section 4.6) indicated that arsenic would not reach groundwater at the fenceline within the 10,000-year simulation period. Thus, the calculated chemical ILCR for WMA C was zero.

It is possible that more carcinogenic chemicals are present in tank waste than are currently reported in the BBI. Inventory data for additional chemicals, potentially including carcinogenic chemicals not analyzed in this SST PA (e.g., organic chemicals), will be generated following waste retrieval through post-retrieval sample analysis. As additional inventory information becomes available, the data will be evaluated under the integrated regulatory closure process described in Chapter 1.0.

6.3.6.4 Non-Carcinogenic Chemical Hazard Index at Waste Management Area C

Tables 6-47 and 6-48 show the estimated peak non-carcinogenic chemical HI by source component for each tank row in WMA C for the WAC 173-340 Method B and Method C exposure scenarios, respectively. For the reference land use case, the composite non-carcinogenic chemical HI (Method B) is below the performance objective in all five tank rows (Table 6-47). Under the WAC 173-340 Method B exposure scenario, the peak HI from the residual waste component is below the performance objective by approximately two or more orders magnitude in all five tank rows.

For the alternative land use case, the composite HI (Method C) does not exceed the performance objective (HI = 1) in any tank row (Table 6-48). The tank row with the highest HI is CR vault. The peak HI for that tank row is below the performance objective by a factor of 2 and is driven by the past releases component. Under the WAC 173-340 Method C exposure scenario, the peak HI from the residual waste component is below the performance objective by approximately three or more orders of magnitude in all five tank rows.

Figure 6-29 shows temporal variations in non-carcinogenic chemical HI from tank row CR vault for the reference land use case. The component contributions for this metric are the same as from those for the all-pathways dose (Section 6.3.6.1) and radiological ILCR (Section 6.3.6.2). For the latter two metrics, the past releases component dominates the cumulative curve for the entire assessment period, owing largely to the inventory of mobile (K_d = 0.0 mL/g) technetium-99 in the past releases. As a result, the composite HI values are driven almost

entirely by the mobile (K_d = 0.0 mL/g) chemical species and the past releases component is dominant over the assessment period.

Estimated HI from each tank row is below the performance objective of 1 at the WMA fenceline.

Chromium, nitrate, and nitrite are the major contributors to the chemical HI.

Table 6-47. Estimated Hazard Index for Reference Case: WAC 173-340 Method B Exposure Scenario by Tank Row in Waste Management Area C [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
C-101	9.01E-03	2332	6.83%	9.01E-03	2332	6.83%	5.33E-03	10481	100.00%
C-102	2.52E-02	2332	19.09%	2.52E-02	2332	19.09%	2.56E-03	10481	48.03%
C-103 [b]	2.61E-03	10511	1.98%	NA	NA	NA	2.61E-03	10481	48.97%
C-201	6.14E-03	2332	4.65%	6.14E-03	2332	4.65%	4.73E-03	10481	88.74%
CR vault	1.32E-01	5711	100.00%	1.32E-01	5711	100.00%	2.56E-04	10481	4.80%

[a] Shading indicates maximum row all components peak HI.
[b] Tank row C-103 contains plugged and blocked pipelines inventory.
NA = not applicable

Table 6-48. Estimated Hazard Index for Alternative Case: WAC 173-340 Method C Exposure Scenario by Tank Row in Waste Management Area C [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
C-101	3.91E-03	2332	6.91%	3.91E-03	2332	6.91%	2.27E-03	10481	100.00%
C-102	1.11E-02	2332	19.61%	1.11E-02	2332	19.61%	1.07E-03	10481	47.14%
C-103 [b]	1.11E-03	10491	1.96%	NA	NA	NA	1.11E-03	10481	48.90%
C-201	2.63E-03	2332	4.65%	2.63E-03	2332	4.65%	1.91E-03	10481	84.14%
CR vault	5.66E-02	5711	100.00%	5.66E-02	5711	100.00%	1.07E-04	10481	4.71%

[a] Shading indicates maximum row all components peak HI.
[b] Tank row C-103 contains plugged and blocked pipelines inventory.
NA = not applicable

Figure 6-29. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row CR Vault

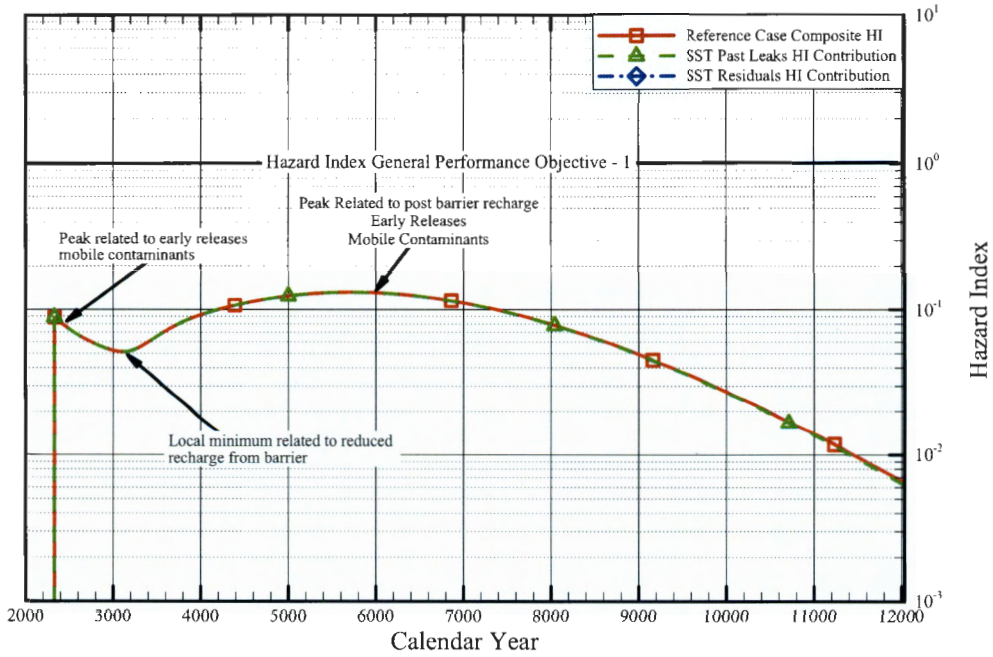


Figure 6-30 and Table 6-49 show the relative contaminant contributions to non-carcinogenic chemical HI from tank row CR vault. The combined contributions from hexavalent chromium and nitrite in past releases dominate the composite HI from the time of peak (year 5711) to the end of the assessment period (year 12032) (Figure 6-30). At the time of peak from residual wastes (year 10481), the combined contributions from hexavalent chromium, nitrite, and nitrate from the past release component contributes over 99% of the composite HI under both the WAC 173-340 Method B and Method C exposure scenarios (Table 6-49). In Table 6-49, results are presented for the composite HI at calendar year 5711 (the peak year for the past release component HI) and at calendar year 10481 (the peak year for tank residuals component HI).

Figure 6-30. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row CR Vault with Driving Contaminant Contributions

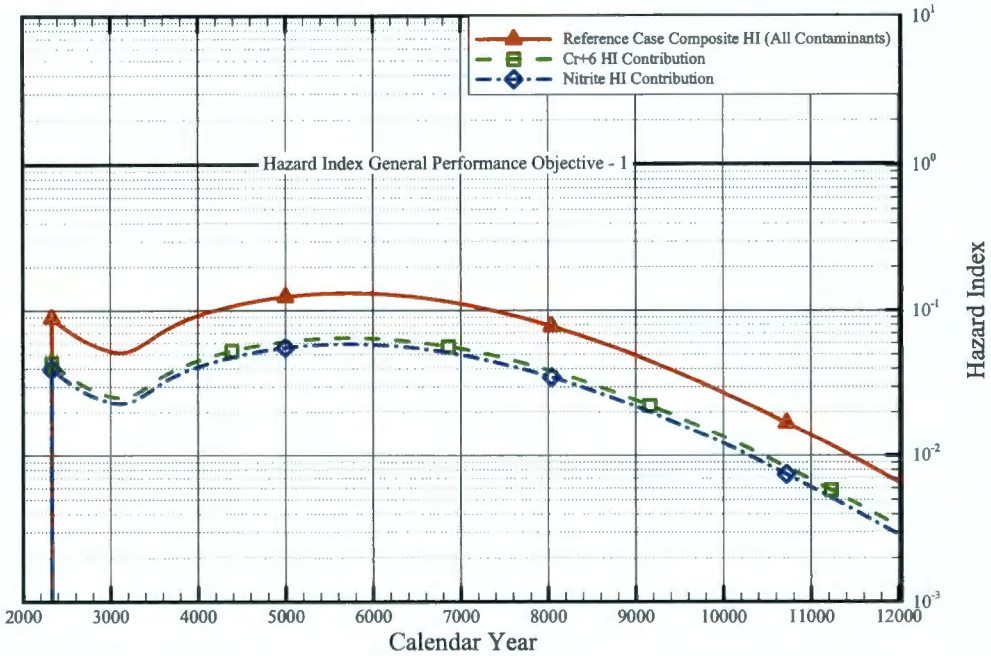


Table 6-49. Fractional Contributions to Composite Hazard Index by Selected Contaminants in Tank Row CR Vault

WAC 173-340 Method B (Reference Case)				
Contaminant	**Calendar Year: 5711**		**Calendar Year: 10481**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Nitrite	5.90E-02	44.68%	8.82E-03	44.34%
Chromium	6.51E-02	49.32%	9.87E-03	49.58%
Nitrate	7.88E-03	5.97%	1.18E-03	5.93%
Fluoride	3.24E-05	0.02%	3.12E-05	0.16%
Other	0.00E+00	<0.01%	3.98E-10	<0.01%
Total	1.32E-01	100%	1.99E-02	100%
WAC 173-340 Method C (Alternative Case)				
Contaminant	**Calendar Year: 5711**		**Calendar Year: 10481**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Nitrite	2.70E-02	47.62%	4.03E-03	47.27%
Chromium	2.60E-02	45.99%	3.95E-03	46.25%
Nitrate	3.60E-03	6.36%	5.40E-04	6.32%
Fluoride	1.48E-05	0.03%	1.43E-05	0.17%
Other	0.00E+00	<0.01%	1.59E-10	<0.01%
Total	5.66E-02	100%	8.54E-03	100%

[a] Chromium, nitrite, and nitrate originated from past releases.

6.3.7 Groundwater Human Health Risk at Waste Management Area B-BX-BY

Table 6-50 compares the estimated impacts for WMA B-BX-BY to the performance objectives for protecting the general public. The values shown are the peak values for the composite source term (i.e., sum of the contributions from past releases and residual waste source components) from the tank row with the highest value. The tank row with highest value for each metric is B-103. The peak values occur either at the very beginning or very end of the assessment period (i.e., at year 2332, the time of assumed loss of institution controls, or at year 12032, the end of the 10,000-year simulation). For the reference land use case, estimated values for both the radiological ILCR (industrial) and non-carcinogenic chemical HI (Method B) are below the performance objective by a small factor. For the alternative land use case, estimated values for the all-pathways dose and non-carcinogenic chemical HI (Method C) are below their performance objectives, while the radiological ILCR (residential) is above the Washington State standard (10^{-5}) but below the federal standard (10^{-4}). The chemical ILCR for both reference (Method B) and alternative (Method C) land use cases is 0 (see Section 6.3.7.3 for additional information on chemical ILCR using Methods B and C). Each metric is discussed individually in the following sections.

Table 6-50. Comparison of Estimated Reference Case Impacts for Waste Management Area B-BX-BY with Performance Objectives for Protecting the General Public

Performance Measure		Performance Objective	Peak Value [a]	Peak Year	Tank Row
All-pathways dose (mrem/yr)		15	5.43E-01	12032	B-103
ILCR (radiological)	Industrial	10^{-4} to 10^{-5}	2.96E-06	2332	B-103
	Residential	10^{-4} to 10^{-5}	**7.10E-05**	2332	B-103
ILCR (chemical carcinogen)	WAC 173-340 Method B	10^{-5}	0 [b]	NA	NA
	WAC 173-340 Method C	10^{-5}	0 [b]	NA	NA
HI (chemical non-carcinogen)	WAC 173-340 Method B	1	4.35E-01	12032	B-103
	WAC 173-340 Method C	1	1.98E-01	12032	B-103

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Calculated in groundwater at the WMA B-BX-BY fenceline. Values shown are the maximum projected values over 10,000 years starting from the end of institutional controls (assumed to occur 300 years after closure).

[b] See Section 6.3.7.3 for additional information on chemical ILCR.

NA = not applicable

6.3.7.1 All-Pathways Dose at Waste Management Area B-BX-BY

Table 6-51 shows the estimated peak all-pathways dose by source component for each tank row in WMA B-BX-BY. The composite dose does not exceed the performance objective (15 mrem/yr) in any tank row and is significantly below the performance objective for most tank rows. The tank row with the highest dose is tank row B-103. The peak dose from that tank row is below the performance objective by a factor of approximately 28 and is driven by the past releases component. Peak doses from the tank residuals component are below the performance objective by at least two orders of magnitude in all seven tank rows.

Estimated all-pathways farmer dose is below the performance objective of 15 mrem/yr at the WMA fenceline.

Technetium-99, carbon-14, iodine-129, and uranium-234/238 are the major contributors to the all-pathways farmer dose from past releases.

Technetium-99 and carbon-14 are the major contributors to the all-pathways farmer dose from tank residuals.

Table 6-51 shows the peak all-pathways farmer dose from all components occurs at approximately year 10400 for tank rows B-201, BY-101, BY-102, and BY-103. The peak all-pathways dose for these tank rows is associated with residual waste mobile contaminants. The residual waste technetium-99 inventory in each tank row is a factor of 10 greater than the technetium inventory associated with past releases for each tank row (Appendix C). Table 6-51 shows the peak all-pathways farmer dose from all components occurs at year 2332 from tank rows B-101 and B-102. Tank row B-101 has a technetium-99 inventory from past releases (3.8 Ci) that is higher than the residual waste technetium-99 inventory for that tank row. Therefore, the peak all-pathways farmer dose is from the past releases in that tank row. Tank row B-102 has a technetium-99 inventory from past releases (0.26 Ci) that is less than the residual waste technetium-99 inventory for that tank row (2.7 Ci). The slower release of grouted residual waste contaminants from the grouted residual waste and the assumption that the residual waste is not exposed to the operational recharge offset the higher technetium inventory in the tanks and results in the past release technetium-99 inventory dominating the all-pathways farmer dose for tank row B-102. Finally, the peak all-pathways farmer dose from all components occurs at year 12032 for tank row B-103. The peak at the end of the simulation period is attributed to the uranium in the past releases associated with this tank row. The uranium contribution dominates the all-pathways farmer dose for this tank row.

In tank rows where the all-pathways dose is dominated by the residual waste component (i.e., tank rows B-201, BY-101, BY-102, and BY-103), the composite all-pathways dose peak year is sometimes earlier than the calculated peak year that occurs when only the dose contributions from tank residual waste are considered. Usually, the composite dose peak year is the same as the peak year for the component that dominates. However, in these instances, the contributions to overall dose from the past releases component are sufficient to shift the composite dose peak to a slightly earlier time.

Figure 6-31 shows temporal variations in all-pathways dose from tank row B-103. The dominance of the past releases component is revealed by the overlap of the composite and past releases curves. The two curves lie on top of one another over most of the assessment period. Tank residuals never make more than a minor contribution to the composite dose. The composite curve exhibits two nearly co-equal maxima, one at the very beginning of the assessment period (year 2332) and another at the very end (year 12032). Both are driven by the past releases component. The composite dose at year 12032 slightly exceeds the dose at year 2332. The composite dose is driven by highly mobile contaminants in past releases at year 2332 and by less mobile contaminants in past releases at year 12032.

Table 6-51. Estimated Peak All-Pathways Dose by Tank Row in Waste Management Area B-BX-BY [a]

All-Pathways Dose Performance Objective: 15 mrem/yr									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row
B-101	1.94E-01	2332	35.73%	1.94E-01	2332	37.24%	2.92E-03	10431	2.52%
B-102	2.19E-02	2332	4.03%	2.19E-02	2332	4.20%	1.88E-02	10451	16.21%
B-103	5.43E-01	12032	100.00%	5.21E-01	12032	100.00%	2.44E-02	10441	21.03%
B-201 [b]	1.69E-03	10441	0.31%	3.28E-06	9631	0.00%	1.68E-03	10451	1.45%
BY-101	9.55E-02	10411 [c]	17.59%	8.62E-02	2332	16.55%	8.78E-02	10441	75.69%
BY-102	3.07E-02	10421 [c]	5.65%	2.84E-02	2332	5.45%	2.82E-02	10441	24.31%
BY-103	1.18E-01	10441	21.73%	2.86E-02	2332	5.49%	1.16E-01	10451	100.00%

[a] Shading indicates maximum row all components all-pathways dose.

[b] Tank row B-201 contains plugged and blocked pipelines inventory.

[c] The all components peak year and tank residuals component peak year do not match because the past releases component contribution is large enough to make the all components peak year occur earlier.

Figure 6-31. All-Pathways Dose for Tank Row B-103

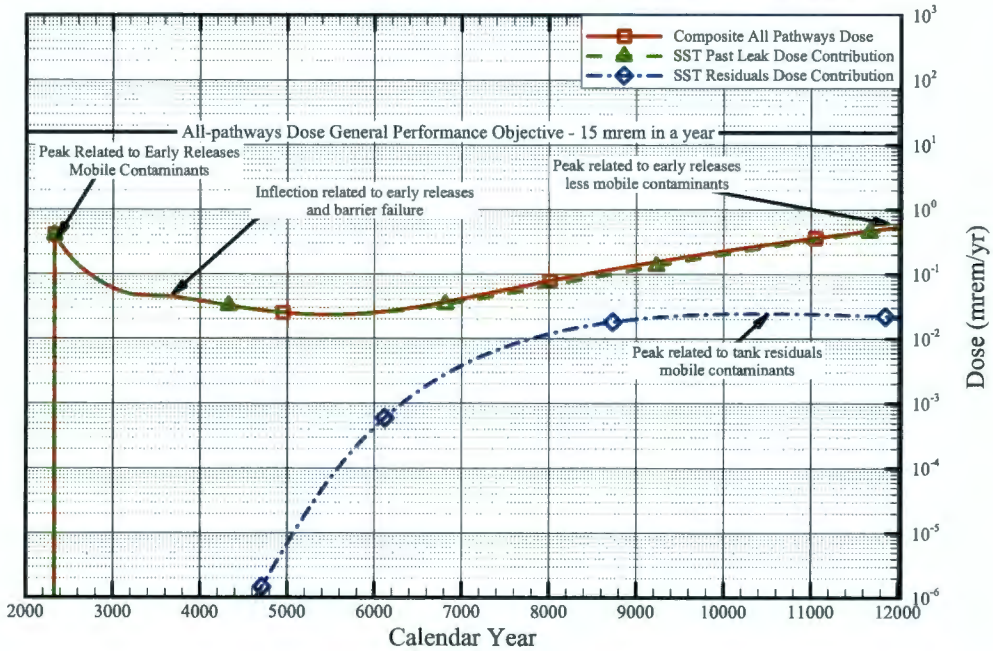


Figure 6-32 and Table 6-52 show the relative contaminant contributions to all-pathways dose from tank row B-103 and further illustrate the dominance of the past releases component. At year 2332, technetium-99 from past releases is responsible for virtually the entire composite dose. Technetium-99 from past releases remains dominant through approximately year 6000, when isotopic uranium takes over and drives the composite dose through the end of the assessment period (Figure 6-32). Two uranium isotopes (uranium-234, uranium-238) make

equal contributions over that time period and together dominate the composite dose at time of peak from both tank residuals (year 10481) and past releases (year 12032) (Table 6-52). In Table 6-52, results are presented for the composite all-pathways dose at calendar year 12032 (the peak year for the past releases component all-pathways dose) and at calendar year 10441 (the peak year for the tank residuals component all-pathways dose).

Figure 6-32. All-Pathways Dose for Tank Row B-103 with Driving Contaminant Contributions

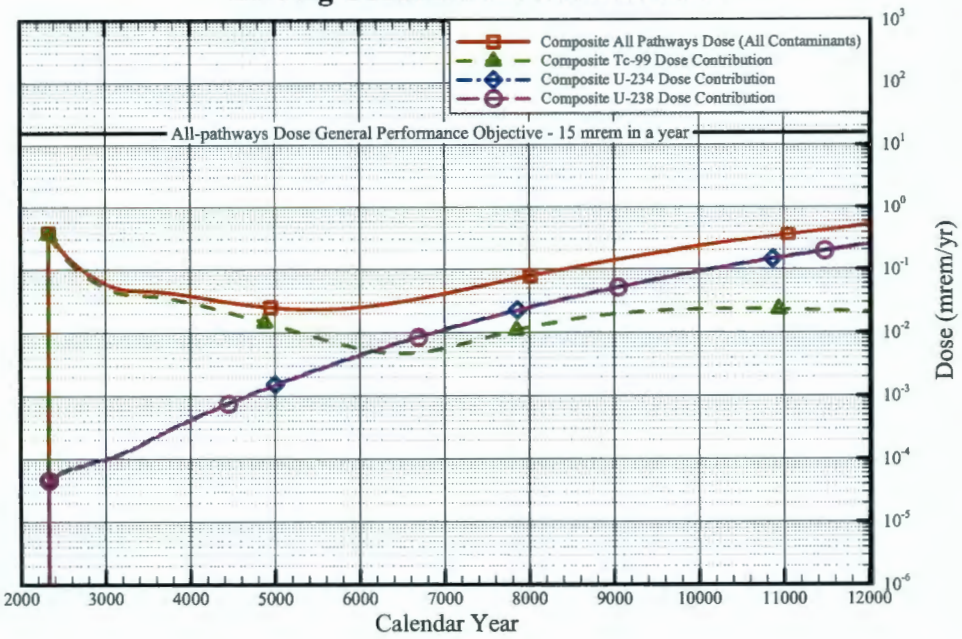


Table 6-52. Fractional Contributions to Composite All-Pathways Dose by Selected Contaminants in Tank Row B-103, Reference Case

Contaminant	Calendar Year : 12032		Calendar Year: 10441	
	Dose mrem/yr	Contribution to Total Dose	Dose mrem/yr	Contribution to Total Dose [a]
Uranium-234	2.49E-01	45.79%	1.18E-01	42.18%
Uranium-238	2.46E-01	45.36%	1.16E-01	41.60%
Technetium-99	2.13E-02	3.92%	2.40E-02	8.57%
Iodine-129	1.33E-02	2.46%	1.47E-02	5.25%
Uranium-235	1.10E-02	2.02%	5.18E-03	1.85%
Uranium-236	2.08E-03	0.38%	9.82E-04	0.35%
Carbon-14	3.85E-04	0.07%	5.25E-04	0.19%
Uranium-233	2.94E-05	0.01%	1.40E-05	<0.01%
Other	7.70E-06	<0.01%	2.24E-06	<0.01%
Total	5.43E-01	100%	2.80E-01	100%

[a] Iodine-129 and uranium originated from past release sources. Carbon-14 and technetium-99 originated from predominantly past release sources.

6.3.7.2 Radiological Cancer Risk at Waste Management Area B-BX-BY

Tables 6-53 and 6-54 show the estimated peak radiological ILCR by source component for each tank row in WMA B-BX-BY for the reference case (industrial scenario) and alternative land use case (residential scenario), respectively. For the reference land use case, the composite radiological ILCR does not exceed the performance objective in any tank row and is an order of magnitude or more below the Washington State standard (10^{-5}) in most tank rows (Table 6-53). The tank row with the highest ILCR is B-103. The peak ILCR from that tank row is below the Washington State standard (10^{-5}) by a factor of approximately 3 and is driven by the past releases component. Under the industrial exposure scenario, the peak ILCR from the tank residuals component is below the Washington State standard (10^{-5}) by a least an order of magnitude in all seven tank rows.

For the alternative land use case, the composite radiological ILCR exceeds the Washington State standard (10^{-5}) in four of the seven tank rows, but is below the federal standard (10^{-4}) (Table 6-54). The tank row with the highest ILCR is B-103. The peak ILCR for that tank row exceeds the Washington State standard (10^{-5}) by a factor of 7 and is driven by the past releases component. Under the residential exposure scenario, the peak ILCR from the tank residuals component approaches the Washington State standard (10^{-5}) in several tank rows and slightly exceeds that standard in two tank rows (BY-101, BY-103).

Estimated ILCR from each tank row is below the performance objective of 10^{-5} at the WMA fenceline for the reference exposure scenario.

Technetium-99 is the major contributor to the peak ILCR.

As noted for the all-pathways dose (Section 6.3.7.1), in tank rows where the radiological ILCR is dominated by the tank residuals component (i.e., tank rows B-201, BY-101, BY-102, and BY-103), the composite ILCR peak year sometimes differs from the tank residuals ILCR peak year (Tables 6-53 and 6-54). This occurs because the contributions to overall ILCR from the past releases component are sufficient to shift the composite ILCR peak to a slightly earlier time.

Note that the peak radiological ILCR for the tank residuals component occurs slightly earlier for the industrial scenario (Table 6-53) than the residential scenario (Table 6-54). This difference is caused primarily by differences in the radiological half-lives for technetium-99 and carbon-14, the top two contributors to the peak ILCR from tank residuals. Technetium-99 drives the peak ILCR under both the industrial and residential scenarios; however, carbon-14 also makes a minor but important contribution. Both technetium-99 and carbon-14 are highly mobile (K_d = 0 mL/g); however, because of half-life differences (5,730 and 211,097 years for carbon-14 and technetium-99, respectively), carbon-14 inventory decreases relative to technetium-99 inventory during the migration period such that their peak years of contamination and ILCR peak values diverge (year 9781 versus year 10461 for carbon-14 and technetium-99, respectively). When the contributions from these two contaminants are summed to generate a total residual waste ILCR curve, the peak for the industrial scenario occurs slightly earlier than the residential scenario, reflecting the influence of the earlier carbon-14 peak. For the residential scenario, however, the total ILCR peak coincides with the technetium-99 peak. This is because the increase in unit risk factors between the industrial and residential scenarios is greater for technetium-99

(factor of 24 increase) than for carbon-14 (factor of 7 increase), thus allowing the technetium-99 ILCR to offset the effects of the earlier carbon-14 peak.

Table 6-53. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Reference Case: Industrial Exposure Scenario by Tank Row in Waste Management Area B-BX-BY [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
B-101	1.29E-06	2332	43.58%	1.29E-06	2332	43.58%	2.24E-08	10451	2.48%
B-102	1.64E-07	2332	5.54%	1.64E-07	2332	5.54%	1.47E-07	10451	16.28%
B-103	2.96E-06	2332	100.00%	2.96E-06	2332	100.00%	1.89E-07	10451	20.93%
B-201 [b]	1.31E-08	10451	0.44%	4.63E-12	9631	0.00%	1.31E-08	10461	1.45%
BY-101	6.91E-07	10441 [c]	23.34%	6.04E-07	2332	20.41%	6.79E-07	10451	75.19%
BY-102	2.21E-07	10451	7.47%	2.00E-07	2332	6.76%	2.18E-07	10451	24.14%
BY-103	9.07E-07	10451	30.64%	2.01E-07	2332	6.79%	9.03E-07	10451	100.00%

[a] Shading indicates maximum row all components peak ILCR.

[b] Tank row B-201 contains plugged and blocked pipelines inventory.

[c] The all components peak year and tank residuals component peak year do not match because the past releases component contribution is large enough to make the all components peak year occur earlier.

Table 6-54. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Alternative Case: Residential Exposure Scenario by Tank Row in Waste Management Area B-BX-BY [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
B-101	**3.04E-05**	2332	42.82%	**3.04E-05**	2332	42.82%	5.42E-07	10451	2.46%
B-102	3.96E-06	2332	5.58%	3.96E-06	2332	5.58%	3.58E-06	10461	16.27%
B-103	**7.10E-05**	2332	100.00%	**7.10E-05**	2332	100.00%	4.58E-06	10461	20.82%
B-201 [b]	3.20E-07	10461	0.45%	2.40E-11	9631	0.00%	3.19E-07	10461	1.45%
BY-101	**1.66E-05**	10451 [c]	23.38%	1.44E-05	2332	20.28%	**1.65E-05**	10461	75.00%
BY-102	5.30E-06	10451	7.46%	4.76E-06	2332	6.70%	5.28E-06	10461	24.00%
BY-103	**2.20E-05**	10451	30.99%	4.78E-06	2332	6.73%	**2.20E-05**	10461	100.00%

Bold indicates the performance objective is exceeded.

[a] Shading indicates maximum row all components peak ILCR.

[b] Tank row B-201 contains plugged and blocked pipelines inventory.

[c] The all components peak year and tank residuals component peak year do not match because the past releases component contribution is large enough to make the all components peak year occur earlier.

Figure 6-33 shows temporal variations in radionuclide ILCR from tank row B-103 for the reference land use case. As noted for the all-pathways dose (Section 6.3.7.1), the dominance of the past releases component is revealed by the overlap of the composite and past releases curves. Past releases drive the composite ILCR over the entire assessment period; however, tank residuals make an important contribution from about year 7000 to year 10000 as revealed by the separation in the composite and past releases curves over that time span (Figure 6-33). Composite ILCR values toward the end of the assessment period are dominated by less mobile contaminants from past releases.

Figure 6-33. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row B-103

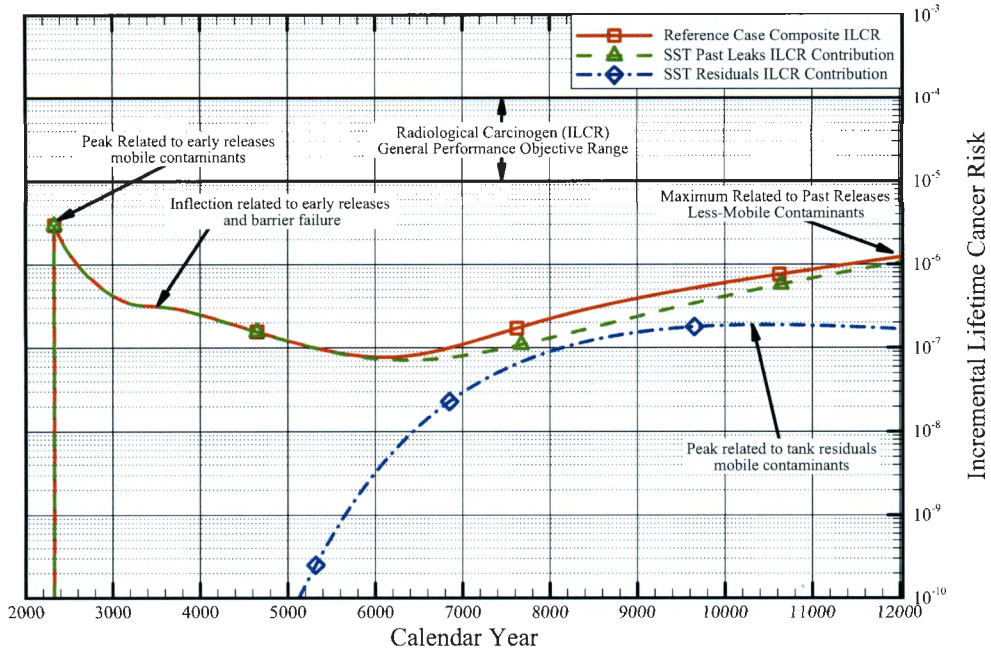


Figure 6-34 and Table 6-55 show the relative contaminant contributions to radiological ILCR from tank row B-103. Technetium-99 from past releases dominates the composite ILCR at the time of peak (year 2332) and remains dominant for several thousand years thereafter (Figure 6-34). From about year 7000 to year 10000, the composite ILCR is driven by the combined contributions of uranium isotopes (primarily uranium 238 and uranium-234) from past releases and technetium-99 from tank residuals. The contribution of technetium-99 from tank residuals declines toward the end of the assessment period and the composite ILCR is dominated by the uranium isotopes from past releases. Under the industrial exposure scenario, the composite ILCR at the time of peak from tank residuals (year 10451) is driven by the uranium isotopes from past releases with a significant contribution (approximately 26%) from technetium-99 in tank residuals (Table 6-55). Under the residential exposure scenario, the relative contribution of the technetium 99 from tank residuals increases to approximately 62% because of the additional exposure pathways (e.g., garden vegetables) included in that scenario (Table 6-55). In Table 6-55, results are presented for the composite ILCR at calendar year 2332 (the peak year for the past releases component ILCR) and at calendar years 10451 and 10461 (the peak years for the tank residuals component industrial and residential ILCR, respectively).

Figure 6-34. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row B-103 with Driving Contaminant Contributions

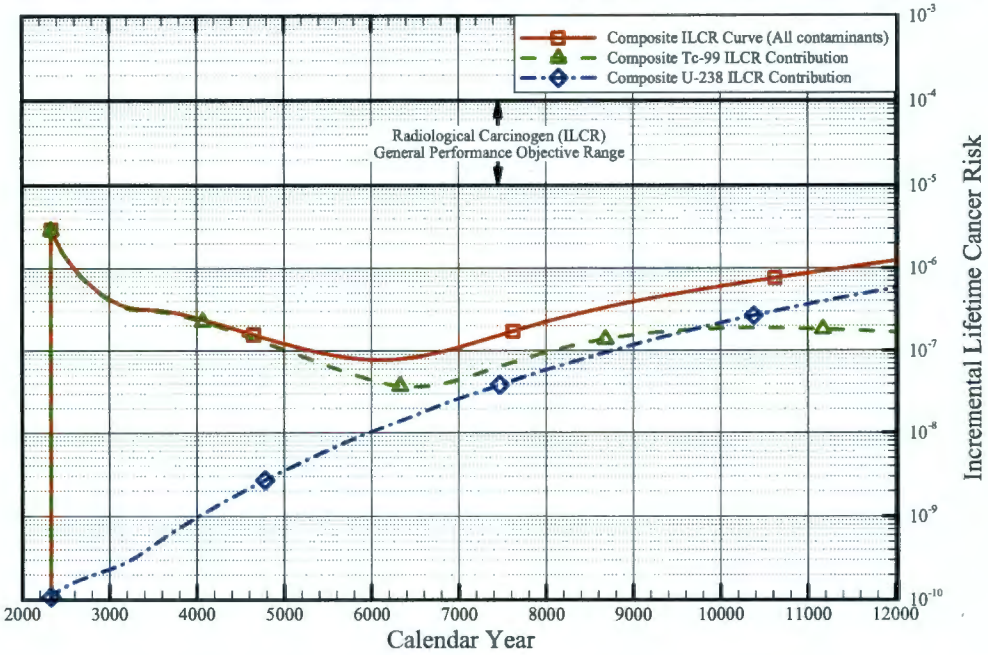


Table 6-55. Fractional Contributions to Composite Incremental Lifetime Cancer Risk by Selected Contaminants in Tank Row B-103 (2 pages)

Industrial Scenario (Reference Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 10451**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	2.90E-06	97.86%	1.89E-07	26.48%
Carbon-14	5.72E-08	1.93%	8.40E-10	0.12%
Iodine-129	6.05E-09	0.20%	2.08E-08	2.91%
Uranium-238	1.08E-10	<0.01%	2.77E-07	38.81%
Uranium-234	8.55E-11	<0.01%	2.13E-07	29.89%
Uranium-235	4.31E-12	<0.01%	1.10E-08	1.54%
Uranium-236	6.92E-13	<0.01%	1.77E-09	0.25%
Other	1.15E-14	<0.01%	5.90E-11	0.01%
Total	2.96E-06	100%	7.13E-07	100%

Table 6-55. Fractional Contributions to Composite Incremental Lifetime Cancer Risk by Selected Contaminants in Tank Row B-103 (2 pages)

Residential Scenario (Alternative Case)				
Contaminant	**Calendar Year: 2332**		**Calendar Year: 10461**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	**7.06E-05**	99.37%	4.60E-06	62.42%
Carbon-14	4.13E-07	0.58%	6.06E-09	0.08%
Iodine-129	3.13E-08	0.04%	1.07E-07	1.46%
Uranium-238	5.76E-10	<0.01%	1.48E-06	20.05%
Uranium-234	4.39E-10	<0.01%	1.10E-06	14.95%
Uranium-235	2.61E-11	<0.01%	6.69E-08	0.91%
Uranium-236	3.56E-12	<0.01%	9.12E-09	0.12%
Tin-126	0.00E+00	<0.01%	5.08E-10	0.01%
Other	5.85E-14	<0.01%	1.30E-10	<0.01%
Total	**7.10E-05**	100%	7.36E-06	100%

Bold indicates the performance objective is exceeded.

[a] Iodine-129 and uranium originated from past release sources. Carbon-14, technetium-99, and tin-126 originated from predominantly past release sources.

6.3.7.3 Chemical Cancer Risk at Waste Management Area B-BX-BY

Two scenarios from the Washington State groundwater cleanup regulations (Method C and Method B from WAC 173-340) were used to assess reference case impacts from nonradiological carcinogenic chemicals (Section 1.9). Of the nonradiological chemicals for which tank waste inventories are currently reported in the BBI, the following five are classified as carcinogenic:

- Arsenic
- Beryllium
- Hexavalent chromium
- Cadmium
- Cobalt

All five are classified as carcinogenic via inhalation but only one, arsenic, is also classified as carcinogenic via ingestion. Because both of the WAC 173-340 groundwater scenarios are based solely on drinking water ingestion, arsenic was the only chemical considered in calculating the chemical ILCR. Arsenic has extremely low near-field (i.e., vadose zone) mobility and was assigned a K_d of 39 mL/g (Spitz and Moreno 1996) for the contaminant fate and transport modeling (Chapter 3.0). Results of that modeling for WMA B-BX-BY (Section 4.7) indicated that arsenic would not reach groundwater at the fenceline within the 10,000-year simulation period. Thus, the calculated chemical ILCR for WMA B-BX-BY was zero.

It is possible that more carcinogenic chemicals are present in tank waste than are currently reported in the BBI. Inventory data for additional chemicals, potentially including carcinogenic chemicals not analyzed in this SST PA (e.g., organic chemicals), will be generated following waste retrieval through post-retrieval sample analysis. As additional inventory information becomes available, the data will be evaluated under the integrated regulatory closure process described in Chapter 1.0.

6.3.7.4 Non-Carcinogenic Chemical Hazard Index at Waste Management Area B-BX-BY

Tables 6-56 and 6-57 show the estimated peak non-carcinogenic chemical HI by source component for each tank row in WMA B-BX-BY for the WAC 173-340 Method B and Method C exposure scenarios, respectively. For the reference land use case (Method B), the composite non-carcinogenic chemical HI is below the performance objective in all seven rows (Table 6-56). The tank row with the highest HI is B-103. In that tank row, the peak HI is below the performance objective by a factor of 2 and is driven by the past releases component. Under the WAC 173-340 Method B exposure scenario, the peak HI from the tank residuals component is below the performance objective by more than an order of magnitude in all seven tank rows.

For the alternative land use case (Method C), the composite HI does not exceed the performance objective (HI = 1) in any tank row and is significantly below the performance objective in most tank rows (Table 6-57). The tank row with the highest HI is B-103. The peak HI from that tank row is below the performance objective by a factor of 5 and is driven by the past releases component. Under the WAC 173-340 Method C exposure scenario, the peak HI from the tank residuals component is below the performance objective by at least two orders of magnitude in all seven tank rows.

Estimated HI from each tank row is below the performance objective of 1 at the WMA fenceline.

Chromium, nitrate, nitrite, and uranium are the major contributors to the chemical HI.

As noted for the all-pathways dose (Section 6.3.7.1), in tank rows where the HI is dominated by the tank residuals component (i.e., tank rows B-201, BY-101, BY-102, and BY-103), the composite HI peak year sometimes differs from the tank residuals HI peak year (Tables 6-56 and 6-57). This occurs because the contributions to overall HI from the past releases component are sufficient to shift the composite HI peak to a slightly earlier time.

Table 6-56. Estimated Hazard Index for Reference Case: WAC 173-340 Method B Exposure Scenario by Tank Row in Waste Management Area B-BX-BY [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
B-101	8.04E-02	2332	18.48%	8.04E-02	2332	19.61%	1.38E-02	10481	18.78%
B-102	4.04E-02	10481	9.29%	6.42E-03	2332	1.57%	4.03E-02	10481	54.83%
B-103	4.35E-01	12032	100.00%	4.10E-01	12032	100.00%	2.84E-02	10481	38.64%
B-201 [b]	1.37E-02	10481	3.15%	4.25E-03	12032	1.04%	1.37E-02	10481	18.64%
BY-101	6.22E-02	2332	14.30%	6.22E-02	2332	15.17%	3.65E-02	10481	49.66%
BY-102	1.34E-02	10481	3.08%	1.13E-02	2332	2.76%	1.34E-02	10481	18.23%
BY-103	7.49E-02	10381	17.22%	1.75E-02	2332	4.27%	7.35E-02	10481	100.00%

[a] Shading indicates maximum row all components peak HI.

[b] Tank row B-201 contains plugged and blocked pipelines inventory.

Table 6-57. Estimated Hazard Index for Alternative Case: WAC 173-340 Method C Exposure Scenario by Tank Row in Waste Management Area B-BX-BY [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
B-101	3.48E-02	2332	17.58%	3.48E-02	2332	18.61%	5.74E-03	10481	19.39%
B-102	1.66E-02	10481	8.38%	2.83E-03	2332	1.51%	1.66E-02	10481	56.08%
B-103	1.98E-01	12032	100.00%	1.87E-01	12032	100.00%	1.17E-02	10481	39.53%
B-201 [b]	5.62E-03	10481	2.84%	1.81E-03	12032	0.97%	5.62E-03	10481	18.99%
BY-101	2.67E-02	2332	13.48%	2.67E-02	2332	14.28%	1.48E-02	10481	50.00%
BY-102	5.50E-03	10481	2.78%	4.87E-03	2332	2.60%	5.50E-03	10481	18.58%
BY-103	3.02E-02	10381	15.25%	7.55E-03	2332	4.04%	2.96E-02	10481	100.00%

[a] Shading indicates maximum row all components peak HI.

[b] Tank row B-201 contains plugged and blocked pipelines inventory.

Figure 6-35 shows temporal variations in non-carcinogenic chemical HI from tank row B-103 for the reference land use case. Component contributions for this metric are more similar to the all-pathways dose (Section 6.3.7.1) than the radiological ILCR (Section 6.3.7.2). As for the all-pathways dose, the past releases component dominates the composite HI curve over the entire assessment period. Unlike the radiological ILCR, the tank residuals component makes no more than a minor contribution at any point in the assessment period. Also, like the all-pathways dose, the highest composite HI value occurs at the very end of the assessment period (year 12032). Composite HI values are driven by mobile contaminants from past releases until approximately

year 5000, at which point less mobile contaminants from past releases take over and dominate through the end of the assessment period.

Figure 6-35. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row B-103

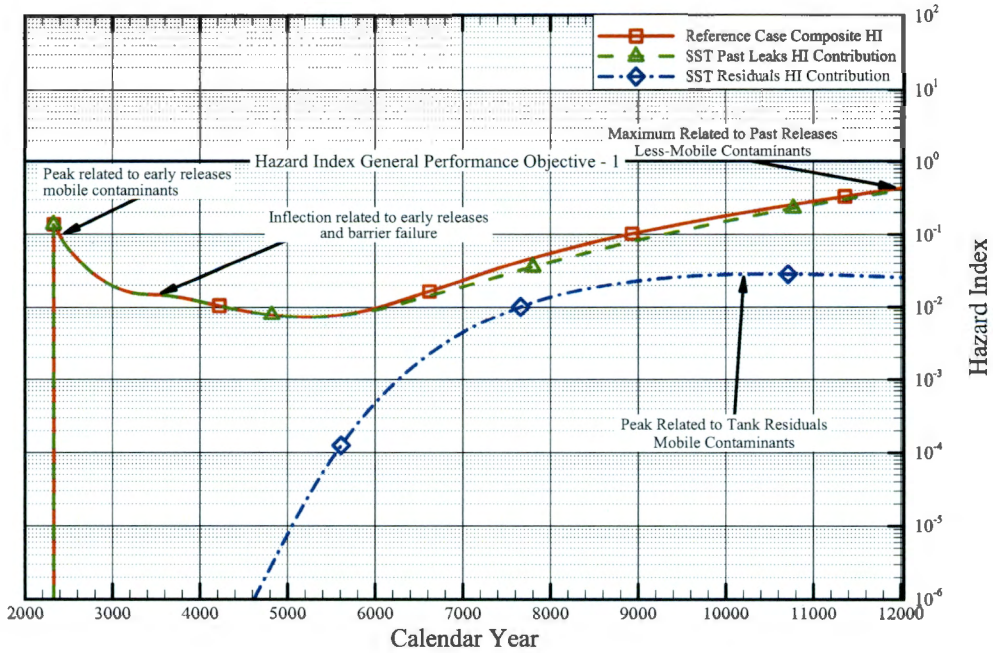


Figure 6-36 and Table 6-58 show the relative contaminant contributions to non-carcinogenic chemical HI from tank row B-103 to BX-111. Hexavalent chromium from past releases dominates the composite HI until approximately year 5000. From that point to the end of the assessment period, the composite HI is driven by uranium from past releases (Figure 6-36). At the time of the maximum hazard index (year 12032), uranium from past releases contributes about 94% of the composite HI value. At the time of peak from tank residuals (year 10481), uranium from past releases contributes approximately 88% of the composite HI under both the WAC 173-340 Method C and Method B exposure scenarios (Table 6-58). In Table 6-58, results are presented for the composite HI at calendar year 12032 (the peak year for the past releases component HI) and at calendar year 10481 (the peak year for the past releases component HI).

Figure 6-36. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row B-103 with Driving Contaminant Contributions

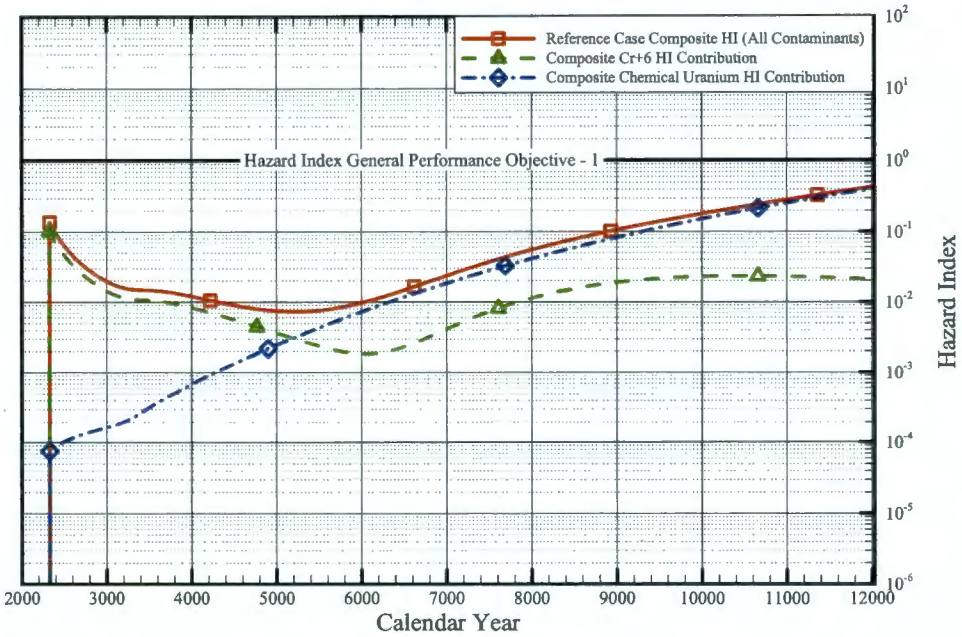


Table 6-58. Fractional Contributions to Composite Hazard Index by Selected Contaminants in Tank Row B-103

WAC 173-340 Method B (Reference Case)				
Contaminant	**Calendar Year: 12032**		**Calendar Year: 10481**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Uranium	4.10E-01	94.13%	1.98E-01	87.35%
Chromium	2.09E-02	4.80%	2.34E-02	10.35%
Fluoride	3.47E-03	0.80%	3.88E-03	1.71%
Nitrite	6.44E-04	0.15%	7.25E-04	0.32%
Nitrate	5.36E-04	0.12%	6.02E-04	0.27%
Other	2.12E-07	<0.01%	4.64E-08	<0.01%
Total	4.35E-01	100%	2.27E-01	100%
WAC 173-340 Method C (Alternative Case)				
Contaminant	**Calendar Year: 12032**		**Calendar Year: 10481**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Uranium	1.87E-01	94.70%	9.05E-02	88.50%
Chromium	8.37E-03	4.23%	9.38E-03	9.17%
Fluoride	1.58E-03	0.80%	1.78E-03	1.74%
Nitrite	2.94E-04	0.15%	3.31E-04	0.32%
Nitrate	2.45E-04	0.12%	2.75E-04	0.27%
Other	8.48E-08	<0.01%	1.88E-08	<0.01%
Total	1.98E-01	100%	1.02E-01	100%

[a] Uranium originated from past releases. Chromium, fluoride, nitrite, and nitrate originated from predominantly past release sources.

6.3.8 Groundwater Human Health Risk at Waste Management Area A-AX

Table 6-59 compares the estimated impacts for WMA A-AX to the performance objectives for protecting the general public. The values shown are the peak values for the composite source term (i.e., sum of dose contributions from past releases and residual waste source components) from the tank row with the highest value. The peak values for each metric occur at the time of assumed loss of institutional controls (year 2332) and in each case are from tank row A-101. For the reference land use case, the estimated HI (Method B) is below the performance objective by about one order of magnitude, while the radiological ILCR (industrial) is under the Washington State standard of 10^{-5} by a factor of 3 and below the federal standard of 10^{-4} by about two orders of magnitude. For the alternative land use case, the estimated all-pathways dose and HI (Method C) are below their respective performance objectives, while the radiological ILCR (residential) is above the Washington State standard of 10^{-5}, but below the federal standard of 10^{-4}. The chemical ILCR for both reference (Method B) and alternative (Method C) land use cases is 0 (see Section 6.3.8.3 for additional information on chemical ILCR using Methods B and C). Each metric is discussed individually in the following sections.

Table 6-59. Comparison of Estimated Reference Case Impacts for Waste Management Area A-AX with Performance Objectives for Protecting the General Public

Performance Measure		Performance Objective	Peak Value [a]	Peak Year	Tank Row
All-pathways dose (mrem/yr)		15	4.68E-01	2332	A-101
ILCR (radiological)	Industrial	10^{-4} to 10^{-5}	3.38E-06	2332	A-101
	Residential	10^{-4} to 10^{-5}	**8.11E-05**	2332	A-101
ILCR (chemical carcinogen)	WAC 173-340 Method B	10^{-5}	0 [b]	NA	NA
	WAC 173-340 Method C	10^{-5}	0 [b]	NA	NA
HI (chemical non-carcinogen)	WAC 173-340 Method B	1	1.60E-01	2332	A-101
	WAC 173-340 Method C	1	6.88E-02	2332	A-101

Bold indicates the performance objective is exceeded in at least one tank row within the WMA.

[a] Calculated in groundwater at the WMA A-AX fenceline. Values shown are the maximum projected values over the first 10,000 years after closure.

[b] See Section 6.3.8.3 for additional information on chemical ILCR.

NA = not applicable

Although the past releases component is the primary contributor to the peak values for each risk metric, the residual waste component makes a significant contribution in the last half of the simulation period in all tank rows. This is because WMA A-AX has the lowest past release volume (Field and Jones 2005) and the third lowest inventory of technetium-99 from the past releases source component in the SST system (Corbin et al. 2005). Technetium-99 is the predominant radionuclide risk driver in the past release source component. The complete past releases component in WMA A-AX comprises four past tank leaks, all of which are less than 5,500 gal (Corbin et al. 2005). Two of the tank leaks occur in the same tank row, and the remaining two leaks are in separate tank rows, leaving a tank row in WMA A-AX without a past tank leak. The low volume of past releases results in lower concentrations in the last half of the

assessment period and consequently tank releases either become dominant during this time frame, or provide a greater contribution than typically seen in 200 East Area WMAs.

6.3.8.1 All-Pathways Dose at Waste Management Area A-AX

Table 6-60 shows the estimated peak all-pathways dose by source component for each tank row in WMA A-AX. The composite dose is significantly below the performance objective (15 mrem/yr) for all tank rows. The tank row with the highest dose is A-101. The peak dose from that tank row is below the performance objective by a little over an order of magnitude and is driven by the past releases component. Peak doses from the residual waste component are below the performance objective by at least three orders of magnitude in all four tank rows.

> Estimated all-pathways farmer dose is below the performance objective of 15 mrem/yr at the WMA fenceline.
>
> Technetium-99, carbon-14, and iodine-129 are the major contributors to the all-pathways farmer dose from past releases.
>
> Technetium-99 and carbon-14 are the major contributors to the all-pathways farmer dose from tank residuals.

Table 6-60 shows the peak all-pathways farmer dose from all components occurs at approximately year 10400 for tank row AX-101. This tank row does not have any past releases associated with it. Therefore, the peak is attributed to mobile residual waste contaminants. Table 6-60 shows the peak all-pathways farmer dose from all components occurs at year 2332 for tank rows A-101, A-104, and AX-102. These tank rows have similar technetium-99 inventories associated with the past releases and residual wastes assigned to these tank rows (Appendix C). The slower release of grouted residual waste contaminants from the grouted residual waste and the assumption that the residual waste is not exposed to the operational recharge results in the past release technetium-99 inventory dominating the all-pathways farmer dose for these tank rows.

Table 6-60. Estimated Peak All-Pathways Dose by Tank Row in Waste Management Area A-AX [a]

All-Pathways Dose Performance Objective: 15 mrem/yr									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row	Peak Dose mrem/yr	Peak Year	Dose Relative to Peak Row
A-101	4.68E-01	2332	100.00%	4.68E-01	2332	100.00%	3.53E-02	10451	100.00%
A-104	9.31E-02	2332	19.89%	9.31E-02	2332	19.89%	3.46E-03	10411	9.80%
AX-101	4.76E-03	10431	1.02%	NA	NA	NA	2.48E-03	10431	7.03%
AX-102	6.89E-02	2332	14.72%	6.89E-02	2332	14.72%	1.05E-02	10451	29.75%

[a] Shading indicates maximum row all components all-pathways dose.

NA = not applicable

Figure 6-37 shows temporal variations in all-pathways dose from tank row A-101. The dominance of the past releases component is revealed by the overlap of the composite and past releases curves for the first third of the assessment period. Only in the last third of the simulation period does the tank residual component make a significant contribution to the composite curve. During this period, a little more than 50% of the dose is caused by mobile contaminants from the residual waste components, with the remainder of the dose is caused by less mobile contaminants from past releases.

Figure 6-37. All-Pathways Dose for Tank Row A-101

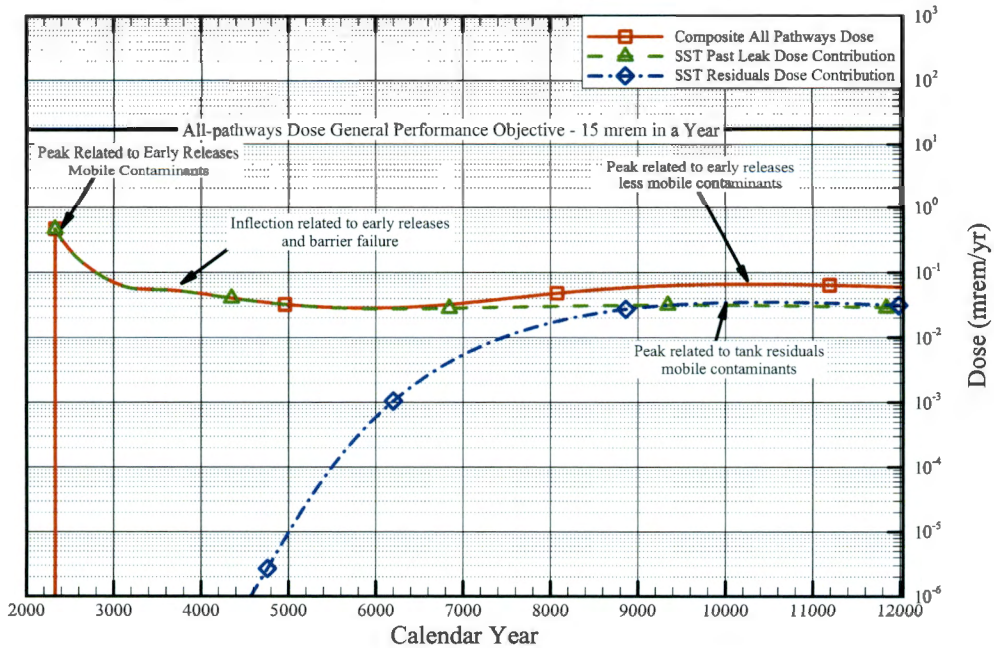


Figure 6-38 and Table 6-61 show the relative contaminant contributions to all-pathways dose from tank row A-101 and further illustrate the dominance of the past releases component. Technetium-99 from past releases dominates the composite dose at the time of peak (year 2332) and remains dominant through the early part of the assessment period. Iodine-129 from past releases becomes dominant at about year 5000 and remains dominant until about the year 9000, when technetium-99 from residual wastes begins to provide an approximately equivalent dose (Figure 6-38). At the time of peak from residual wastes (year 10451), technetium-99 from residual wastes contributes approximately 53% of the composite dose, and iodine-129 from past releases contributes approximately 47% (Table 6-61). In Table 6-61, results are presented for the composite all-pathways dose at calendar year 2332 (the peak year for all-pathways dose from the past releases component) and at calendar year 10451 (the peak year for all-pathways dose from the residuals wastes component).

Figure 6-38. All-Pathways Dose for Tank Row A-101 with Driving Contaminant Contributions

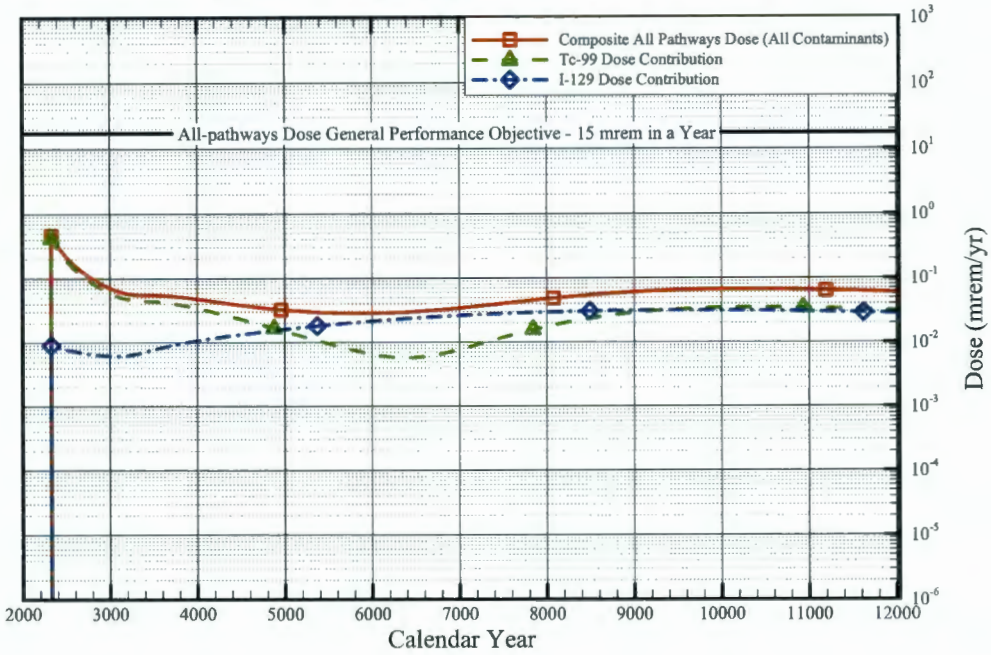


Table 6-61. Fractional Contributions to Composite All-Pathways Dose by Selected Contaminants in Tank Row A-101, Reference Case

Contaminant	Past Releases Peak Year: 2332		Residual Waste Peak Year: 10451	
	Dose mrem/yr	Contribution to Total Dose	Dose mrem/yr	Contribution to Total Dose [a]
Technetium-99	4.21E-01	89.81%	3.52E-02	52.94%
Carbon-14	3.86E-02	8.25%	1.32E-04	0.20%
Iodine-129	9.06E-03	1.94%	3.11E-02	46.76%
Uranium-233	2.02E-08	<0.01%	4.98E-05	0.07%
Uranium-234	3.46E-09	<0.01%	8.62E-06	0.01%
Uranium-238	2.95E-09	<0.01%	7.53E-06	0.01%
Other	2.88E-10	<0.01%	3.80E-06	<0.01%
Total	4.68E-01	100%	6.65E-02	100%

[a] Iodine-129 and uranium originated from past release sources. Carbon-14 and technetium-99 originated from both past release and residual waste sources.

6.3.8.2 Radiological Cancer Risk at Waste Management Area A-AX

Tables 6-62 and 6-63 show the estimated peak radiological ILCR by source component for each tank row in WMA A-AX for the reference case (industrial scenario) and alternative land use case (residential scenario), respectively. For the reference land use case, the composite radiological ILCR does not exceed the performance objective in any tank row (Table 6-62). The tank row with the peak ILCR is tank row A-101. The peak ILCR for that tank row is below the Washington State standard (10^{-5}) by an order of magnitude and is driven by the past releases component. Under the industrial exposure scenario, the peak ILCR from the residual waste component is below the Washington State standard (10^{-5}) by at least two orders of magnitude in all four tank rows.

For the alternative land use case, the composite radiological ILCR exceeds the Washington State standard (10^{-5}) in three of the four tank rows (Table 6-63). In the peak row, tank row A-101, the peak ILCR exceeds the Washington State standard (10^{-5}) by a factor of 8, but is below the federal standard (10^{-4}) by a factor of 1.2. The peak ILCR for tank row A-101 is driven by the past releases component. Under the residential exposure scenario, the peak ILCR from the residual waste component is below the Washington State standard (10^{-5}) by at least an order of magnitude for all four tank rows.

Estimated ILCR from each tank row is below the performance objective of 10^{-5} at the WMA fenceline for the reference exposure scenario.

Technetium-99 is the major contributor to the peak ILCR.

Table 6-62. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Reference Case: Industrial Exposure Scenario by Tank Row in Waste Management Area A-AX [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
A-101	3.38E-06	2332	100.00%	3.38E-06	2332	100.00%	2.76E-07	10461	100.00%
A-104	6.95E-07	2332	20.56%	6.95E-07	2332	20.56%	2.60E-08	10451	9.42%
AX-101	3.66E-08	10451	1.08%	NA	NA	NA	1.90E-08	10451	6.88%
AX-102	5.25E-07	2332	15.53%	5.25E-07	2332	15.53%	8.17E-08	10451	29.60%

[a] Shading indicates maximum row all components peak ILCR.

NA = not applicable

Table 6-63. Estimated Peak Radionuclide Incremental Lifetime Cancer Risk for Alternative Case: Residential Exposure Scenario by Tank Row in Waste Management Area A-AX [a]

Radiological Cancer Risk Performance Objective: $10^{-4} - 10^{-5}$									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row	Peak ILCR	Peak Year	ILCR Relative to Peak Row
A-101	**8.11E-05**	2332	100.00%	**8.11E-05**	2332	100.00%	6.73E-06	10461	100.00%
A-104	**1.68E-05**	2332	20.72%	**1.68E-05**	2332	20.72%	6.27E-07	10451	9.32%
AX-101	8.88E-07	10451	1.09%	NA	NA	NA	4.61E-07	10451	6.85%
AX-102	**1.27E-05**	2332	15.66%	**1.27E-05**	2332	15.66%	1.99E-06	10461	29.57%

Bold indicates the performance objective is exceeded.

[a] Shading indicates maximum row all components peak ILCR.

NA = not applicable

Figure 6-39 shows temporal variations in radionuclide ILCR from tank row A-101 for the reference land use case. As noted for the all-pathways dose (Section 6.3.8.1), the dominance of the past releases component in the first third of the assessment period is revealed by the overlap of the composite and past releases curves. Here again, the two curves are virtually indistinguishable during the first third of the modeling period. The primary difference between radionuclide ILCR and all-pathways dose is the residual waste component becomes the dominant component beginning about year 7200 for radionuclide ILCR, while for the all-pathways dose the residual waste component accounts for about half of the dose during the same period. Composite ILCR values late in the assessment period are dominated by mobile contaminants from residual wastes.

Figure 6-40 and Table 6-64 show the relative contaminant contributions to radiological ILCR from tank row A-101. As noted for the all-pathways dose (Section 6.3.8.1), this data further illustrates the dominance of the past releases component in the early part of the simulation period. This data also underscores the difference between ILCR and all-pathways dose, which is the dominance of residual wastes in the later part of the model time frame. Technetium-99 from past releases dominates the composite ILCR at the time of peak (year 2332) and remains dominant through the early part of the assessment period. Technetium-99 from residual waste begins to dominate the composite ILCR around the year 7000 and remains dominant through the rest of the simulation time frame. Iodine-129 from past releases provides an important contribution to the composite ILCR during the entire simulation time frame, with its peak contribution occurring between the years 6000 and 7000 (Figure 6-40). Under the industrial exposure scenario, iodine-129 from past releases contributes approximately 14% of the composite ILCR at the time of peak from residual waste (year 10461), and technetium-99 from residual waste contributes about 86% (Table 6-64). Under the residential exposure scenario, the relative contribution from technetium-99 at the time of peak from residual waste is greater than for the industrial scenario (97%) because of the additional exposure pathways (e.g., garden vegetables) included in this scenario (Table 6-64). In Table 6-64, results are presented for the composite ILCR at calendar year 2332 (the peak year for ILCR from past releases component) and at calendar year 10461 (the peak year for ILCR from the residual wastes component).

Figure 6-39. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row A-101

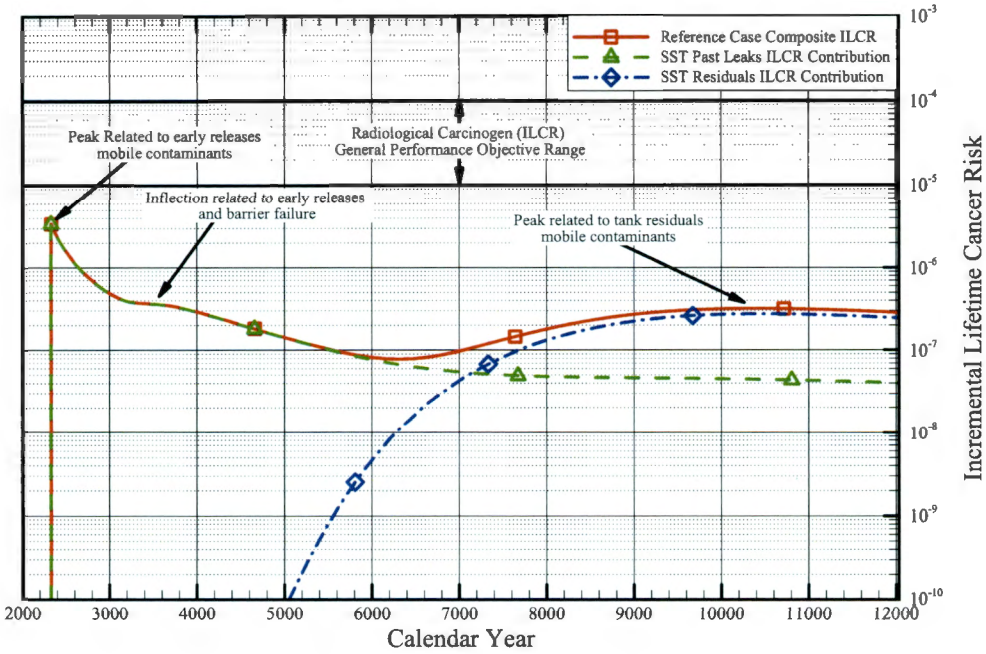


Figure 6-40. Radionuclide Incremental Lifetime Cancer Risk for the Industrial Exposure Scenario for Tank Row A-101 with Driving Contaminant Contributions

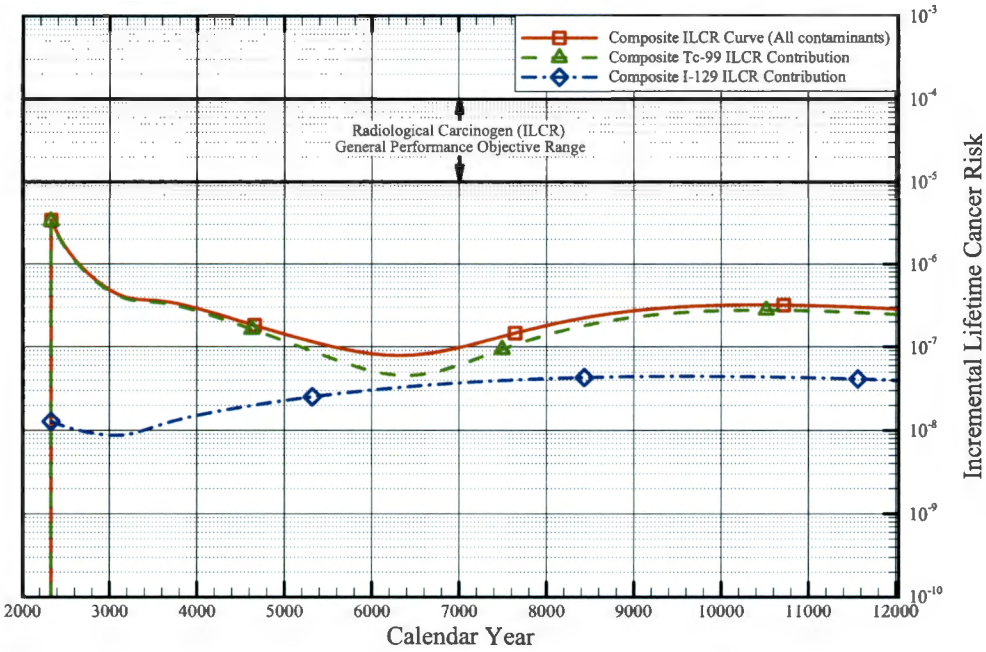


Table 6-64. Fractional Contributions to Composite Incremental Lifetime Cancer Risk by Selected Contaminants in Tank Row A-101

Industrial Scenario (Reference Case)				
Contaminant	**Past Releases Peak Year: 2332**		**Residual Waste Peak Year: 10461**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	3.31E-06	97.79%	2.77E-07	86.22%
Carbon-14	6.19E-08	1.83%	2.11E-10	0.07%
Iodine-129	1.28E-08	0.38%	4.39E-08	13.67%
Tin-126	0.00E+00	<0.01%	4.89E-11	0.02%
Uranium-233	3.61E-14	<0.01%	8.94E-11	0.03%
Uranium-238	6.97E-15	<0.01%	1.79E-11	0.01%
Other	6.92E-15	<0.01%	1.67E-11	0.01%
Total	3.38E-06	100%	3.21E-07	100%
Residential Scenario (Alternative Case)				
Contaminant	**Past Releases Peak Year: 2332**		**Residual Waste Peak Year: 10461**	
	ILCR	**Contribution to Total ILCR**	**ILCR**	**Contribution to Total ILCR [a]**
Technetium-99	**8.06E-05**	99.37%	6.74E-06	96.70%
Carbon-14	4.48E-07	0.55%	1.52E-09	0.02%
Iodine-129	6.63E-08	0.08%	2.27E-07	3.26%
Tin-126	0.00E+00	<0.01%	7.27E-10	0.01%
Uranium-233	1.86E-13	<0.01%	4.60E-10	0.01%
Other	7.30E-14	<0.01%	1.81E-10	0.01%
Total	**8.11E-05**	100%	6.97E-06	100%

Bold indicates the performance objective is exceeded.

[a] Iodine-129 and uranium originated from past release sources. Carbon-14, technetium-99, and tin-126 originated from predominantly residual waste sources.

6.3.8.3 Chemical Cancer Risk at Waste Management Area A-AX

Two scenarios from the Washington State groundwater cleanup regulations (Method C and Method B from WAC 173-340) were used to assess reference case impacts from nonradiological carcinogenic chemicals (Section 1.9). Of the nonradiological chemicals for which tank waste inventories are currently reported in the BBI, the following five are classified as carcinogenic:

- Arsenic
- Hexavalent chromium
- Cobalt
- Beryllium
- Cadmium

All five are classified as carcinogenic via inhalation but only one, arsenic, is also classified as carcinogenic via ingestion. Because both of the WAC 173-340 groundwater scenarios are based solely on drinking water ingestion, arsenic was the only chemical considered in calculating the chemical ILCR. Arsenic has extremely low near-field (i.e., vadose zone) mobility and was assigned a K_d of 39 mL/g (Spitz and Moreno 1996) for the contaminant fate and transport modeling (Chapter 3.0). Results of that modeling for WMA A-AX (Section 4.8) indicated that

arsenic would not reach groundwater at the fenceline within the 10,000-year simulation period. Thus, the calculated chemical ILCR for WMA A-AX was zero.

It is possible that more carcinogenic chemicals are present in tank waste than are currently reported in the BBI. Inventory data for additional chemicals, potentially including carcinogenic chemicals not analyzed in this SST PA (e.g., organic chemicals), will be generated following waste retrieval through post-retrieval sample analysis. As additional inventory information becomes available, the data will be evaluated under the integrated regulatory closure process described in Chapter 1.0.

6.3.8.4 Non-Carcinogenic Chemical Hazard Index at Waste Management Area A-AX

Tables 6-65 and 6-66 show the estimated peak non-carcinogenic chemical HI by source component for each tank row in WMA A-AX for the WAC 173-340 Method B and Method C exposure scenarios, respectively. For the reference land use case, the composite non-carcinogenic chemical HI (Method B) is below the performance objective in all four tank rows. The composite non-carcinogenic chemical HI is greatest in tank row A-101 (Table 6-65). In that tank row, the peak HI is below the performance objective by two orders of magnitude and is driven by the past releases component. Under the WAC 173-340 Method B exposure scenario, the peak HI from the residual waste component is below the performance objective by an order of magnitude or more in all four tank rows.

For the alternative land use case, the composite HI (Method C) does not exceed the performance objective (HI = 1) in any tank row (Table 6-66). The tank row with the highest HI is tank row A-101. The peak HI for that tank row is below the performance objective by two orders of magnitude and is driven by the past releases component. Under the WAC 173-340 Method C exposure scenario, the peak HI from the residual waste component is below the performance objective by approximately two or more orders of magnitude in all four tank rows.

Estimated HI from each tank row is below the performance objective of 1 at the WMA fenceline.

Chromium, nitrate, and nitrite are the major contributors to the chemical HI.

In tank rows where the HI is dominated by the residual waste component (i.e., tank rows AX-101 and AX-102), the composite HI peak year is sometimes later than the calculated peak year that occurs when the HI contributions from only the tank residual wastes are assumed. Usually, the composite HI peak year is the same as the peak year for the component that dominates HI (i.e., the residual waste component). However, in these instances, the contributions to overall HI from past release components, although small, continue to increase as contributions from the tank residual component contributions decrease. This combination of HI changes over time is sufficient to shift the composite HI peak to a slightly later time.

In tank row AX-101, the residual waste component HI (driven by chromium) declines after a peak year of 10481. During the same period, the past releases component HI (driven by nitrite, but comprised of several less mobile components such as uranium) is exhibiting a gradual increase in the same tank row. The rate of past release contribution increase is enough to offset the rate of residual waste contribution decrease between the years 10481 and 10491. When the

two contributions are added together to form the composite HI, the magnitude of the past releases component HI contribution (approximately 1% of the composite HI) coupled with the increasing contribution of that component causes the composite HI to increase to a peak year of 10491. After 10491, the rate of decrease for the residual waste contribution is so rapid that the overall composite HI decreases as well.

Table 6-65. Estimated Hazard Index for Reference Case: WAC 173-340 Method B Exposure Scenario by Tank Row in Waste Management Area A-AX [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
A-101	1.60E-01	2332	100.00%	1.60E-01	2332	100.00%	1.13E-01	10481	100.00%
A-104	1.78E-02	2332	11.13%	1.78E-02	2332	11.13%	1.25E-02	10481	11.06%
AX-101	9.41E-02	10481	58.81%	NA	NA	NA	6.66E-02	10481	58.94%
AX-102	3.12E-03	10491	1.95%	2.76E-03	2332	1.73%	3.06E-02	10481	27.08%

[a] Shading indicates maximum row all components peak HI.
NA = not applicable

Table 6-66. Estimated Hazard Index for Alternative Case: WAC 173-340 Method C Exposure Scenario by Tank Row in Waste Management Area A-AX [a]

Non-Carcinogenic Chemical Hazard Index Performance Objective: 1									
Tank Row	All Components			Past Releases Component			Residual Waste Component		
	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row	Peak HI	Peak Year	HI Relative to Peak Row
A-101	6.88E-02	2332	100.00%	6.88E-02	2332	100.00%	4.52E-02	10481	100.00%
A-104	7.55E-03	2332	10.97%	7.55E-03	2332	10.97%	5.03E-03	10481	11.13%
AX-101	3.77E-02	10481	54.80%	NA	NA	NA	2.67E-02	10481	59.07%
AX-102	1.27E-03	10491	1.85%	1.16E-03	2332	1.69%	1.23E-02	10481	27.21%

[a] Shading indicates maximum row all components peak HI.
NA = not applicable

Figure 6-41 shows temporal variations in non-carcinogenic chemical HI from tank row A-101 for the reference land use case. The component contributions for this metric differ from those for the all-pathways dose (Section 6.3.8.1). For the all-pathways dose, the past releases component dominates the cumulative curve from the beginning of the assessment period to about the year 9000, when residual wastes begin to contribute an approximately equal dose. Iodine-129 in the past releases component causes the significant contribution in the last half of the simulation period because it is semi-mobile (K_d = 0.2 ml/g). In contrast, the inventory of less-mobile chemicals (e.g., uranium) in the past releases is very minor. As a result, the composite HI values are driven almost entirely by the mobile (K_d = 0 ml/g) chemical species and the residual waste component becomes dominant over the last half of the assessment period. The mobile chemicals in past releases dominate the composite HI curve from the time of peak

(year 2332) to about the year 6000, at which point the mobile chemicals in residual wastes take over and dominate through the end of the assessment period.

> Peak groundwater impacts within a given WMA are driven by past releases.
>
> Estimated ILCR for tank rows for the residential scenario are higher than the estimated impacts for the industrial scenario due to the additional pathways assumed for the contaminants to expose an individual.

Figure 6-41. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row A-101

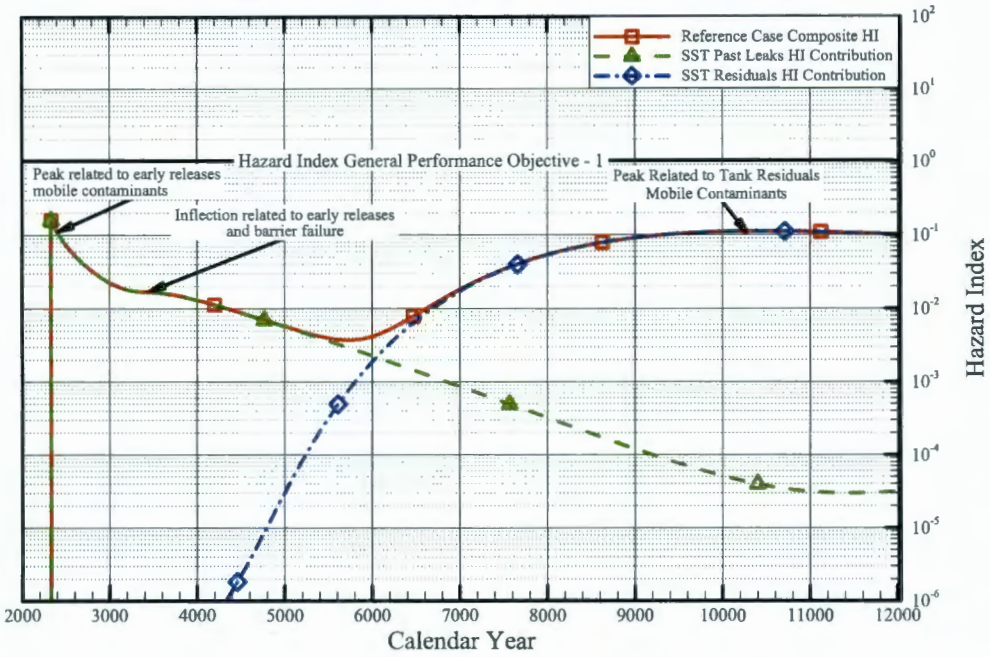


Figure 6-42 and Table 6-67 show the relative contaminant contributions to non-carcinogenic chemical HI from tank row A-101. The combined contributions from hexavalent chromium and nitrite in past releases dominate the composite HI from the time of peak (year 2332) to about year 5800 when residual wastes become dominant (Figure 6-42). From that point to the end of the assessment period, the composite HI is driven almost entirely by hexavalent chromium. The significant drop-off in the nitrite contribution reflects the much lower nitrite inventory in residual wastes compared with past releases. At the time of peak from residual wastes (year 10481), hexavalent chromium from the residual waste component contributes over 98% of the composite HI under both the WAC 173-340 Method C and Method B exposure scenarios (Table 6-67). In Table 6-67, results are presented for the composite HI at calendar year 2332 (the peak year for HI from the past releases component) and at calendar year 10481 (the peak year for HI from the tank residuals component).

Figure 6-42. Hazard Index for the WAC 173-340 Method B Exposure Scenario for Tank Row A-101 with Driving Contaminant Contributions

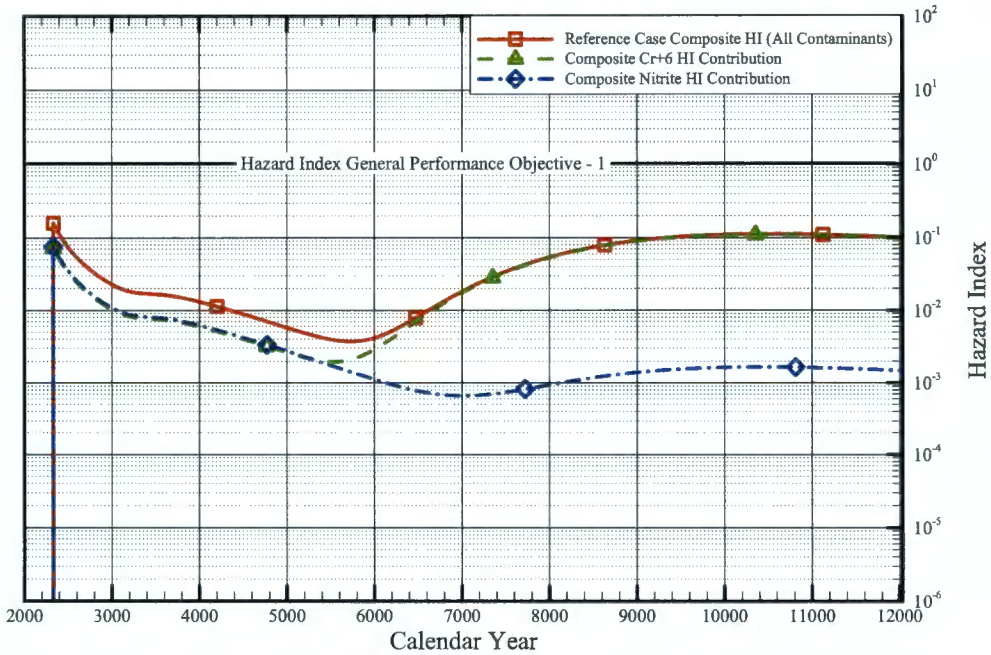


Table 6-67. Fractional Contributions to Composite Hazard Index by Selected Contaminants in Tank Row A-101

WAC 173-340 Method B (Reference Case)				
Contaminant	**Past Releases Peak Year: 2332**		**Residual Waste Peak Year: 10481**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Nitrite	7.60E-02	47.61%	1.67E-03	1.48%
Chromium	7.24E-02	45.40%	1.11E-01	98.35%
Nitrate	8.29E-03	5.20%	1.61E-04	0.14%
Fluoride	1.87E-03	1.17%	2.12E-05	0.02%
n-butyl alcohol	9.99E-04	0.63%	1.59E-07	<0.01%
Other	4.90E-09	<0.01%	1.30E-05	0.01%
Total	1.60E-01	100%	1.13E-01	100%
WAC 173-340 Method C (Alternative Case)				
Contaminant	**Past Releases Peak Year: 2332**		**Residual Waste Peak Year: 10481**	
	HI	**Contribution to Total HI**	**HI**	**Contribution to Total HI [a]**
Nitrite	3.47E-02	50.47%	7.62E-04	1.68%
Chromium	2.90E-02	42.11%	4.44E-02	98.12%
Nitrate	3.79E-03	5.51%	7.38E-05	0.16%
Fluoride	8.55E-04	1.24%	9.70E-06	0.02%
n-Butyl alcohol	4.57E-04	0.66%	7.28E-08	<0.01%
Other	2.24E-09	<0.01%	5.92E-06	0.01%
Total	6.88E-02	100%	4.53E-02	100%

[a] Chromium, fluoride, nitrate, nitrite, and n-butyl alcohol originated from predominantly residual waste sources.

6.4 COMPARISON OF INADVERTENT HUMAN INTRUDER IMPACTS TO PERFORMANCE OBJECTIVES

Chapter 5.0 describes the inadvertent intruder analysis. Table 6-68 compares the estimated impacts to the performance objectives for protecting the inadvertent intruder for each SST WMA. The time of comparison starts at 500 years after closure. The acute exposure performance objective for the well driller is met by a factor greater than 16. The continuous exposure performance objective is met by a factor of approximately 15 or more for all WMAs for the reference case scenario (i.e., rural pasture). However, the sensitivity case of suburban garden with a resident scenario exceeds the 100 mrem/yr standard at 500 years for tanks AX-102, SX-115, and TX-118. Plutonium-239, plutonium-240, and amercium-241 are the major contributors.

Intruder performance objectives are met for the reference scenarios (well driller and rural pasture). The suburban gardener estimated impacts exceed the performance objective of 100 mrem in a year in WMAs A-AX, S-SX, and TX-TY.

Table 6-68. Intruder Scenario Doses at 500 Years After Closure (Year 2532)

WMA	Worst Source Location	Reference Cases		Sensitivity Cases	
		Well Driller mrem	Rural Pasture [a] mrem	Suburban Garden [a] mrem	Commercial Farm mrem
A-AX	AX-102 (tank plus leak)	18	4.8 (2183)	**108 (2590)**	0.13
B-BX-BY	B-101	4.2	1.0	23 (2239)	0.029
C	C-201 (tank plus leak)	12	2.9	65 (2277)	0.082
S-SX	SX-115 (tank plus leak)	29	6.6 (2237)	**147 (4885)**	0.18
T	T-106 (tank plus leak)	1.3	0.46	22 (2241)	0.0072
TX-TY	TX-118	30	6.7	**148 (3522)**	0.19
U	U-106	6.4	1.4	31 (2228)	0.039

Bold indicates potentially above performance objective.

[a] The times in parentheses are the calendar year. At the time shown in parentheses, the intruder dose matches the performance objective of 500 mrem for the acute exposure, or 100 mrem for the chronic exposures. Doses without a time in parentheses meet the objective within 100 years of WMA closure.

6.5 COMPARISON OF EFFECTS OF RELEASES TO AIR TO PERFORMANCE OBJECTIVES

This section presents the effects of releases to air in the following sections:

- Overview (Section 6.5.1)
- Doses from tritium and carbon-14 emissions (Section 6.5.2)
- Emission rate of radon-222 above the waste (Section 6.5.3)
- Conclusions (Section 6.5.4).

6.5.1 Overview

Earlier PA analyses (Wood et al. 1995a, 1996; Mann et al. 2001) have shown that the effects of contaminant releases to the air are negligible for both ILAW and solid waste buried in trenches with more than 16 ft (5 m) of cover above the waste. The estimated inventories for tritium, carbon-14, and transuranic nuclei contributing to the radon-222 inventory are small for the SSTs.

The principal mechanism by which nuclides migrate from the waste to the ground surface is gaseous diffusion. The analysis in Rittmann (2004) shows that convection mechanisms such as atmospheric pressure and temperature variations, wind, and rainfall have negligible secondary effects on the release of contaminants to the air.

The diffusion of radioactive gases such as tritium, carbon-14, and radon-222 can be represented using Fick's Law of diffusion with a loss term for radioactive decay (Jury et al. 1991). The amount available for diffusion (i.e., the source concentration) is changing with time due to the release mechanism for the contaminants from the waste form and radioactive decay. Two cases (one for tritium and carbon-14 and the other for radon-222) must be considered because the performance objectives differ. The tritium and carbon-14 performance objective is to limit the air pathway dose near each WMA to less than 10 mrem per year. The radon-222 performance objective is to limit the surface emanation rate to less than 20 $pCi/m^2/s$.

The air emissions following closure are estimated using a simple model that provides an upper bound on the possible doses from tritium and carbon-14, and the possible emission rate of radon-222 at the ground surface above the waste. The estimated bounding doses for tritium and carbon-14 emissions are well below the performance objective of 10 mrem per year. The emission rate of radon-222 at the ground surface above the waste is well below the performance objective of 20 $pCi/m^2/s$.

6.5.2 Doses from Tritium and Carbon-14 Emissions

Because the estimated WMA closure inventories for tritium and carbon-14 are small, a bounding approach is used to estimate the air release doses for this risk assessment. Specifically, half the entire tritium and carbon-14 inventories for each WMA are released over a 1-year period, the first year after closure. The other half diffuses downward. This approach ignores diffusion from the waste that has been occurring during the past decades. A bounding approach avoids the task of defining release mechanisms and rates of progress through the overlying soils. The total inventories for tritium and carbon-14 in each WMA at the time of closure are shown in Table 6-69. All WMA are assumed to be closed at the beginning of calendar year 2032.

Bounding air pathway doses from each WMA are significantly below the performance objective of 10 mrem in a year.

The air pathway doses are calculated by multiplying the total inventories at WMA closure for tritium and carbon-14 by their corresponding unit release dose factors from Rittmann (2004), and summing the EDE from these two contaminants. The unit dose factors were derived using a unit annual release (1 Ci), a bounding air transport factor (1.0E-04 s/m^3), and the CAP88-PC software from EPA (EPA 2000b). The air transport factor is a bounding value that applies to annual emission near the border of a large area source.

Table 6-69. Total Tritium and Carbon-14 Inventories and Air Pathway Doses

WMA	Total Inventory at Closure [a]		Total Dose mrem [b]
	Tritium Ci	Carbon-14 Ci	
A-AX	0.20	0.29	0.19
B-BX-BY	2.50	1.00	0.69
C	4.80	0.41	0.33
S-SX	14.29	1.62	1.24
T	3.89	1.18	0.82
TX-TY	0.66	0.50	0.34
U	1.27	0.29	0.21

[a] WMA closure occurs at the end of calendar year 2032. The residual tank inventories (from HTWOS for January 2032) were not decayed. The tank leaks from DOE-ORP (2000) are defined for January 2001 and were decayed 31 years. Three unplanned release inventories in C tank farm are defined for January 1994 and were decayed 28 years.

[b] Total dose is calculated for locations near the WMA using effective dose equivalent factors from CAP88-PC (EPA 2000b). The doses accumulate during the first year after closure when one-half the inventory at closure is released into the air. Most of the total comes from carbon-14.

The CAP88-PC (EPA 2000b) results include food pathways and use the default parameter file of the program. The tritium and carbon-14 are modeled using specific activity models, which tend to maximize the doses from garden produce and animal products such as milk and meat. In a specific activity model the activity concentration (tritium and carbon-14) in air is divided by the mass concentration of the nonradioactive element (hydrogen or carbon) in air. This ratio is multiplied by the concentration of the element in a food item to calculate the contamination level in the food item. The specific activity models used in CAP88-PC assume that all the water and all the carbon in plants comes from the air. This ignores irrigation water and carbon in soil and greatly exaggerates the resulting doses.

6.5.3 Emission Rate of Radon-222 above the Waste

The radon-222 emanation rate from the ground surface is estimated using the diffusion formula derived in Appendix E of Rittmann (2004). This rate depends on the thickness of the waste, the depth of the soil cover, the assumed diffusivity of radon gas through the waste and soil cover, and the concentration of radium-226 in the waste. The radium-226 produces radon-222 by radioactive decay. The radium-226 is produced by the radioactive decay of curium-242, plutonium-238, uranium-238, uranium-234, and thorium-230. Because the radium-226 accumulates slowly with time, with most of it coming from the uranium-238 and uranium-234, the radium-226 concentration reaches its maximum value at times greater than 100,000 years after closure.

Bounding radon-222 emanation rates from each WMA are significantly below the performance objective of 20 pCi/m^2/s and occur at times greater than 500,000 years after SST closure.

Because the estimated WMA closure inventories for the precursors of radon-222 are small, a bounding approach is used to estimate the air release rate for this risk assessment. Specifically, the maximum concentration of radium-226 in the waste is used in the diffusion calculation. It is assumed that the uranium has not migrated appreciably from its initial location in the waste. Both the residual tank waste and the soil contamination plumes from tank leaks and other UPRs are assumed to be located 15 ft (4.572 m) bgs. In effect, the layer of grout and the tank dome are ignored. This approach certainly exaggerates the rate at which radon-222 escapes from the waste matrix and diffuses to the ground surface. The formulas used to calculate the radon emanation rate at the ground surface are shown in Section 3.2.3.

The radon diffusivity through the soil is taken to be 0.01 cm^2/s. This is based on the approximate binary diffusivity of radon in air (0.1 cm^2/s) scaled by a tortuosity factor of 0.1 to account for diffusion in the soil pore space. The largest theoretical radon sources and associated fluxes in each WMA are shown in Table 6-70.

Table 6-70. Largest Radon-222 Flux by Waste Management Area

WMA	Peak Waste Radon-222 Source Location [a]	Peak Rn-222 Flux pCi/m^2/s [b]	Time After Closure years
A-AX	A-102	2.7	505,000
B-BX-BY	BX-102 (tank residual plus leak)	3.5	2,160,000
C	C-203 (tank residual plus leak)	6.8	2,480,000
S-SX	S-102	1.6	1,605,000
T	T-102	0.51	2,250,000
TX-TY	TX-108	1.1	1,780,000
U	U-105	0.77	688,000

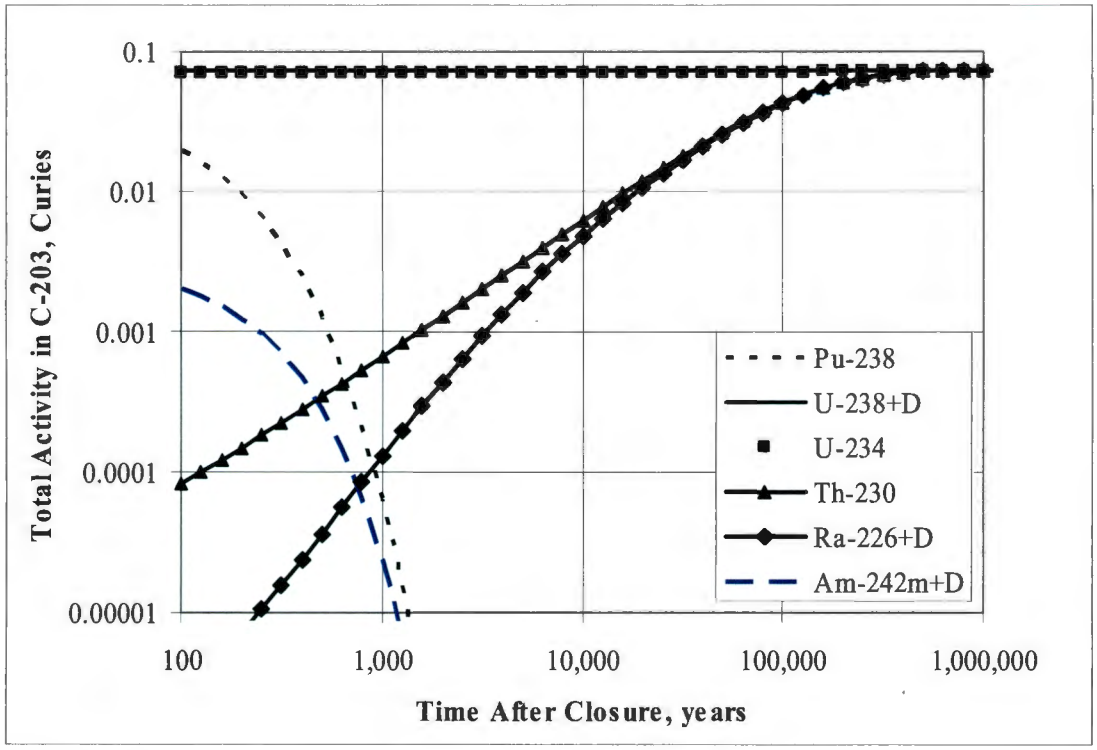
[a] All waste types are located 15 ft below ground surface and are tank residuals unless otherwise noted. Horizontal areas assigned to peak source provided in Appendix E, Section E1.0.

[b] The approximate diffusion coefficient for radon-222 in this soil is 0.01 cm^2/s.

A graph of the total activity of radionuclides that produce radium-226 is shown in Figure 6-43. The inventories shown are for tank C-203, the tank with the largest eventual radon-222 emission rate. The leak from C-203 produces 1,000 times less radon-222. The radon-222 emission rate is proportional to the radium-226 activity. The peak in radium-226 activity at about 2.5 million years is not visible in the figure. All of the curves show a very gradual rise to the peak value. The radon-222 emission rate reaches 99% of the peak value within 650,000 years in every source listed in Table 6-70.

Values for radon released from each tank are provided in Appendix E, Section E3.0.

Figure 6-43. Total Activity of Radionuclides that Produce Radium-226 in Tank C-203



6.5.4 Conclusions

The bounding doses for tritium and carbon-14 emissions are well below the performance objective of 10 mrem per year. The emission rate of radon-222 at the ground surface above the waste is well below the performance objective of 20 pCi/m^2/s. These estimated impacts are truly bounding for the following reasons:

- One-half the entire WMA inventories of tritium and carbon-14 is released in a gaseous form during the first year after closure. This ignores: 1) emissions that may occur prior to facility closure, 2) potential release rates from the waste being much smaller (e.g., carbon is in the form of carbonates and organics, which convert to carbon dioxide slowly), and 3) subsurface structures such as the tank dome and infiltration barrier that slow the diffusion rate.

- The doses for tritium and carbon-14 were calculated using a specific activity model that assumes all the water and carbon in plants comes from the air.
- The radon-222 emission rate estimates use only 15 ft of soil as a diffusion barrier even though the waste is greater than 15 ft from the ground surface.
- The radon-222 emission rate is the peak value at enormous times after site closure. This ignores movement of uranium away from its original location in the WMA. Any movement would be downward, increasing the radon-222 travel time to the ground surface. Increased travel time means lower radon-222 emission rates due to radioactive decay.

6.6 ALARA ANALYSIS

To keep exposures as low as reasonably achievable (ALARA), design, operations, and analysis projects must cooperate closely. The RPP Retrieval/Closure Program is committed to such integration. The design for closing the tank farms is expected to be optimized using the results of these studies.

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7.0 INTERPRETATION OF RESULTS

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7.0 INTERPRETATION OF RESULTS

This chapter provides an interpretation of the results developed in preceding chapters of the SST PA. The groundwater, air release, and intruder pathways are discussed. The chapter concludes with a review of the major limitations in the analysis, a presentation of conclusions and, finally, a path forward that addresses the major limitations of the SST PA.

7.1 GROUNDWATER PATHWAY

The groundwater is impacted by three sources of contamination from the WMA closure system: tank waste residuals, past releases, and ancillary equipment residuals. A distinct difference exists between estimated impacts from grouted tank waste residuals (Section 7.1.1) and from past releases (Section 7.1.2).

7.1.1 Tank Waste Residuals

Table 7-1 summarizes the impacts to groundwater resulting from the tank waste residuals after the closure of each WMA. Minimal risk to human health from grouted tank residuals is estimated to occur through the groundwater pathway. These results assume retrieval to HFFACO criteria, (i.e., less than 1% by volume per tank) (Ecology et al. 1989) and emplacement of surface barriers to infiltration.

Impacts are based on peak groundwater concentrations estimated at the WMA fenceline over the 10,000-year simulation period. The impacts of tank waste residuals from the reference case are below groundwater performance objectives for each WMA. In fact, the estimated impacts from WMAs C, B-BX-BY, A-AX, and T are more than 10 times below groundwater performance objectives for beta-photon dose, technetium-99, iodine-129, chromium, the all-pathways farmer, and the industrial radiological and nonradiological exposure scenarios. Impacts from grouted tank residuals are first observed in years 4000 to 6000 and peak in years 8000 to 10000.

Based on the reference case for the groundwater pathway, tank waste residuals impacts are below groundwater performance objectives.

7.1.2 Past Tank Waste Releases

As shown in Table 7-1, the groundwater impacts from past releases present a significantly different conclusion at the WMA fenceline compared to tank waste residual groundwater impacts. With the exception of WMA C, past groundwater release impacts exceed at least two MCLs (i.e., technetium-99 and beta-photon) for every WMA by over a factor of 10. The chromium performance objective is also exceeded for each WMA, except for WMA C. These impacts occur over the first 300 years after closure. Peak groundwater impacts from past releases are projected to occur by the year 2050, and then slowly subside. Groundwater concentrations are below performance objectives in approximately the year 2332 at the WMA fenceline due to natural attenuation. WMAs T and S-SX are the exceptions and do not meet performance objectives until approximately years 2490 and 2373, respectively. Leaks during waste retrieval do not alter the potential noncompliance situation in most WMAs (with the possible exception of WMA C), but instead exacerbate the level of noncompliance.

Table 7-1. Estimated Reference Case Groundwater Impacts at the Waste Management Area Fenceline

Performance Objective	Maximum Contaminant Level[a]				Exposure Scenarios[b]		
	Beta-Photon 4 mrem/yr	Tc-99 900 pCi/L	I-129 1 pCi/L	Cr 0.10 mg/L	All-Pathways Farmer 15 mrem	Radiological ILCR Industrial 1.0E-4 to 1.0E-5	WAC 173-340 Hazard Index Method B 1.0
WMA	***Tank Residuals***						
S-SX	◇	◇	◇	◇	◇	◇	◇
T	◇	◇	◇	◇	◇	◇	◇
TX-TY	◇	◇	◇	◇	◇	◇	◇
U	◇	◇	◇	◇	◇	◇	◇
C	◇	◇	◇	◇	◇	◇	◇
B-BX-BY	◇	◇	◇	◇	◇	◇	◇
A-AX	◇	◇	◇	◇	◇	◇	◇
WMA	***Past Releases***						
S-SX	●	●	◇	●	◇	●	●
T	●	●	◇	●	◇	●	◇
TX-TY	●	●	◇	●	◇	◇	◇
U	●	●	◇	●	◇	◇	◇
C	◇	◇	◇	◇	◇	◇	◇
B-BX-BY	●	●	◇	●	◇	◇	◇
A-AX	●	●	◇	●	◇	◇	◇

Below Performance Objective:

◇ Greater than a factor of 10

◇ Less than a factor of 10

Above Performance Objective:

● Greater than a factor of 10

● Less than a factor of 10

[a] Evaluated from year 2000 to 12032.

[b] Evaluated from year 2332 to 12032.

ILCR = incremental lifetime cancer risk

Health impacts estimated from exposure scenarios generally satisfy performance objectives because of the restriction placed on groundwater use until the year 2332, (i.e., 300 years after closure). The prohibition on groundwater use and well drilling has been implemented on the Central Plateau in a recent CERCLA Record of Decision for the 221-U Facility, also known as the Canyon Disposition Initiative (EPA et al. 2005), through the implementation of institutional controls until drinking water standards are achieved and EPA and Ecology authorize removal of restrictions. These "scenario" performance objectives as shown for WMAs T and S-SX are not met due to the estimated groundwater impacts from past releases extending beyond year 2332. WMA S-SX meets the scenario performance objectives shortly after closure (year 2373), while WMA T meets the objectives by year 2490. When the dose/ILCR of past releases is compared to that of tank waste residuals, the impacts are not significantly different.

A small number of contaminants actually drive the human health risk groundwater impacts from past releases. The reference case indicated that only 21 contaminants reach groundwater in measurable concentrations. Only six groundwater contaminants cause the exceedance of groundwater performance objectives: technetium-99, tritium, carbon-14, chromium, nitrate, and nitrite. The beta particle and photon radioactivity dose metric of 4 mrem/yr is also exceeded (Table 7-2).

Only six groundwater contaminants and the beta particle and photon radioactivity doses cause the exceedance of groundwater performance objectives.

Table 7-2. Reference Case Estimated Peak Impacts from Past Releases at the Waste Management Area Boundary (3 pages)

Contaminant	Peak Estimate at WMA Fenceline [a]	Groundwater MCL
Waste Management Area S-SX		
Beta particle and photon (mrem/yr)	●	4
Tritium (pCi/L)	●	20,000
Carbon-14 (pCi/L)	●	2,000
Technetium-99 (pCi/L)	●	900
Chromium (mg/L)	●	0.1
Nitrate (mg/L)	●	45
Nitrite (mg/L)	●	3.3
Waste Management Area T		
Beta particle and photon (mrem/yr)	●	4
Tritium (pCi/L)	◇	20,000
Carbon-14 (pCi/L)	●	2,000
Technetium-99 (pCi/L)	●	900
Chromium (mg/L)	●	0.1
Nitrate (mg/L)	●	45
Nitrite (mg/L)	●	3.3
Waste Management Area TX-TY		
Beta particle and photon (mrem/yr)	●	4
Tritium (pCi/L)	◇	20,000
Carbon-14 (pCi/L)	◇	2,000
Technetium-99 (pCi/L)	●	900
Chromium (mg/L)	●	0.1
Nitrate (mg/L)	●	45
Nitrite (mg/L)	●	3.3

Table 7-2. Reference Case Estimated Peak Impacts from Past Releases at the Waste Management Area Boundary (3 pages)

Contaminant	Peak Estimate at WMA Fenceline [a]	Groundwater MCL
Waste Management Area U		
Beta particle and photon (mrem/yr)	●	4
Tritium (pCi/L)	◇	20,000
Carbon-14 (pCi/L)	◇	2,000
Technetium-99 (pCi/L)	●	900
Chromium (mg/L)	●	0.1
Nitrate (mg/L)	◇	45
Nitrite (mg/L)	●	3.3
Waste Management Area C		
Beta particle and photon (mrem/yr)	◇	4
Tritium (pCi/L)	◇	20,000
Carbon-14 (pCi/L)	◇	2,000
Technetium-99 (pCi/L)	◇	900
Chromium (mg/L)	◇	0.1
Nitrate (mg/L)	◇	45
Nitrite (mg/L)	◇	3.3
Waste Management Area B-BX-BY		
Beta particle and photon (mrem/yr)	●	4
Tritium (pCi/L)	◇	20,000
Carbon-14 (pCi/L)	◇	2,000
Technetium-99 (pCi/L)	●	900
Chromium (mg/L)	●	0.1
Nitrate (mg/L)	◇	45
Nitrite (mg/L)	◇	3.3

Table 7-2. Reference Case Estimated Peak Impacts from Past Releases at the Waste Management Area Boundary (3 pages)

Contaminant	Peak Estimate at WMA Fenceline [a]	Groundwater MCL
Waste Management Area A-AX		
Beta particle and photon (mrem/yr)	●	4
Tritium (pCi/L)	◇	20,000
Carbon-14 (pCi/L)	◇	2,000
Technetium-99 (pCi/L)	●	900
Chromium (mg/L)	●	0.1
Nitrate (mg/L)	◇	45
Nitrite (mg/L)	●	3.3

Below Performance Objective:

◇ Greater than a factor of 10

◇ Less than a factor of 10

Above Performance Objective:

● Greater than a factor of 10

● Less than a factor of 10

[a] Estimates were based on groundwater MCLs evaluated from year 2000 to 12032.

Table 7-3 presents the level of potential immobilization or remediation of past releases necessary to meet the MCL for technetium-99 at each WMA fenceline. Peak groundwater estimates for technetium-99 are found in Chapter 4.0. The results indicate that extensive remediation of the mobile contaminants from past releases contributing to groundwater impacts would be necessary in most of the WMAs (with the exception of WMA C) for the purpose of meeting performance objectives.

Table 7-3. Level of Potential Immobilization of Past Releases Needed to Meet Maximum Contaminant Level for Technetium-99 [a]

WMA	Immobilization Percent of Mobile Inventory Required
S-SX	99
T	99
TX-TY	98
U	95
C	None
B-BX-BY	90
A-AX	91

[a] Technetium-99 groundwater concentration performance objective = 900 pCi/L.

7.1.3 Releases from Residual Waste in Ancillary Equipment

The waste transfer infrastructure for each WMA includes a complex system of pipelines (i.e., transfer lines), MUSTs, diversion boxes, vaults, valve pits, and other miscellaneous structures that are referred to as ancillary equipment. Waste remaining in the MUSTs was assumed retrieved to a residual volume proportional to that required under the HFFACO for the 200-Series tanks (i.e., 30 ft^3) (Ecology et al. 1989).

Lambert (2005) conducted an extensive literature review of historical records to determine the volume of waste in the plugged pipelines within each WMA. Pipeline residual inventories were estimated based on the plugged pipeline volumes given in Lambert (2005). Inventory contained in plugged pipelines is assumed to remain in the WMA after closure. Non-plugged pipelines were assumed to have negligible waste residuals.

Once the volume of residual waste remaining in all the ancillary equipment was estimated, the inventory associated with the waste volume was calculated by multiplying the volume by the average chemical composition of the waste in the SSTs within the tank farm. The residual inventories developed for the plugged or blocked pipelines and MUSTs are believed to represent the bulk of the contamination that will remain in ancillary equipment at closure.

The SST PA results suggest that the technetium-99 residual waste within all the ancillary equipment has a negligible impact on groundwater quality. Table 7-4 presents the maximum impacts estimated for ancillary equipment for technetium-99. Two maxima are shown for each WMA to capture the differing release mechanisms assumed for MUSTs and pipeline residual wastes. Concentrations attributable to these sources in groundwater are quite small. Analysis of other mobile contaminants supports a similar conclusion that the groundwater impact from ancillary equipment is also quite small (Chapter 4.0).

The SST PA results suggest that the technetium-99 residual waste within all the ancillary equipment has a negligible impact on groundwater quality.

Table 7-4. Peak Groundwater Impacts from Ancillary Equipment Residuals at the Waste Management Area Fenceline for Technetium-99

Waste Management Area	Peak Technetium-99 Groundwater Concentration from Pipeline Residual Waste pCi/L	Year	Peak Technetium-99 Groundwater Concentration from MUST Residual Waste pCi/L	Year
S-SX	5.48	2094	0.066	8191
T	NA	NA	0.0805	8191
TX-TY	2.17	2094	3.78	8191
U	31.5	2094	3.80	8191
C	0 [a]	5711	0.184	10461
B-BX-BY	0 [a]	5711	0.310	10461
A	NA	NA	0.242	10461

[a] Contaminant concentration was not above effective zero of 1.0E-02 pCi/L for radionuclides or 1.0E-05 mg/L for nonradionuclides.
NA = not applicable; no plugged pipelines within the waste management area

7.2 INADVERTENT INTRUDER AND AIR IMPACTS

Table 7-5 provides a comparison of estimated dose to the performance objectives for protection of the inadvertent intruder and the protection of air resources in the year 2532, or 500 years after closure.

Table 7-5. Air and Intruder Impacts in Year 2532 – Ratio of Estimated Dose to Performance Objective

WMA	Intruder Impacts [a]					Air Impacts [b]	
	Worst Sources and Location	Reference Case		Sensitivity Cases		Dose from Tritium and Carbon-14	Radon Flux
		Well Driller	Rural Pasture	Suburban Gardener	Commercial Farm		
A-AX	AX-102 [c]	◆	◆	●	◆	◆	◇
B-BX-BY	B-101 [d]	◆	◆	◇	◆	◆	◇
C	C-201 [c, d]	◆	◆	◇	◆	◆	◇
S-SX	SX-115 [c]	◆	◆	●	◆	◇	◆
T	T-106 [c]	◆	◆	◇	◆	◆	◆
TX-TY	TX-118	◆	◆	●	◆	◆	◆
U	U-106	◆	◆	◇	◆	◆	◆

Below Performance Objective:

◆ Greater than a factor of 10

◇ Less than a factor of 10

Above Performance Objective:

● Less than a factor of 10

[a] Performance objectives are 500 mrem for the well driller and 100 mrem/yr for chronic exposure scenarios.

[b] Performance objective is 10 mrem/yr for air dose and 20 pCi/cm^2/s for radon flux.

[c] Tank residual plus past release for intruder impacts.

[d] Tank residual plus past release for air impacts.

7.2.1 Inadvertent Intruder

Impacts include both acute and chronic dose. Reference case exposure scenarios are well driller (acute dose) and rural farmer with a dairy cow (chronic dose). Alternate exposure scenarios considered for purposes of a sensitivity analysis are chronic dose for a suburban resident with a garden and for a commercial farmer.

The analytical results indicate that only the sensitivity case of the suburban resident with a garden exceeds the performance objective for three WMAs (Table 7-5). Doses are generally more than a factor of 10 below applicable performance objectives. Chapter 5.0 and Appendix E present a complete analysis of both acute and chronic dose impacts to the inadvertent intruder.

The analytical results indicate that only the suburban resident with a garden for the inadvertent intruder exceeds the performance objective.

7.2.2 Impact of Volatile Radionuclide Release to the Air

Also shown in Table 7-5 are estimates of air impacts from the release of radionuclides from tank residuals. The air release analysis provides a bounding estimate of impacts. Impacts to the air from radionuclides (i.e., tritium and carbon-14) after tank closure are below their performance objectives. This naturally follows because the inventory of these radionuclides left after closure is projected to be quite small. The DOE time of evaluation is 1,000 years and the point of evaluation is at the surface cover above the waste.

The emission rate of radon-222 at the ground surface above the waste is also well below the performance objective of 20 $pCi/m^2/s$. Radon is the daughter of radium, whose inventory increases over time through the decay of uranium. Section 6.5 and Appendix E present the complete analysis for the radon-222 air concentration above each source within each WMA.

Impacts to the air from volatile radionuclides after tank closure are below their performance objectives.

7.3 SENSITIVITY AND "WHAT IF" ANALYSIS

A series of sensitivity and "what if" cases were developed to complement the reference case analysis. In the sensitivity and "what if" analyses, reference case input parameter values for those parameters affecting contaminant migration were varied. A range of parameter values reflecting variability in the engineered and natural components of the system were evaluated.

These results were used to: 1) determine parameters strongly affecting estimated peak or maximum groundwater concentrations (Section 7.3.1), 2) evaluate the impacts of single barrier underperformance on total system performance (Section 7.3.2), and 3) estimate a cumulative variability (potentially remaining at closure) around peak or maximum value estimates (Section 7.3.3). Sections 7.3.1 through 7.3.3 summarize those results with respect to specific source terms (e.g., contaminant/waste type combinations). Complete results of the sensitivity and "what if" analyses are contained in Section 4.11.

7.3.1 Sensitivity of Engineered Components and Geologic Features

The sensitivity and "what if" analyses evaluated parameter-specific effects on estimated groundwater contamination levels relative to the reference case estimates at WMAs C and S-SX. The selected analyses were grouped into three categories:

- Recharge (infiltration) estimates
- Source term characteristics (e.g., inventory, inventory location, release rate)
- Hydrologic parameters (e.g., vadose zone and aquifer hydraulic conductivity, vadose zone thickness between waste and the water table, contaminant K_d).

The impact of a given parameter change was quantified by taking the ratio of the peak or maximum estimate from the sensitivity and "what if" case to that of the reference case. When comparing parameter effects, larger ratio values above unity indicate larger potential peak values and increased sensitivity to changes in that parameter. Ratio values below unity also indicate sensitivity to the parameter change, but with the potential for decreased groundwater impact. Ratios of unity indicate no change in peak values and no sensitivity to the parameter change.

Table 7-6 lists the parameters that most strongly affected the potential for peak value increases relative to base case estimates for specific contaminant/waste type combinations. Parameter value changes that decreased peak values, although not shown here, were also estimated (Section 4.11). Those parameters which most affected maximum values differed somewhat, depending on the contaminant/waste type combination.

- For tank waste residual releases, changes to release rate values (diffusion coefficients) and post-barrier emplacement recharge rates, particularly after barrier design life, were the most significant parameters.
- For mobile contaminants in past releases, the center of mass migrated most rapidly and changes to the operational period recharge rate (prior to surface barrier emplacement) significantly impacted peak groundwater concentrations by a factor of 2. Post-barrier recharge rates had little effect on mobile contaminant groundwater concentrations. In all cases for mobile contaminants, no parameter value change caused more than about a three-fold increase in the peak value ratios.
- For semi-mobile contaminants in past releases, sorption effects and post-barrier recharge rates were significant. For all but one case (i.e., reduction of K_d from 0.2 to 0.1 mL/g at WMA C), contaminant sorption retarded migration rates enough so that it was the post-barrier emplacement recharge rates that carried the center of the contaminant mass to the unconfined aquifer. Therefore, changes to post-barrier recharge rates and changes to sorption coefficients were significant.

Table 7-6. Comparison of Sensitivity and "What If" Case Parameter Change Effects that Increase Peak Values

Contaminant	Waste Type	WMA	Parameter	Peak Value Ratios
Mobile	Tank residual	C	Diffusion coefficient	3.2
			Post-barrier recharge	1.8 to 2.1
			Hydrologic parameters	1.1 to 1.5
Mobile	Tank residual	S-SX	Diffusion coefficient	3.2
			Post-barrier recharge	2.1 to 2.3
			Hydrologic parameters	1.2 to3.3
Mobile	Past release	C	Operational recharge	1.7
			Hydrogeologic properties	1.1 to 1.5
Mobile	Past release	S-SX	Operational recharge	1.5
			Hydrologic parameters	1.1 to 2.7
Semi-mobile	Past release	C	Sorption coefficient (K_d)	7.5
			Post-barrier recharge	3.0 to 3.4
			Hydrologic parameters	1.1 to 2.9
Semi-mobile	Past release	S-SX	Sorption coefficient (K_d)	1.7
			Post-barrier recharge	4.0
			Hydrologic parameters	1.0 to 3.3

7.3.2 Effect of Barrier Underperformance on the Waste Management Area Closure System

Multiple barriers have been assumed in this analysis to minimize to the extent possible environmental contamination effects from wastes that remain in the WMAs after closure. These barriers have a direct impact on the groundwater migration pathway. In accordance with a defense in depth philosophy, three barriers (i.e., a surface cover, the grouted tank structure, and the vadose zone) are assumed to operate independently and redundantly to prevent unacceptable groundwater contamination levels for tank residuals at all WMA fencelines. For past releases, two barriers (i.e., the surface cover and the vadose zone) are assumed to mitigate the impacts of past releases contaminants on groundwater at the WMA fencelines. To gain perspective on the robustness of total system performance, the impacts of single barrier underperformance were evaluated using a combination of sensitivity and "what if" case results.

To estimate the effect of underperformance of a particular barrier, the parameters were identified that quantified the barrier function. These included recharge rates (history and rates) for the surface cover and contaminant release rate for the grouted tank structure. For the vadose zone, these included hydraulic properties and the thickness of the vadose zone between the waste and the unconfined aquifer. Then, increases in peak values resulting from parameter value changes were selected from the sensitivity and "what if" case results (expressed as maximum to maximum value ratios). Finally, relevant maximum value ratios for a given barrier were multiplied to derive a cumulative underperformance factor (this same process is used to estimate the cumulative high side variability factor described in Section 7.3.3). Multiplication of the reference case maximum value by this factor estimates the maximum value increase due to degradation of overall system performance because of underperformance of that barrier.

Table 7-7 estimates potential increases in peak values for mobile contaminants in tank residuals for underperformance of the surface cover, the grouted tank structure, the vadose zone, and the engineered system (surface cover plus grouted tank structure). Of the individual barriers, the largest impact occurs from grouted tank structure performance. Enhanced release rates because of increased diffusion rates or advective release provided a possible range of degraded performance. The largest impact was estimated if the total engineered system underperforms.

Table 7-7. Effects of Barrier Underperformance on Total System Performance for Tank Residual Waste

Barrier	Significant Parameters	Waste Management Area	
		C	S-SX
Surface cover	Post-barrier recharge	1.8	2.0
Grouted tank structure	Advection/diffusion	3.2 to 7.9	3.3 to 9.0
Vadose zone	Hydrologic parameters	1.2	1.2
Engineered system (surface cover and grouted tank structure)	Post-barrier recharge and advection/diffusion	5.7 to 14.2	6.7 to 18

Table 7-8 estimates potential increases in peak values for mobile (K_d = 0 mL/g) and semi-mobile (K_d= 0.2 mL/g) contaminants in past releases for underperformance of the surface cover or the vadose zone. For the semi-mobile contaminants, an additional significant parameter in the vadose zone is the K_d value. Barrier underperformance with respect to K_d value was estimated as a reduction in the K_d value from 0.2 to 0.1 mL/g. This parameter provides the largest underperformance impact for past releases, particularly at WMA C where the cumulative underperformance factor of 26.1 was estimated.

Table 7-8. Effects of Barrier Underperformance on Total System Performance for Past Releases

Barrier	Significant Parameters	Mobile		Semi-Mobile	
		WMA C	WMA S-SX	WMA C	WMA S-SX
Surface cover	Post-barrier recharge	1.4	1.2	5.2	4.0
Vadose zone	K_d, hydrologic parameters	3.0	2.4	26.1	2.1

7.3.3 Cumulative Variability Around the Peak Estimated Values

The cumulative variability analyses were completed to estimate a range of plausible future groundwater contamination levels caused by variability in multiple features and processes influencing contaminant migration simultaneously. To complete these calculations, the results from single feature or process variability analyses that expressed features or processes as parameters and variability as parameter ranges (e.g., specific sensitivity and "what if" analyses summarized in Section 7.3.1) were combined.

To combine results of single parameter variability analyses into a cumulative variability calculation, sets of relevant sensitivity and "what if" case results were selected. The selected set of analyses and associated results were those known to influence contaminant migration for specific initial contaminant/waste type conditions (e.g., technetium-99 in past releases, Section 4.11.4). These results, expressed as peak ratios, estimated changes in groundwater contamination levels with respect to the reference case result because of feature or process variability (e.g., see Table 4-61 in Section 4.11.4 and Table 7-6). Cumulative variability was then calculated as the product of all peak ratios that either increased or decreased groundwater contamination estimates relative to the reference case result (e.g., high or low cumulative variability factors, respectively). Multiplication of the reference case peak value by the high and low factors yielded a range of estimated plausible peak contamination levels around the reference case value. Given the current state of knowledge, only cases involving variability that is unlikely to be reduced by future data collection or closure actions (e.g., irreducible variability) were considered.

Such estimates are qualitative because the validity of the product factor requires that various processes represented by these linear factors are independent of each other as they simultaneously influence contaminant migration, and that the estimated peak impact occurs within the period of simulation. Corroborating multiple parameter change sensitivity analyses were completed to generate peak-to-peak value ratios for comparison with the cumulative parameter variability factors. These comparisons showed very good agreement (e.g., from no

difference to no more than a factor of 2 difference) indicating that the assumption of independent variables is largely valid.

Table 7-9 presents these cumulative estimates of variability about the peak. The results indicate that higher variability exists in the estimate of moderately mobile contaminants compared to mobile contaminants. For this SST PA and based on the results shown in Table 7-9, an order of magnitude factor of 10 above and below reference case groundwater impact estimates was selected to represent the level of variability remaining in estimates of peak groundwater contamination at closure. The accuracy of the method does not support a finer level of detail. A similar estimate of cumulative variability based on a probabilistic uncertainty analysis has been documented in DOE-RL (1999).

The variability associated with mobile contaminants is more important than the variability associated with semi-mobile contaminant because the mobile contaminants dominate the groundwater impacts with respect to the performance objectives. Semi-mobile contaminants are shown to have a higher variability factor, on the order of 19 to 36. However, their contribution to groundwater performance metrics is small when compared to the impacts from mobile contaminants.

Table 7-9. Cumulative Variability Estimates Around Peak Values

	Past Releases		Tank Waste Residuals
	Mobile	Semi-Mobile	Mobile
WMA C cumulative high side variability factor	11.2	19.3	3.9
WMA C cumulative low side variability factor	0.2	0.2	0.1
WMA S-SX cumulative high side variability factor	6.4	36.0	8.9
WMA S-SX cumulative low side variability factor	0.1	0.1	0.2

The cumulative variability factors indicate the consequences of irreducible variability in closure system features and processes that affect eventual groundwater contamination levels. With this variability (about an order of magnitude above and below the reference case estimates), a range of groundwater contamination levels and associated health effects (i.e., health effects are assumed directly proportional to contamination levels) can be incorporated into the evaluation of the closure system performance. In Tables 7-1 and 7-2, several reference case health effect estimates are within a factor of 10 of their respective performance objectives and if a ten-fold increase in contamination levels is assumed, the likelihood of achieving performance objectives at the WMA fenceline is lessened. These general observations can be made for assumed ten-fold increases and decreases in groundwater contamination levels relative to the reference case:

- For tank residuals, the majority of associated health effects at the WMA fenceline remain below respective performance objectives for increased levels (e.g., in the reference case, all performance objectives were satisfied). In a few cases, health effects exceed performance objectives by a factor of less than 10. For decreased levels, all WMA fenceline health effects are more than 10 times less than the performance objectives.
- For past releases, more performance objectives were exceeded or satisfied at the WMA fenceline relative to the reference case results, with increased or decreased levels,

respectively. With the exception of WMA C, at least one performance objective is exceeded at the WMA fenceline over the total estimated health effects range. At WMA C, where no performance objectives are exceeded in the reference case, a few exceedances occur at the high end of the groundwater contamination range that are within an order of magnitude of the performance objective.

Given these comparisons over the range of plausible outcomes provided by the cumulative variability analysis, a sense of the degree of compliance with performance objectives has been determined. When the total range of estimated contamination levels as defined by this analysis is considered, it is concluded generally that performance objectives are expected to be met from tank residual sources and not from past releases at the WMA fenceline.

It is important to collect information where possible to improve the estimated range of future groundwater contamination levels. The sensitivity and "what if" case analyses show areas where improvements are plausible and useful (e.g., tank residual inventory and release mechanisms). Conversely, the analyses also indicate areas where additional information will have limited usefulness for refining groundwater contamination estimates. Those areas where significant benefit of future data collection has been identified are described in Sections 7.5 and 7.7. These results, along with other aspects of system performance, will be taken into account to make risk-informed decisions regarding tank system closure.

7.4 RESULTS FROM THE "WHAT IF" ANALYSIS

Table 7-10 summarizes the results of the "what if" analyses described in Chapter 3.0 and evaluated in Chapter 4.0. Though the analysis includes semi-mobile contaminants and is replicated for WMA S-SX, only results for WMA C and mobile constituents (e.g. technetium-99 and hexavalent chromium) are presented here. Table 7-10 addresses the variability or uncertainty in the reference case as examined through the analysis of alternative conceptualizations as listed under the column titled "Conditions." Questions shown under the column heading "Conditions" are answered for tank waste residual and past release peak impacts to groundwater. The degree of impact or variability is based on a comparison of peak or maximum estimated values over the entire reference case simulation to the peak or maximum estimated impact associated with the various conditions shown. The results of this analysis are summarized below.

- Factors influencing the variability of tank waste residual impacts often do not influence the variability of past leak impacts.
- Timing of placement of a surface barrier to infiltration only affects past releases impacts and does not change estimated impacts to groundwater from tank waste residuals.
- Complete failure of the grout matrix encapsulating the tank waste residual increases the impact of tank waste residuals on groundwater by a factor of nearly 8 times the reference case estimates.
- Increased infiltration over the closed waste site (by an assumed farming scenario) increased the estimated impacts of tank waste residuals on groundwater by a factor of 12.2 but had no effect on past leak impacts.

- Leaving more waste in the tanks at closure increases the peak groundwater impacts in direct proportion to the amount assumed to remain in the reference case. For example, 10 times more waste than assumed in the reference case increases the peak impacts to groundwater by a factor of 10.
- Variability in the magnitude of past leak estimates increases the estimate of peak groundwater impacts from this waste source by a factor of 4.
- The presence of clastic dikes within the waste site is estimated to have only a marginal impact on groundwater impacts when compared to the impact of past releases.
- The results shown in Table 7-10 for WMA C are substantially replicated by the results estimated for WMA S-SX with the exception of the variability associated with estimated past releases. Past releases in WMA S-SX tend to be larger and are better characterized by historical information and through field investigations. The variability of peak groundwater impacts for WMA S-SX from the selected range of past leak quantities vary from a low of 0.40 to a high of 1.44 times the reference case results. In contrast, WMA C peak groundwater estimates from past releases vary from a low of 0.42 to a high of 4.01.

7.5 LIMITATIONS

The SST PA presents a comprehensive analysis of the impacts from the closed WMA system. However, limitations are inherent in the interpretation of results. These limitations are discussed below.

7.5.1 Inventory

Estimated human health impacts are directly related to the amount of waste causing those impacts (i.e., source). Tank waste residual estimates have only been validated against a fairly small number of retrieved tanks and only for a limited number of tank waste retrieval technologies. Estimated ancillary equipment inventories are more uncertain; however, the total inventory is anticipated to be less than the tank residual inventory.

Past release inventory assumptions also play a significant role in the cleanup process associated with each WMA. Considerable effort has been expended in evaluating the historical WMA operational records and reprocessing records that can provide estimates of this waste source. The variability in each past release estimate is inversely related to the size of the event. Larger releases are generally better known than smaller releases. Large past releases typically have much more characterization data than smaller releases. Past release impacts are directly correlated to the quality of this source of data.

7.5.2 Use of Waste Management Areas C and S-SX Information to Simulate Other Waste Management Areas

Site-specific geohydrologic data were used to simulate WMAs C and S-SX. Geohydrologic data for WMAs C and S-SX were extrapolated to support the simulation of all other WMAs. Past releases were simulated at the same depth for each WMA giving rise to peak concentrations occurring in the same year across WMAs within the 200 East Area and 200 West Areas, respectively.

Table 7-10 Alternatives to the Reference Case or "What if" Conditions Summary of Results [a] (3 pages)

Barrier/Feature	Alternative	Condition	Description/Action	Peak Groundwater Concentration Ratios Relative to Reference Case
Surface Barrier	1	What is the impact of not closing the farm until 2032?	An earlier (year 2020) placement of the final closure interim barrier (as opposed to year 2032 for the base case).	Tank waste residual groundwater impacts – 1.00
				Past release groundwater impacts – 0.54
	2	What is the impact of not closing the farms by 2032?	A later (year 2050) placement of the final closure barrier will be examined.	Tank waste residual groundwater impacts – 0.98
				Past release groundwater impacts increased – 1.39
	3	What is the impact of an interim barrier by 2010 over major leaks?	An interim barrier will be placed over the large leaks in WMA C beginning in the year 2010.	Tank waste residual – NA
				Past release groundwater impacts – 0.41
	4	What is the impact of episodic infiltration?	The impacts of episodic infiltration are considered sufficiently analyzed in past work by Smoot et al. (1989).	Tank waste residual groundwater impacts unchanged
				Past release groundwater impacts unchanged
	5	What if the barrier subsides?	Degradation of the effectiveness of the barrier due to localized subsidence. It is believed that any useful analysis of this issue at this time requires a more advanced closure and barrier design conceptualization.	NA
				NA
	6	What if irrigated farming occurs after the loss of passive control (500 years)?	Based on information in Mann et al. (2001), an enhanced infiltration rate of 50mm/yr will be assumed to occur over the closed tank farm with the cover assumed removed. Enhanced infiltration would begin at the end of passive institutional controls/sensitivity case.	Tank waste residual groundwater impacts – 13.94
				Past release groundwater impacts – 1.00
	7	What if the barrier fails at the end of passive controls?	Assume that the barrier fails at the end of passive controls (500 years). Failure is assumed through loss of silt-loam mix and infiltration increases to background of 3.0 mm/yr in the 200 East Area (Last et al. 2004a).	Tank waste residual groundwater impacts increased – 1.91
				Past release groundwater impacts – 1.00
	8	What if the barrier fails prior to the end of passive controls?	Assume that the barrier fails at the end of 300 years. Failure is assumed through loss of silt-loam mix and infiltration increases to background of 3.0 mm/yr in the 200 East Area (Last et al. 2004b).	Tank waste residual groundwater impacts – 1.79
				Past release groundwater impacts – 1.00

Table 7-10 Alternatives to the Reference Case or "What if" Conditions Summary of Results [a] (3 pages)

Barrier/Feature	Alternative	Condition	Description/Action	Peak Groundwater Concentration Ratios Relative to Reference Case
Grouted Tank/ Structure	9a	What if the 100-Series tanks leak during retrieval?	Simulate a retrieval leak loss of 8,000 gal per tank for a 100-Series tank that is assumed to be by the modified sluicing retrieval method.	Tank waste residual groundwater impacts – NA
				Past release groundwater impacts – 0.22
	10	What if retrieval leaks occur at the 200-Series tanks, regardless of the use of dry retrieval methods?	Simulate the effects of a 400-gal leak for each 200-Series tank.	Tank waste residual groundwater impacts – NA
				Past release groundwater impacts – 0.00
	11	What if the grout does not provide the level of encapsulation expected?	Conduct a bounding analysis of this situation based on the assumption of an advection-dominated release for residual tank wastes.	Tank waste residual groundwater impacts – 7.85
				Past release groundwater impacts – NA
	12	What if more tank waste residue is left than expected?	This possibility is addressed by increasing the tank waste residual inventory by a factor of 10.	Tank waste residual groundwater impacts – 10.0
				Past release groundwater impacts – NA
	13	What if a retrieval leak occurs over a past leak prior to tank stabilization?	Simulate an 8,000-gal retrieval leak occurring over a past leak.	Tank waste residual groundwater impacts – NA
				Groundwater impacts increase over past release – 1.24
	14	What if the tanks behave like a "bathtub" and collect water, which then releases suddenly?	The void space left within the tank after grout fill is minimal that this is considered a highly unlikely scenario and is bounded by other analyses.	NA
				NA

Table 7-10 Alternatives to the Reference Case or "What if" Conditions Summary of Results [a] (3 pages)

Barrier/Feature	Alternative	Condition	Description/Action	Peak Groundwater Concentration Ratios Relative to Reference Case
Vadose Zone	15	What if potential preferential paths were missed during characterization?	Incorporate clastic dike effects for the retrieval leak simulation of 8,000 gal for a 100-Series tank that is assumed to be retrieved by the modified sluicing method of retrieval.	Tank waste residual – NA
				Groundwater impacts equivalent to 0.39 of reference case.
	16	What if the groundwater level does not decline as projected?	Simulate the effect by decreasing the vadose zone thickness by 2 m.	Tank waste residual groundwater impacts – 1.07
				Past release groundwater impacts – 1.13
	17	What if the depths of past leaks were underestimated?	Increase the depth of a past leak by 20 ft.	Tank waste residual – NA
				Past release groundwater impacts – 1.57
	18	What if past leak contamination was underestimated?	Estimate plausible high estimates applicable to WMA C.	Tank waste residual – NA
				Past release groundwater impacts – 4.01
	19	What if remediation of up to 50% of past leaks were possible?	Simulate the removal or immobilization of 5%, 25%, and 50% of mobile contaminants from past leaks.	Tank waste residual – NA
				Past release groundwater impacts – 0.05, 0.25, and 0.50
	20	What is the effect of assuming vadose zone anisotropy for the vadose zone geologic units?	Simulate assuming isotropic saturated hydraulic conductivity for the individual geologic units within the vadose zone.	Tank waste residual impacts – 0.84
				Past release groundwater impacts – 1.64
Unconfined Aquifer	21	What if the plume moves faster in the aquifer than predicted?	Increase the saturated hydraulic conductivity.	Tank waste residual impacts – 0.75
				Past release groundwater impacts – 0.76

[a] Based on results from mobile contaminants for WMA C as found in Section 4.11

NA = not applicable

7.5.3 Tank Waste Residual Release Model

Diffusion-controlled release models are applied to porous solid waste forms (cemented or grouted wastes). The effective diffusion coefficient is based on leach test data and reflects retardation of a constituent in the matrix (i.e., by reaction with the cementitious matrix or adsorption onto matrix additives), as well as the physical hindrance in pores and the tortuosity of the matrix. The current release model assumes that contaminants are not bound in the grout matrix and are available for diffusion release. Credit is not taken for the tank structure, the grout form, or potential reducing conditions within the grout or waste material that may sequester parts of the inventory currently considered to be completely mobile (e.g., technetium-99). All tanks are assumed to release at the same time.

7.5.4 Recharge Rates

The recharge rates for the surface cover in this analysis are expected to be reduced as the specific detailed design proceeds. Very recent work, *Recharge Data Package for the 2005 Integrated Disposal Facility Performance Assessment* (Fayer and Szecsody 2004), recommends that much lower recharge rates for the surface cover and post-surface cover times are attainable based on extensive field, laboratory, and computer studies.

7.5.5 Impacts Do Not Include Surrounding Facilities

The surrounding waste disposal facilities in close proximity to the SST WMAs have or will eventually have impacts to human health. Currently, the impacts associated with groundwater, air, and intruder analyzed in the SST PA will be integrated into the evaluation of impacts to be included in the composite analysis to allow a cumulative estimate of impacts from all waste disposal facilities (including the SST WMAs) to groundwater. The composite analysis is an integrated assessment of groundwater impacts required by DOE O 435.1 to address cumulative effects.

7.5.6 Limited Sensitivity Analysis

The results of the sensitivity analysis are presented in Section 4.11 for a limited number of closure design and residual waste assumptions. The sensitivity analysis was limited to parameters associated with WMAs S-SX and C. Future analyses will incorporate data from other SST WMAs as well as additional conceptualizations. As engineered components or geologic features of the model are improved, modified, or better understood, the sensitivity analysis will be adjusted in an appropriate manner.

7.6 CONCLUSIONS

The SST PA implements guidance from DOE O 435.1, HFFACO, *Atomic Energy Act of 1954*, NRC (2000), CERCLA, RCRA, and HWMA requirements. The regulatory process as described in the HFFACO, Appendix I (Ecology et al. 1989) is important to understanding the use and acceptance of this work. This guidance provides the direction for much of the content and approach used in the analysis. Foremost among this guidance is the recognition that the analyses will be iterative, building on the results of previous and ongoing analyses, field studies, design improvements and engineering studies, and the closure strategy as defined in the HFFACO, Appendix I (Ecology et al. 1989).

The information and analysis provided in this SST PA allows DOE to address decisions on tank closure using a defense in depth approach to safety. The SST PA analysis defined the engineering components and geologic features that are relied upon to produce the long-term performance of the WMA closure system, and subjected each barrier to a rigorous analysis (Section 4.11). Features of this analysis required the definition of a reference case, definition of key parameters and their respective ranges (i.e., sensitivity analysis), and the analysis of the impacts of alternative conceptual models of the WMA closure system. The sensitivity analysis allowed the prioritization of those elements of the WMA closure system that were important to overall performance and indicated where additional information or design changes were needed to achieve and maintain the highest level of performance possible.

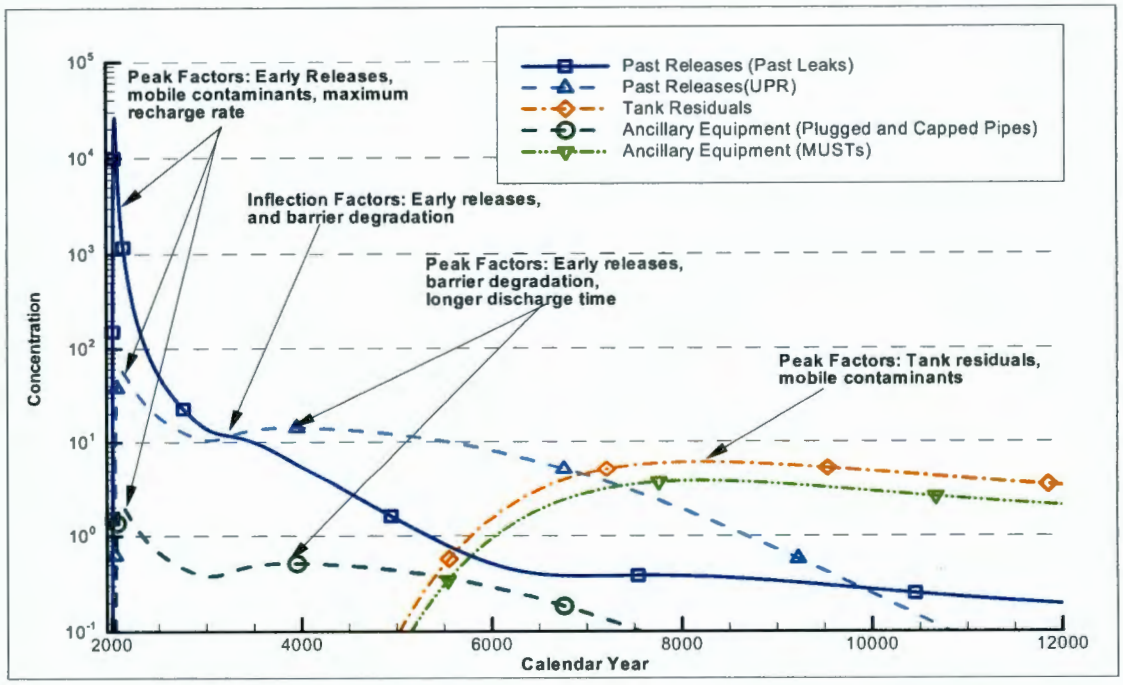
The SST PA examined long-term risks from three primary contaminant pathways: groundwater, inadvertent intruder, and air. The groundwater pathway displays unique attributes that are a result of infiltration, past practices, and waste migration. As described in Chapter 4.0, past releases that are not chemically or physically immobilized will impact groundwater over the next 300 years. Limited impacts from past releases were inferred from contaminant sampling data in groundwater monitoring wells near WMAs S-SX, T, TX-TY, U, and B-BX-BY. Grouted tank waste residuals are not estimated to impact groundwater until the years 4000 to 6000. The generic double-peaked characteristic shown in the curves in Figure 7-1 typifies groundwater impact results and is important to understanding the results and conclusions.

The SST PA results support the following actions:

- Retrieval of tank wastes and the grouting of tank residuals
- Institution of interim measures to reduce the impacts of past releases to the groundwater
- Examination of the potential for more aggressive final corrective measures to remediate past releases beyond what is possible through interim measures.

These estimates of risk are relatively insensitive to the expected range of parameters controlling their transport and to the alternative conceptualizations considered. With the exception of WMAs TX-TY and U, groundwater impacts are more than an order of magnitude below all performance objectives (Table 7-1). WMAs TX-TY and U are below groundwater performance objectives but by less than an order of magnitude. Groundwater impacts from facilities outside the WMA are expected to have already occurred or will occur in a manner similar to past releases (i.e., over the next 300 years), and not significantly alter the groundwater impacts estimated from tank waste residuals. Impacts through other pathways are also expected to be small. Specifically, air impacts from radionuclides remaining in tank waste residuals are expected to be inconsequential. The results of the intruder analysis also support waste retrieval and grouting of the tank residuals. With sampling of the tank waste residual to confirm that the residual waste conforms to the assumptions used in the SST PA (i.e., tank waste residual inventory), this analysis supports retrieval of the waste and the grouting of tank waste residuals if retrieved to acceptable levels.

Figure 7-1. Schematic of Typical Groundwater Impact Results



Groundwater impacts from past releases are estimated to be more than a factor of 10 above groundwater performance objectives. Though not shown to eliminate this problem, interim measures, particularly interim surface barriers to recharge, have been recommended in the past by a number of analysts (Myers 2005; Knepp 2002a, 2002b). Interim measures are measures that can be implemented relatively quickly and usually through a much simplified regulatory process. These analyses, including the SST PA, only examine risk to human health, and are not sufficiently comprehensive to support a final decision; instead, they contribute to the discussion that can lead to a decisive action. Interim barriers to infiltration are supported for those WMAs having large and/or incontrovertible past releases, (i.e., WMAs S-SX, T, B-BX-BY, and U).

The impact from past releases on groundwater is simply too large in relation to the stringent groundwater performance objectives to be mitigated under the assumptions used in this analysis even if interim measures are put in place immediately. For this reason, the SST PA results support the application of the RCRA Corrective Action process to formalize the regulatory approach and support examination of measures beyond interim measures to address groundwater impacts estimated from past releases in or near each WMA. With implementation of institutional controls that prevent groundwater use for 300 years at the WMA fenceline, all groundwater performance objectives are met through natural attenuation except for WMAs S-SX and T, which meet the groundwater performance objectives at their fenceline boundary in the years 2373 and 2490, respectively.

With implementation of institutional controls that prevent groundwater use for 300 years after closure at the WMA fenceline, all groundwater performance objectives are met through natural attenuation except for WMAs S-SX and T.

7.7 PATH FORWARD

A continued iterative approach to improving the information used in this SST PA is recommended. The SST PA documents the current baseline but, by the nature of any baseline, changes will occur and must be addressed. This change is driven by insights from laboratory studies, field efforts, numerical analyses, and maturation of closure design.

The methodology implemented in the SST PA naturally results in the development of a path for future work that is directed to reduce uncertainty where possible, and to validate basic assumptions that support the SST PA. The following provides such a path.

7.7.1 Improved Estimates of Past Release Inventories Lost to the Vadose Zone

Estimates of past release inventories that are consequential to the potential compliance status of a WMA will be improved. Large past releases are relatively well characterized; however, in some WMAs, risks are exceeded for relatively small release volumes (i.e., less than 6,000 gal). These releases have not been investigated in the field under the RCRA Corrective Action process. Most of these releases are categorized in Field and Jones (2005) as either small leaks or having no evidence of higher leak volumes. Information from soil sampling in the leak area or additional data from geophysical techniques may refine the associated inventory of these leak volumes. Past releases into the vadose zone are clearly indicated as the controlling factor for the estimates of early (i.e., less than 400 years after closure) groundwater impacts. Selected past release estimates will be refined for use in future analyses.

7.7.2 Use of Site-Specific Data to Model Each Waste Management Area

Site-specific data will be used to simulate WMAs T, TX-TY, U, A-AX, and B-BX-BY. Results based on site-specific information for WMA C and WMA S-SX were used as the templates for analysis for the 200 East Area and 200 West Area WMAs, respectively. Future revisions to the SST PA will use separate, WMA-specific analyses. Specific sensitivity analyses associated with issues within each WMA will also be identified and analyzed.

7.7.3 Development of Improved Tank Waste Residual Release Models

Releases of mobile contaminants from grouted tank residuals will be a focus of future work. The analysis of tank waste residuals demonstrated that their impact was below every groundwater performance objective considered. However, the closeness of the predicted impacts to the very stringent groundwater performance objectives for mobile contaminants demonstrated the need for additional work to better ensure future compliance. Work in four areas is indicated by this finding:

- Knowledge of the tank residual inventory
- Improved model of tank waste residual release mechanisms
- Improved understanding of the longevity of the tank waste form
- Additional data collection in selected areas to reduce uncertainty.

Groundwater impacts vary linearly with tank waste residual inventory. Representative estimates of mobile long-lived constituents for tank residuals are necessary to further demonstrate compliance with relevant performance objectives. Sampling of tank waste residuals after retrieval is the only source of this information and will be collected as part of the closure process.

The second area in need of additional investigation is the development of an improved model of tank waste residual release mechanisms. The current approach uses a single diffusional release model for each mobile constituent. The entire inventory is assumed available for instantaneous diffusional release to the environment. Laboratory, theoretical, and numerical work based on measurements taken from actual waste contents remaining in tanks after waste retrieval will be used to improve this functional area of the model.

Waste form longevity and failure mechanisms will receive a more in-depth analysis. The current analysis assumed the remaining tank waste residual is covered with grout whose primary properties remain intact for the period of the analysis. The impact of complete loss of grout integrity would worsen conditions by a factor of approximately 8 compared to the advective release case (Section 4.11.2). Given the early nature of predictions regarding the quantity of waste likely to remain in the tank after waste retrieval is complete, analysis of the longevity and associated failure mechanism of the grout form will be undertaken. Similarly, the impacts of the current tank structure underlying the waste (e.g., the steel liner and concrete shell) on contaminant release have not been addressed. A more specific simulation of the grouted tank structure will also be undertaken.

7.7.4 Estimation of the Level of Impacts from Surrounding Facilities on Impacts from Waste Management Areas

The current SST PA focuses on impacts from facilities and conditions found within the SST WMAs. Future work will incorporate the impacts from other surrounding cribs, ditches, and other disposal sites, including the double-shell tanks, into the impacts estimated in this analysis.

7.7.5 Expansion of the Sensitivity Analysis

The sensitivity analysis will be expanded to include additional alternative conceptualizations to further test the robustness of the WMA closure design and assumptions regarding waste remaining in the closed system. Future sensitivity analyses will incorporate data from other SST WMAs.

7.8 REFERENCES

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