APPENDIX N
VADOSE ZONE FLOW AND TRANSPORT

The description of the movement of groundwater and solutes through the vadose zone from the ground surface to the water table of the underlying, unconfined aquifer is a major element in estimation of impacts on groundwater quality and human health for this *Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington (TC & WM EIS)*. At the Hanford Site, past operations, current practices, and proposed future activities will affect groundwater conditions for long periods of time. For this reason, the assessment of potential impacts relies on mathematical modeling of vadose zone processes rather than monitoring or measurement of conditions. The scope of vadose zone analysis for this *TC & WM EIS* is large, including contributions from tanks and ancillary equipment at 18 high-level radioactive waste tank farms, six sets of cribs and trenches (ditches) immediately associated with tank farm activities, proposed new Integrated Disposal Facilities for radioactive and hazardous waste, and closure of the Fast Flux Test Facility. In addition, approximately 380 facilities not included in the scope of decisions of this *TC & WM EIS* are analyzed for their contribution to cumulative impacts.

The primary objective of vadose zone analysis is to estimate the rates and magnitudes of movement to the unconfined aquifer of water and solutes introduced with natural recharge, planned liquid discharges, leaks, spills, and disposals. The estimates of release to the vadose zone described in Appendix M and transport through the unconfined aquifer described in Appendix O interface closely with the vadose zone analysis described in this appendix. A secondary objective of vadose zone analysis is to provide an understanding of the influence of the proposed Black Rock Reservoir on future Hanford Site (Hanford) hydrologic conditions. Estimates of human health impacts, based on integration of estimates of the rate of release (see Appendix M) and the rate of transport through the vadose (Appendix N) and saturated (see Appendix O) zones are presented in Appendix Q. Comparisons of impacts within and across alternatives are presented in Chapters 5 and 2, respectively.

The balance of this appendix comprises a description of the technical approach to vadose zone analysis, a summarization of results for *Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington (TC & WM EIS)* alternatives, and a discussion of the sensitivity analysis of major parameters incorporated into the analysis of vadose zone processes. Although best available data and models are used to construct the analysis described in this appendix, uncertainty in results remains. This uncertainty derives from variability in natural conditions such as rates of precipitation and recharge and spatial heterogeneity of soil types, as well as lack of knowledge in areas such as the applicability of specific models to site-specific locations and conditions and the type of climate to be experienced in the future.

N.1 TECHNICAL APPROACH TO VADOSE ZONE ANALYSIS

The technical approach to vadose zone analysis involves selection of the upper-level framework for the analysis and implementation of framework specifics, including specification of the spatial extent of model study areas, characterization of geologic conditions, development of model grid configurations, and establishment of values of model parameters. The following sections describe these two elements of the vadose zone analysis.

N.1.1 Upper-Level Approach

The upper-level approach involves consideration of the boundaries of the model domain, the degree of integration of vadose and saturated zone analysis, and the establishment of initial and boundary conditions for the model. The required spatial extent of the model domain is that of the Hanford Site, approximately 1,450 square kilometers (560 square miles), with model depth ranging from 10 to 200 meters. The time frame for the analysis is from the start of site operations in calendar year 1944 out to 10,000 years in the future. The 10,000-year period of analysis is longer than the 1,000-year period

recommended in the U.S. Department of Energy (DOE) guidance for performance assessment of low-level radioactive waste and deactivated high-level radioactive waste (HLW) facility closure (DOE Guide 435.1-1) but adequate to capture the longer vadose zone travel times of select constituents of potential concern for the *TC & WM EIS* analysis.

The preferred approach to groundwater modeling is full integration of vadose and saturated zone analysis with transient location of the water table determined as part of the solution of a single model. Because of the large extent of the model domain, the small size of subareas of interest, and the long time period for analysis, the implementation of this approach is not practical with state-of-the-art computing capabilities. A second approach to integration of vadose and saturated zone analysis would be the specification of a single, large-scale saturated zone model; specification of smaller subarea models for integrated vadose and saturated zone analysis; and integration of the subarea models with the single, large-scale saturated zone model. Because of the rather small size of the required subareas and the time requirements for computation of transient water table locations for multiple subareas, this approach is also not practical at the current time. Specific issues that complicate integration of the MODFLOW (modular three-dimensional finite-difference groundwater flow model) saturated zone and STOMP (Subsurface Transport Over Multiple Phases) vadose zone–saturated zone models are the short duration of the transient period to be represented by the simulations and the spatial variation of the water table.

The upper-level approach adopted for this *TC & WM EIS* groundwater analysis is the development of a single, large-scale saturated zone model followed by the development of multiple small-scale vadose zone–only models that are coupled with the saturated zone model through equivalent specification of boundary conditions to provide a consistent, integrated analysis of transient groundwater conditions. The development, calibration, and implementation of the large-scale saturated zone model are described in Appendix L. Simulation of the vadose zone subareas is accomplished using the STOMP computer code (White and Oostrom 2000, 2006). The STOMP model uses an integrated-volume, finite-difference approach to solve nonlinear water and solute transport balances for the vadose zone. Features of the STOMP model used in the *TC & WM EIS* analysis include (1) a three-dimensional representation of geology, hydraulic properties, and grid geometry; (2) temporal and spatial variability of groundwater recharge at the ground surface; (3) temporal and spatial variability of water and solute injection at any horizontal location and vertical depth; and (4) water and solute output fluxes at specified surfaces. Three-dimensional representation was selected to incorporate spatial heterogeneity of geologic and recharge conditions and to explicitly simulate the complexity of travel time behavior due to lateral spreading and preferential flow reflecting local conditions. The relationships of moisture content and pressure and moisture content and hydraulic conductivity within the vadose zone were simulated using the van Genuchten and Mualem models (van Genuchten 1980; Mualem 1976). These models contain seven adjustable parameters: saturated moisture content, residual moisture content, saturated hydraulic conductivity for three spatial directions, and two additional empirical constants that are determined by comparison with site data.

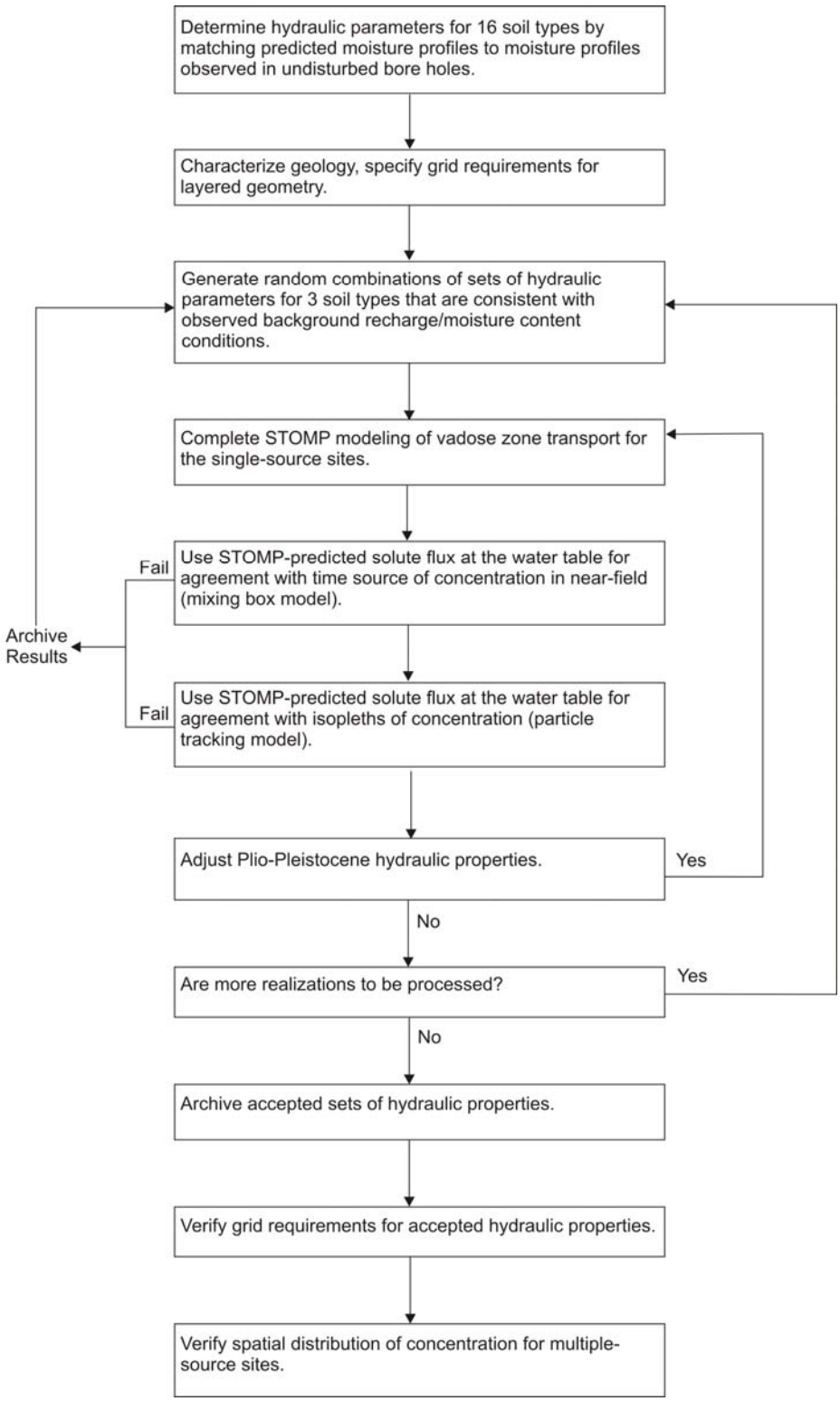
N.1.2 Vadose Zone Model Implementation

More than 400 subarea models are required for analysis of *TC & WM EIS* alternative and cumulative analysis sites. Each of these is simulated as a rectangular box where the upper surface represents the ground surface and the lower surface, the water table. The thickness of this box, different for each subarea site, is established from the long-term steady state of the unconfined aquifer model. Boundary conditions for the upper surface at each site are a specified recharge determined by technical guidance (DOE 2005) and zero flux of solute. Boundary conditions for the lower surface are atmospheric pressure and a zero gradient of solute. Boundary conditions for each of the four sides of the box are zero flow of water and solute.

The pattern of the horizontal grid for each subarea was based on the aqueous discharge from the source. The grid pattern and model extents were incorporated to limit the effect the boundary conditions and node size had on the model conditions. All nodes within the source were equal in size and were bounded by the source site boundary. Grid sizes could increase or decrease by the harmonic rule, meaning node lengths could increase or decrease by one and a half the adjacent node length. Sources with no aqueous discharge could have node length no greater than 20 meters (66 feet) within the source site. The node size could increase by the harmonic rule to at least 120 meters (39 feet) from the source boundary. Sources with aqueous recharge were categorized as moderate (<1 meter [3 feet] per year) or heavy (>1 meter [3 feet] per year). Moderate recharge sites had a grid length of no larger than 5 meters (16 feet) within the source site. The maximum 5-meter (16-foot) grid length continued to 50 meters (164 feet) from the site boundary. The grid size increased by the harmonic rule to a distance 150 meters (492 feet) from the site boundary. The heavy recharge site had a grid length of no larger than 5 meters (16 feet) within the source site. The maximum 5-meter (16-foot) grid length continued to 50 meters (164 feet) from the site boundary. The grid size increased by the harmonic rule to a distance of 170 meters (558 feet) from the site boundary.

Given these conditions, development of the model was completed by specifying values of hydraulic properties for 16 Hanford soil types and subarea-specific geology and grid dimensions. In summary, the process for the selection of hydraulic parameter values involved the matching of predicted to measured borehole moisture content profiles for all 16 soil types followed by the matching of randomly generated to observed unconfined aquifer conditions for 3 primary soil types. It also provided for consistency with values of saturated hydraulic conductivity determined in the calibration of the saturated zone model and with area-specific geology and grid size requirements. A flow diagram for the process is presented as Figure N–1, and greater detail is provided in the following paragraphs.

A stepwise, iterative procedure was applied to determine area-specific geology and grid dimensions and to identify values of hydraulic properties that best match conditions observed at the site. In an initial step, values of vadose zone parameters were determined for the 16 soil types by matching moisture content profiles predicted using the van Genuchten relationship to moisture content profiles measured in 140 undisturbed vadose zone boreholes. Values of saturated hydraulic conductivity were restricted to ranges consistent with the calibrated saturated zone model. An example of the match between predicted and observed moisture contents for an undisturbed borehole in the 200-East Area is presented as Figure N–2. The blue dots in the figure represent moisture content determined by the neutron scattering method. The red line is the model fit to the borehole data. The horizontal gray lines represent soil contact changes. The soils represented in this figure are Hanford Gravel, Hanford Sand, Plio-Pleistocene Silt, and Plio-Pleistocene Gravel. At this stage, sensitivity analysis was performed for generic 200-East and 200-West Areas to establish grid size requirements for accurate computations. Given this information, the interpretation of borehole data was applied to assign soil types for each of the approximately 400 study areas on a grid block–specific basis. An example of the interpreted borehole data is presented as Figure N–3, where the lithology of the cross-section is vertically exaggerated. Figure N–3 represents a geologist's interpretation of the subsurface geology at B- and BX-Tank Farms in the 200-East Area. Single or multiple cross sections of interpreted borehole data were used to specify a three-dimensional spatial distribution of soil types that is encoded into STOMP input files for each of the study areas. An example of this translation into STOMP input data is presented in Figure N–4 for the TX Tank Farm in the 200-West Area. The STOMP data of Figure N–4 for the 200-West Area show layers of Plio-Pleistocene soils present at the TX Tank Farm that are not present in the borehole data of Figure N–3 for the 200-East Area at the B- and BX-Tank Farms. Not all of the 16 soil types are present at all locations; within the specific cross section presented as Figure N–4, for example, only 7 of those soil types are found. This contrast is representative of the level of detail of the spatial distribution of soil types that is captured in the interpretation and translation process.



Key: STOMP=Subsurface Transport Over Multiple Phases.

Figure N–1. Flow Diagram for Selection of Values of Vadose Zone Hydraulic Parameters

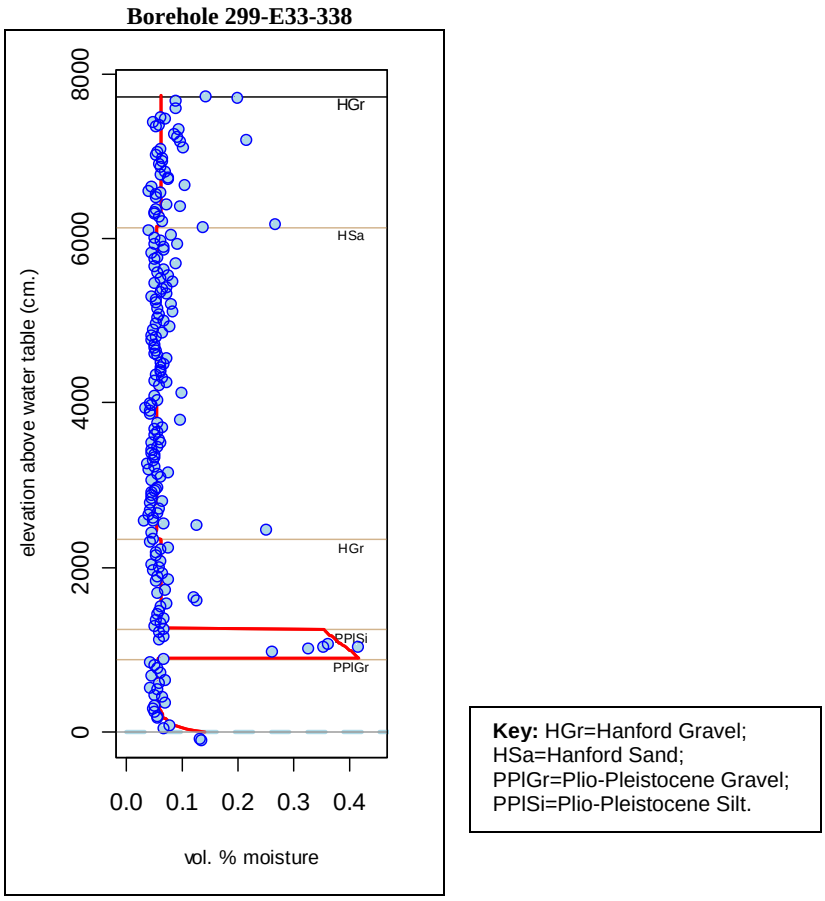


Figure N–2. Predicted and Measured Moisture Content Profiles

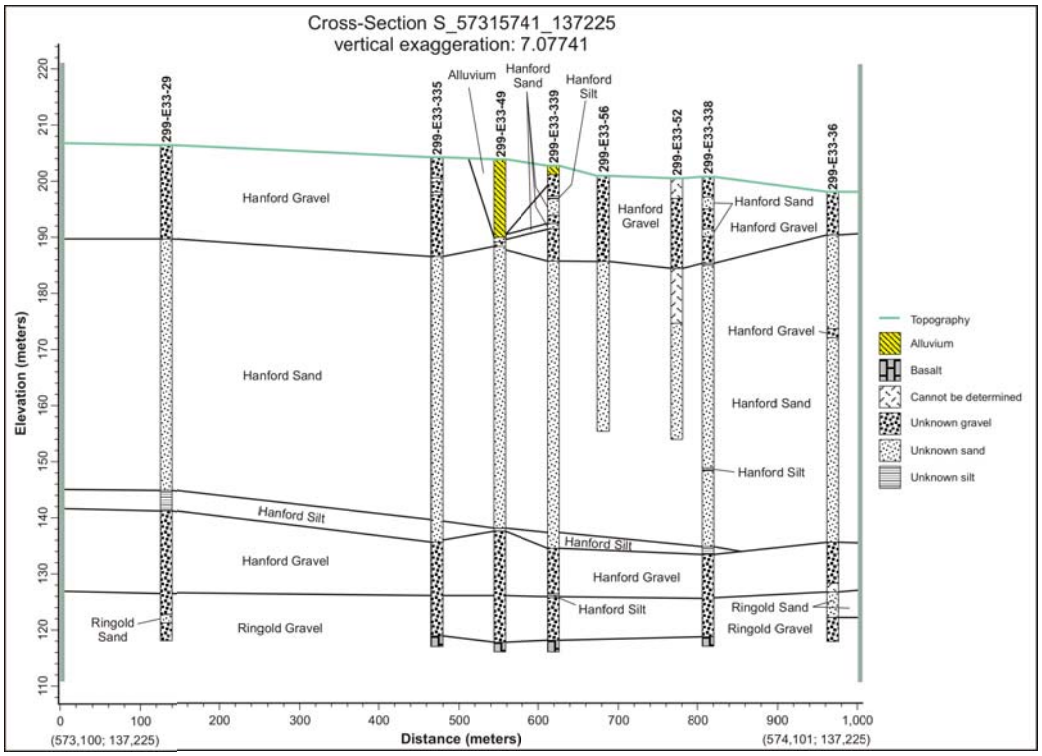


Figure N–3. Borehole Stratigraphy Data

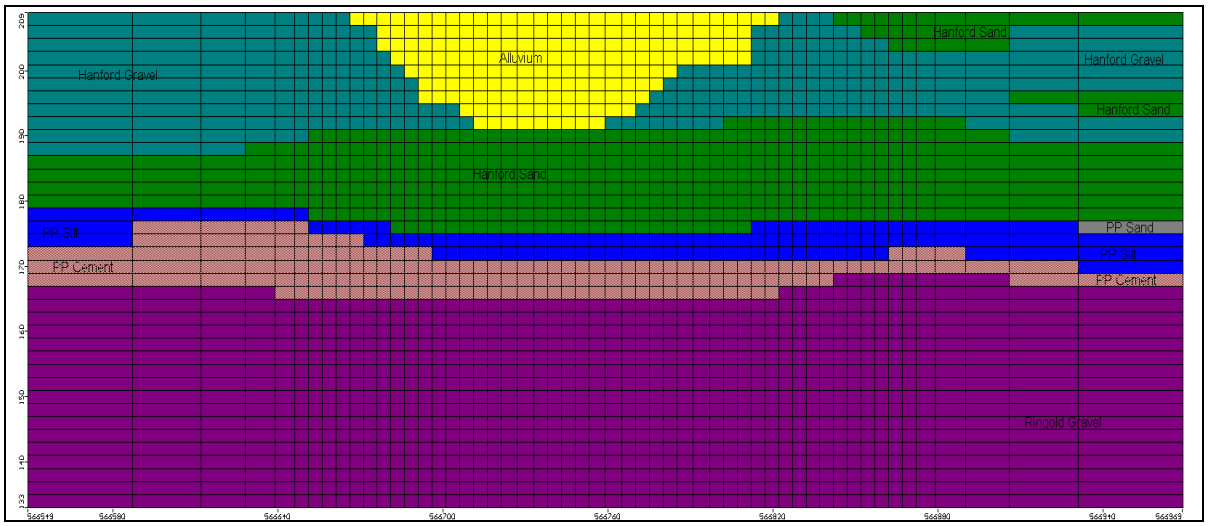


Figure N–4. Vertical Cross Section of a Grid for a STOMP Vadose Zone Model Volume for the TX Tank Farm (200-West Area)

The final element of the model development process, the establishment of final values of the van Genuchten parameters, was accomplished by selecting parameter values that match conditions observed in the unconfined aquifer. Two data sets were employed: (1) observed conditions in the unconfined aquifer that could reasonably be associated with a single source in the vadose zone; and (2) observed conditions in the unconfined aquifer, primarily concentrations of hydrogen-3 (tritium), that are associated with a group of sources. The first data set was used to select the parameter values; the second, to verify the final set of parameter values. The three sets of concentration data for the unconfined aquifer for single-source sites were (1) the concentration of beta activity below the BY Cribs, (2) the beta activity below the BC Cribs, and (3) the activity of iodine-129 in the vicinity of the 216-T-26 Crib.

The review of area-specific geology established that three soil types, Hanford Gravel, Hanford Sand, and Ringold Gravel, jointly represent more than 90 percent of the sediments present in the vadose zone at Hanford. Also, a travel time sensitivity analysis conducted for simple layered geometry established that the movement of water and solute through the vadose zone is largely controlled by these three soil types, with a secondary contribution from Plio-Pleistocene Silt in the 200-West Area. In particular, this finding is applicable for the three areas for which single-source data are available. Accordingly, the refinement of hydraulic parameter values focused on Hanford Gravel, Hanford Sand, and Ringold Gravel. For these three soil types, a systematic search of the parameter space was conducted. To ensure that the entire space of admissible parameter values was investigated, a statistical search and screening were performed. The search involved specification of the range of values for each parameter and random selection of values from uniform distributions defined over the range. The screening involved calculation of the moisture content at a specified constant rate of recharge and comparison thereof with the range of moisture content observed at the site. The step of the procedure identified 18 million combinations of sets of hydraulic parameter values that met the initial screening requirement.

The simulation of movement through the vadose at the three single-source sites was implemented using the STOMP computer code. Predicted fluxes of solute in the water were then used to estimate concentrations in the unconfined aquifer; in the near-field, a mixing-box model was used, and at distances removed from the source, a particle tracking model. At this stage, hydraulic properties of the Plio-Pleistocene Silt were adjusted as needed to match conditions at the 216-T-26 Crib. Sets of values that passed each of these tests were judged acceptable for use in vadose zone analysis. This step of the analysis is described in the following paragraphs using the BY Cribs as an example.

A time series of measurements of gross-beta activity and technetium-99 concentrations at a single location in the unconfined aquifer below the BY Cribs is presented as Figure N–5. The gross-beta data include contributions from beta-emitters other than technetium-99, while more recently, concentrations of technetium-99 have been measured separately and reported in addition to the concentrations of gross-beta activity. Using *TC & WM EIS* data for inventory of technetium-99, historical dates of aqueous discharge and current values of vadose zone hydraulic parameters, the time series of concentration of technetium-99 below the BY Cribs was estimated using the STOMP model and is presented in Figure N–6. The predicted concentration profile reflected in that figure shows an early peak due to rapid movement of the large initial aqueous discharge and a long-term plateau due to a more gradual release of technetium-99 retained in the vadose zone. The early peak of the predicted technetium-99 profile occurs at the same time as the early peak of the measured total beta profile (see Figure N–5) but is lower because of the presence of radionuclides other than technetium-99 among beta emitters. The concentration level measured and predicted for technetium-99 for the current time period are in general agreement. Thus, the predicted concentration profile for technetium-99 shows qualitative agreement with the reported concentration of gross-beta activity, supporting continued investigation of this set of values for the vadose zone hydraulic parameters.

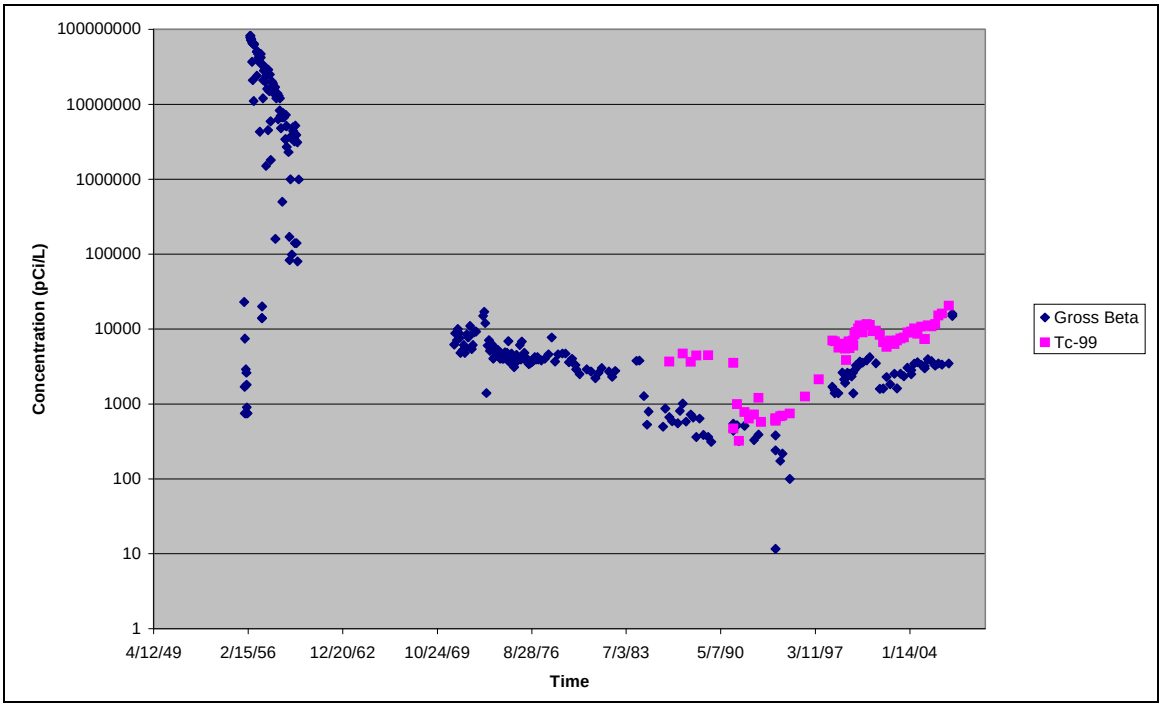


Figure N–5. Time Series of Measured Gross Beta Activity Below the BY Cribs (observed at well 299-E33-7)

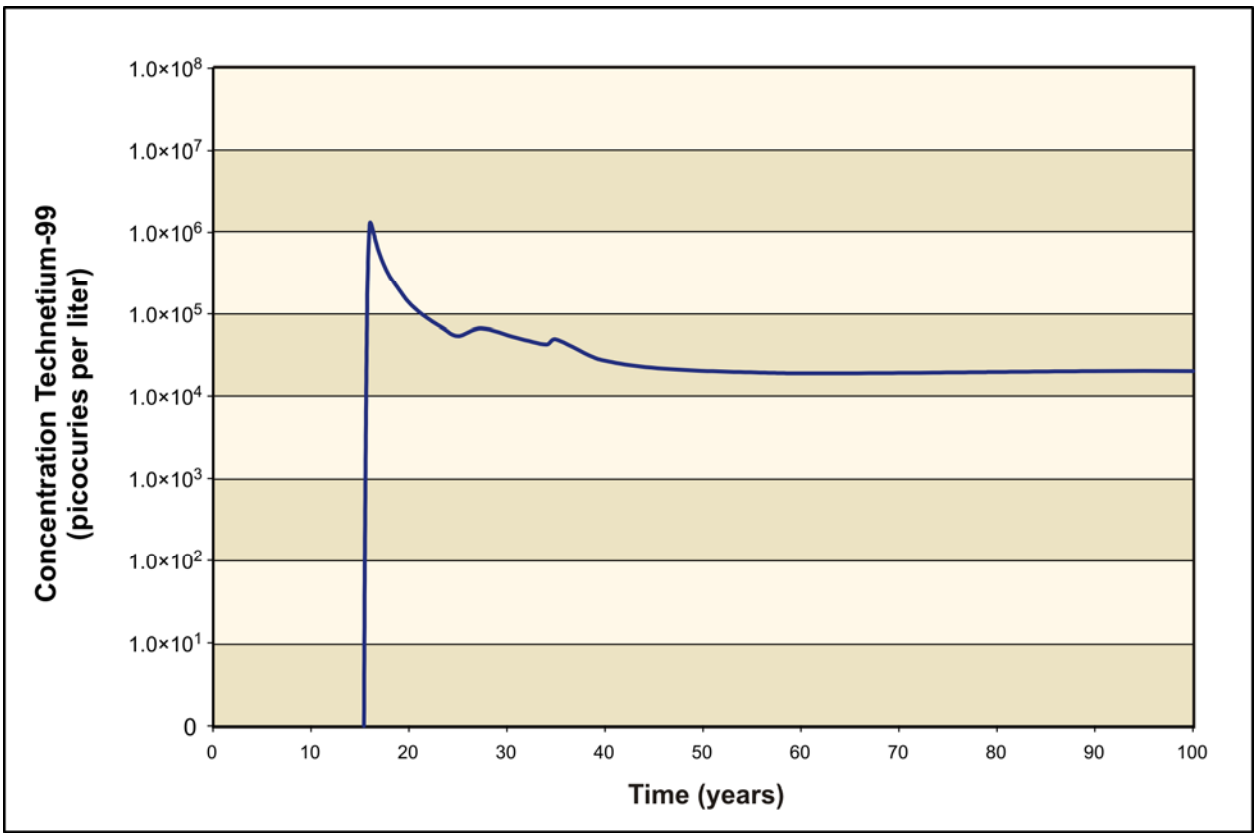
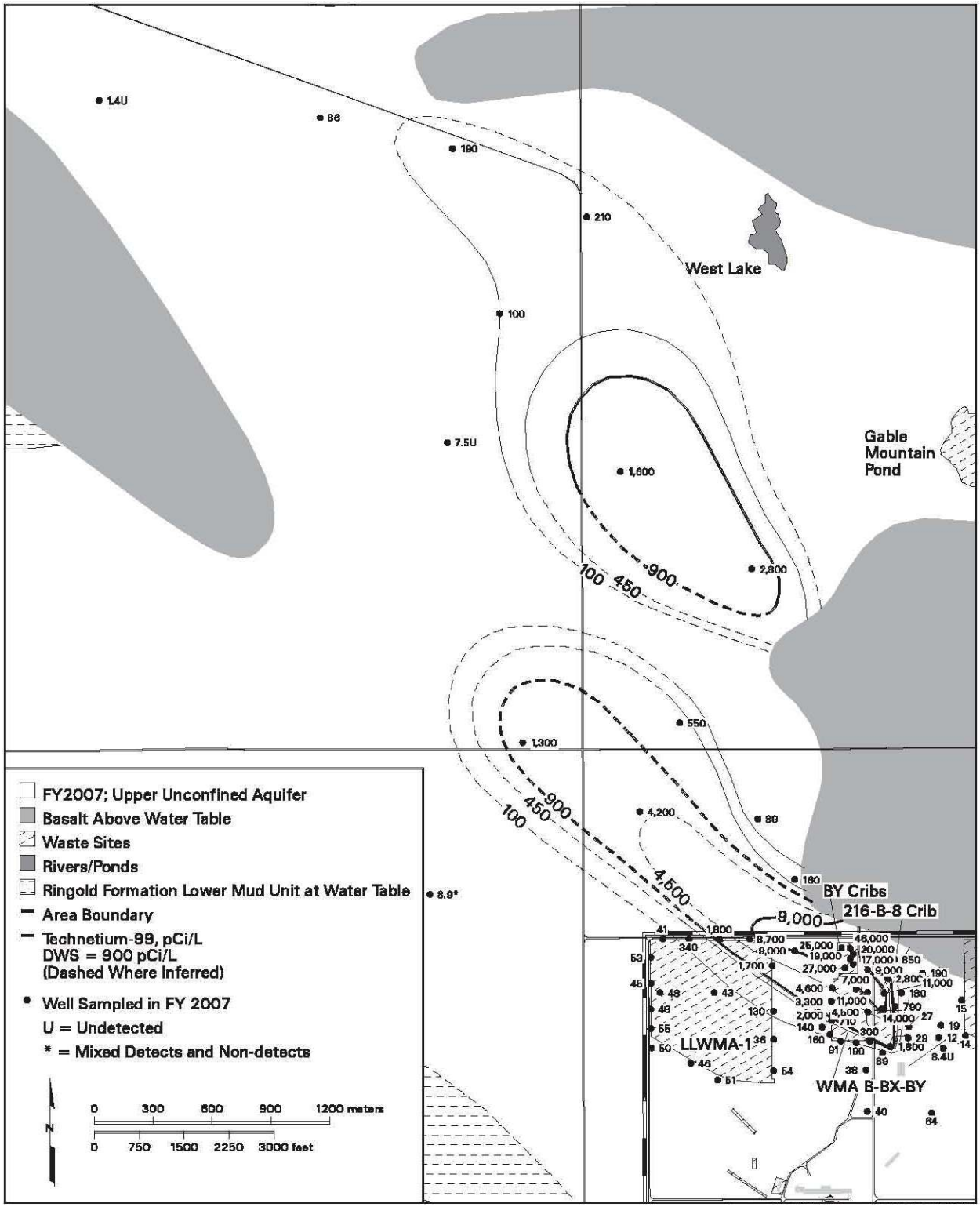


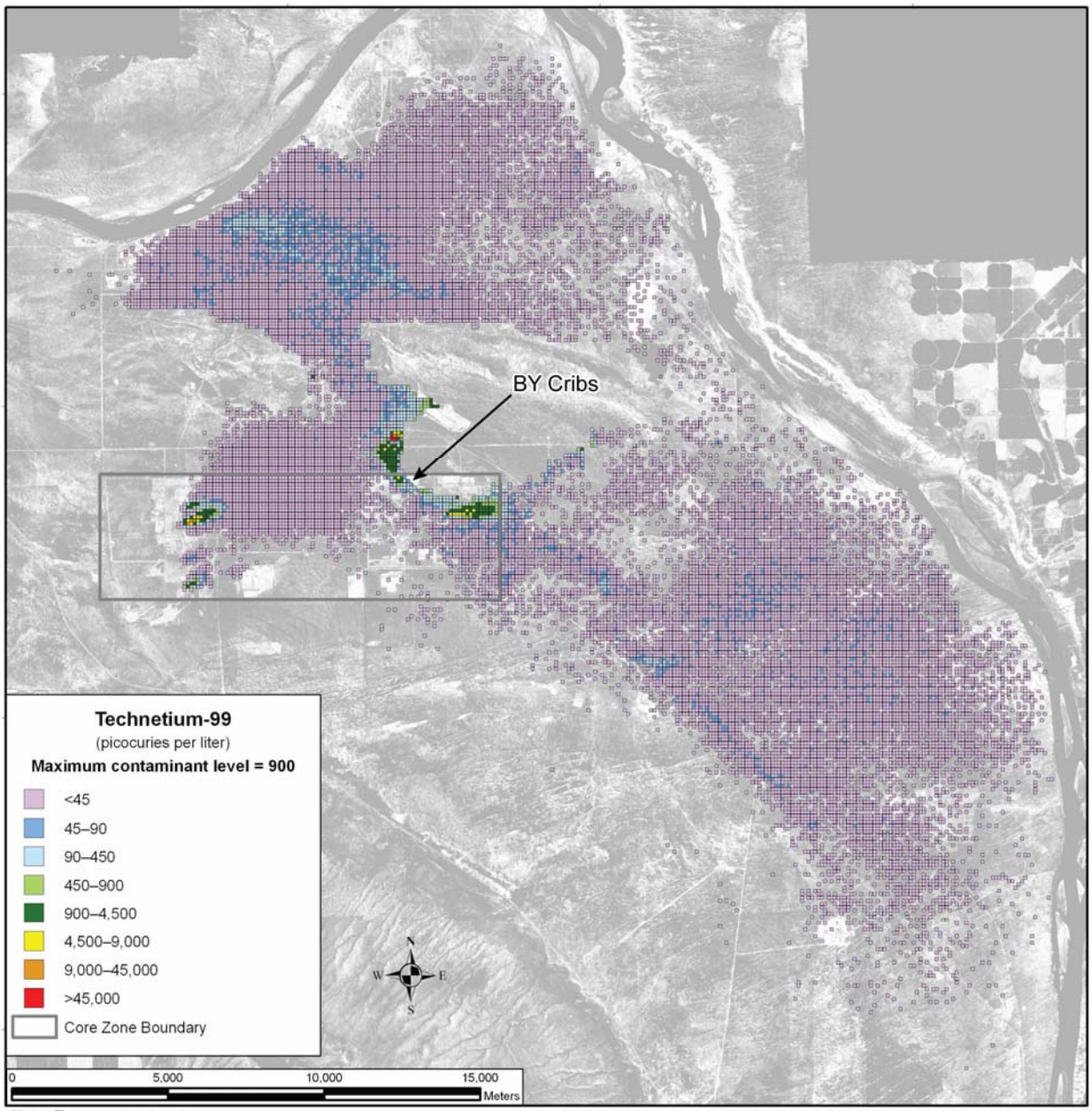
Figure N–6. Time Series of Predicted Concentration of Technetium-99 Below the BY Cribs

In addition to reports of time series of concentrations at single locations, the site monitoring program reports estimates of the spatial distribution of contaminants at specific points in time. Estimates of isopleths of concentration of technetium-99 near the BY Cribs based on measurements reported for 2007 are presented in Figure N–7. These data were used to provide additional testing of the proposed set of values of vadose zone hydraulic parameters. The approach used *TC & WM EIS* source data for the BY Cribs, the STOMP vadose zone model, the MODFLOW-predicted transient flow field, and a particle tracking transport model to predict spatial distribution of technetium-99 in the unconfined aquifer for calendar year 2005. The results of this analysis are presented in Figure N–8. The predicted concentrations show both qualitative and quantitative agreement with measured concentrations, with high levels near the sources and decreasing levels in the northwest direction. The predicted concentrations also show movement to the southeast due to transient flow in that direction under the influence of high aqueous discharges from past Hanford operations.



Key: DWS=Drinking Water Standard; LLWMA=low-level waste management area; WMA=waste management area.

Figure N–7. Isopleths of Concentration of Technetium-99 near the BY Cribs



Note: To convert meters to feet, multiply by 3.281

Figure N–8. Particle Tracking Model Output of Technetium-99 Concentrations for Calendar Year 2005 due to Sources at the BY Cribs

Final verification of the parameter values involved sensitivity analysis of grid size dependence and comparison of predictions with measurements for two multiple-source plumes in the unconfined aquifer. For sources associated with the Reduction-Oxidation (REDOX) Facility, a contour plot of the measured concentration of tritium in the unconfined aquifer in calendar year 2007 (Hartman and Webber 2008) is presented in Figure N–9, and the predicted spatial distribution of tritium for calendar year 2005 is presented in Figure N–10. While the predicted concentrations are higher than the measured concentrations, the plumes are similar in terms of spatial extent, continued high concentration at the source, and lengths parallel and perpendicular to the primary direction of flow to the east. On the basis of this quantitative agreement of a factor of less than five quantitative agreements, the values of vadose zone hydraulic parameters are supported by this analysis. Presented in the four plates of Figure N–11 is a groundwater monitoring report interpretation of the evolution of the tritium plume in the unconfined aquifer in the 200-East Area (Hartman, Morasch, and Webber 2004, 2006; Hartman and Webber 2008) as derived for sources associated with the Plutonium-Uranium Extraction (PUREX) Plant. The predicted spatial distribution of tritium for calendar year 2005 is presented in Figure N–12. The measured and predicted distributions of concentration have features in common, including the general shape of the overall spatial distribution, a persistence of elevated concentrations near the source in the southeastern portions of the 200-East Area, an area of elevated concentration in the northeastern lobe of the plume that is migrating toward the Columbia River, and a disruption of the southeast portion of the plume due to activities at the Energy Northwest complex near the Columbia River. The qualitative and quantitative agreement of the measured and predicted concentrations supports use of the selected values of vadose zone parameters. Values for the 16 soil types accepted for use in this *TC & WM EIS* vadose zone analysis are presented as Table N–1. Vadose zone soil parameters for three soil types (Hanford Sand, Hanford Gravel, and Ringold Gravel) are within the range of values established in calibration of the MODFLOW groundwater model. The groundwater soil parameters are described in Appendix L.

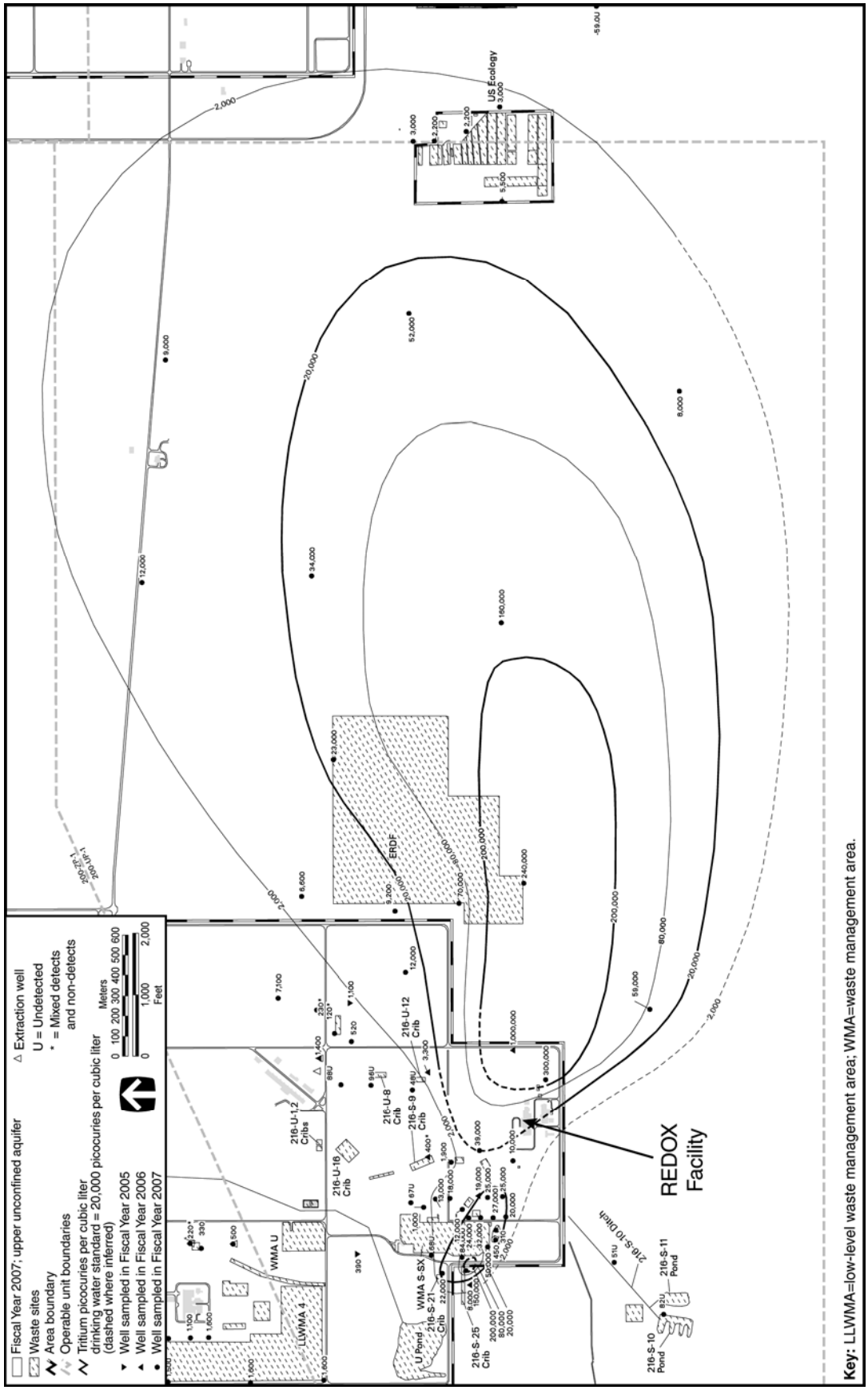


Figure N–9. Isopleths of Concentration of Hydrogen-3 (Tritium) for the Reduction-Oxidation Facility, Monitoring Program

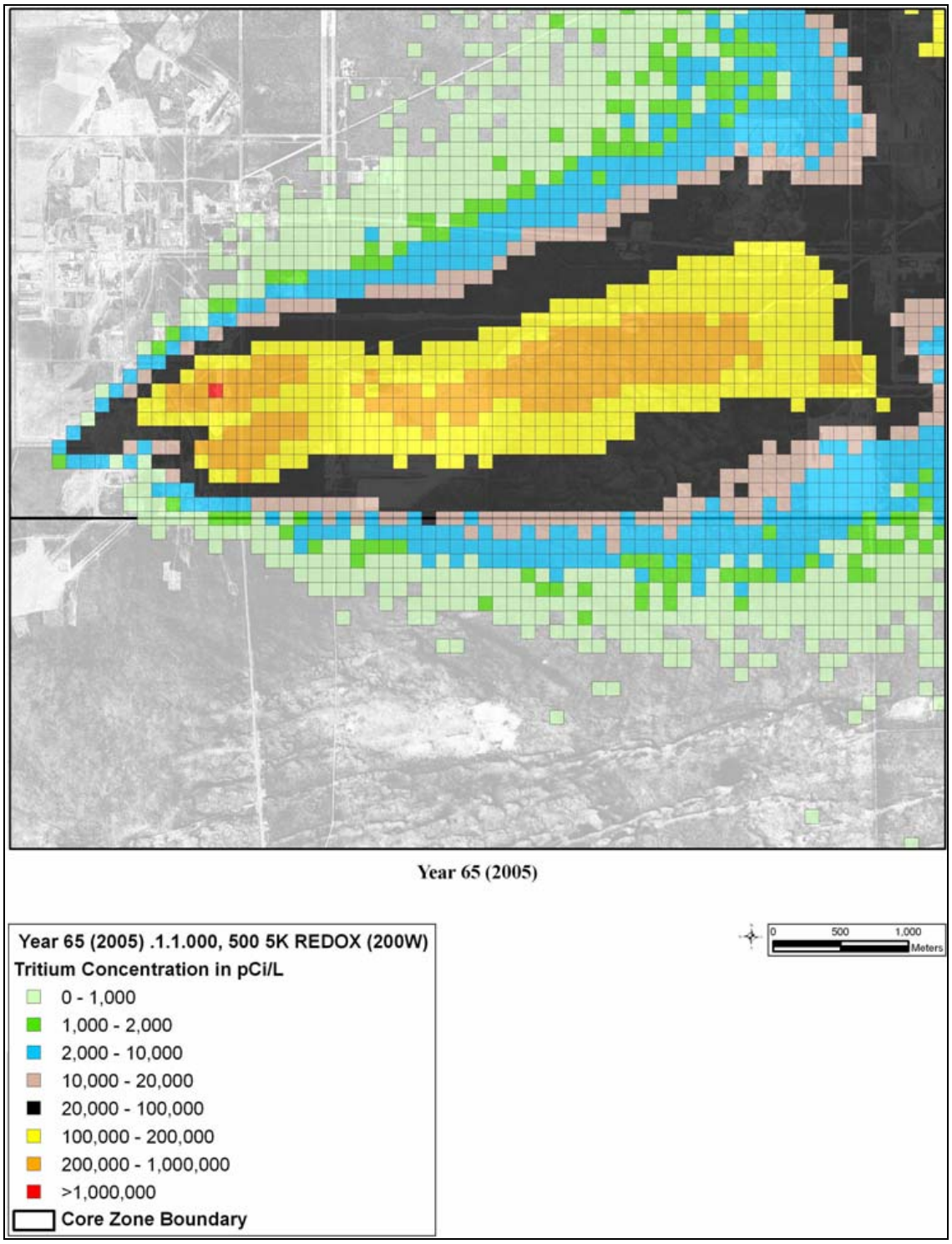
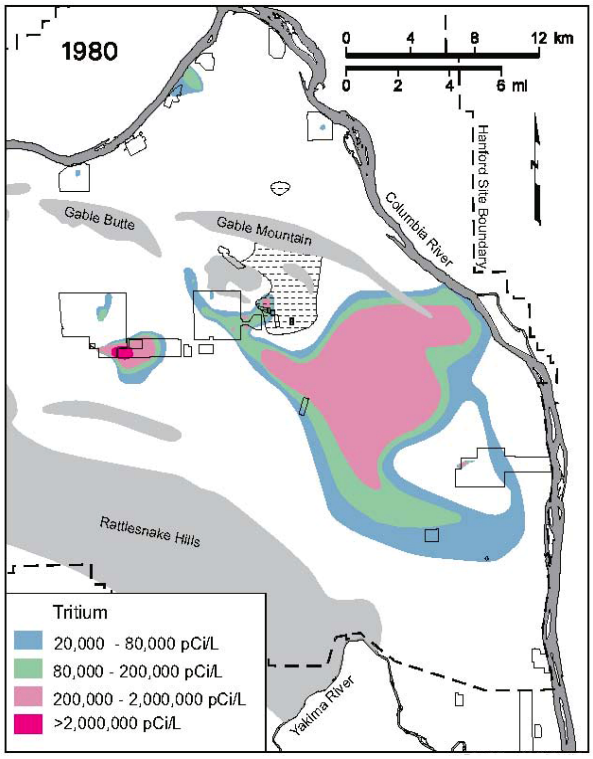
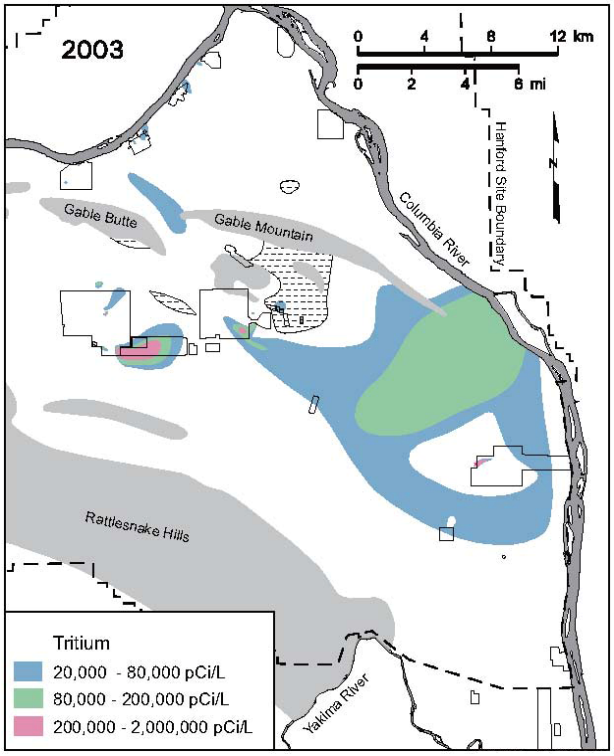


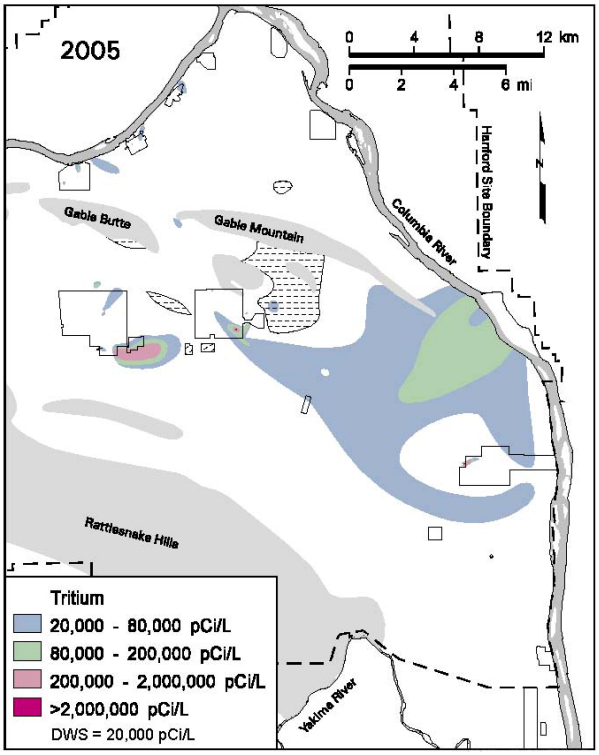
Figure N–10. Isopleths of Concentration of Hydrogen-3 (Tritium) for the Reduction-Oxidation Facility, *TC & WM EIS* Analytic Result



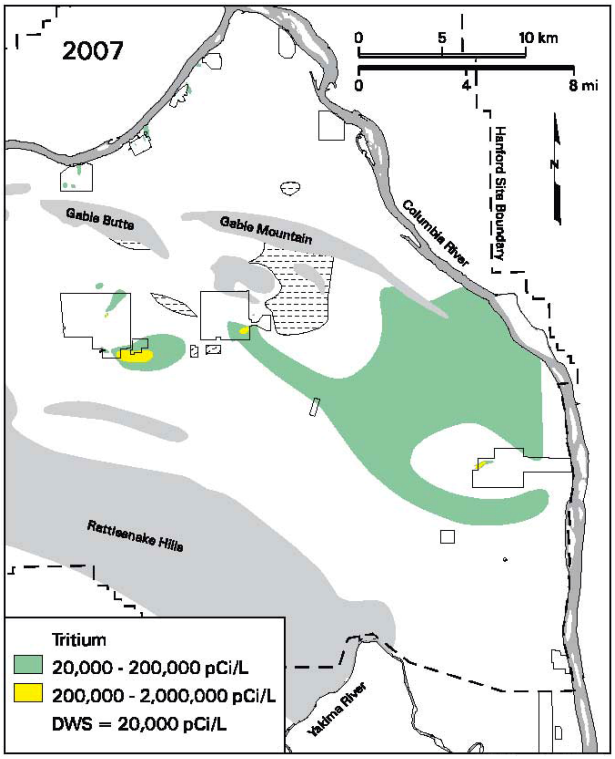
Source: Hartman, Morasch, and Webber 2004.



Source: Hartman, Morasch, and Webber 2004.



Source: Hartman, Morasch, and Webber 2006.



Source: Hartman and Webber 2008.

Figure N–11. Groundwater Monitoring-Based Interpretation of Ongoing Development of the 200-East Area Hydrogen-3 (Tritium) Plume

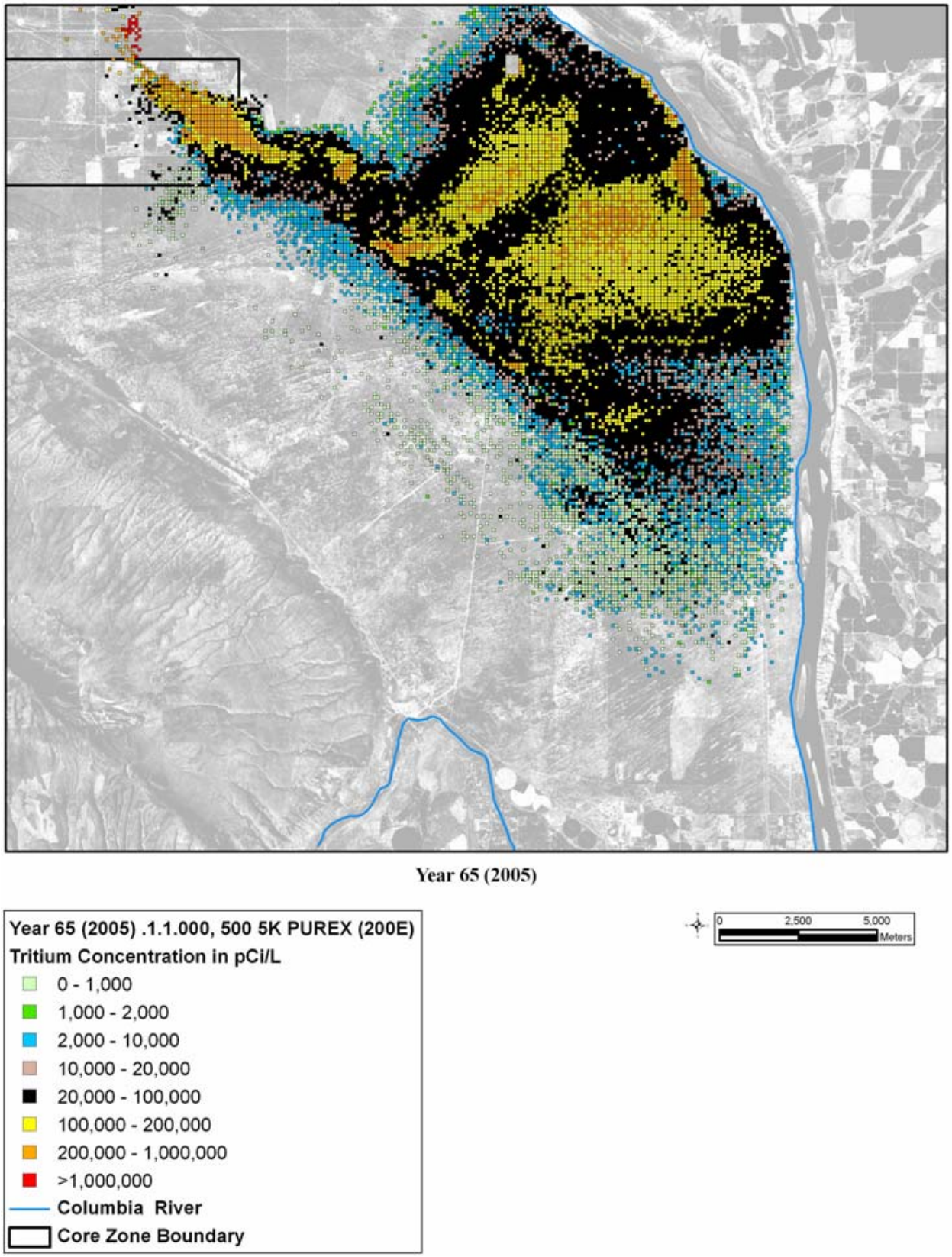


Figure N–12. Isopleths of Concentration of Hydrogen-3 (Tritium) for the Plutonium-Uranium Extraction (Plant), *TC & WM EIS* Analytic Result

Table N–1. Values of Hydraulic (van Genuchten) Parameters for *TC & WM EIS* Analysis Case

Soil Type	Saturated Porosity	Alpha	*n*	Residual Saturation	Vertical Hydraulic Conductivity (centimeters per second)
Alluvium	3.8×10^{-1}	5.0×10^{-2}	1.7	4.0×10^{-2}	8.7×10^{-3}
Hanford Gravel	2.7×10^{-1}	7.1×10^{-2}	2.0	1.7×10^{-1}	1.25×10^{-2}
Hanford Sand	3.0×10^{-1}	6.58×10^{-1}	1.6	8.0×10^{-2}	2.02×10^{-2}
Hanford Silt	3.5×10^{-1}	5.0×10^{-3}	1.8	1.89×10^{-1}	1.7×10^{-3}
Hanford Mud	5.0×10^{-1}	4.0×10^{-3}	2.1	5.0×10^{-2}	5.8×10^{-5}
Plio-Pleistocene Gravel	2.5×10^{-1}	5.0×10^{-2}	1.8	1.93×10^{-1}	8.1×10^{-2}
Plio-Pleistocene Sand	3.0×10^{-1}	9.0×10^{-2}	2.1	7.9×10^{-2}	8.7×10^{-3}
Plio-Pleistocene Silt	4.0×10^{-1}	1.0×10^{-2}	1.8	1.9×10^{-1}	1.2×10^{-3}
Plio-Pleistocene Mud	4.0×10^{-1}	1.25×10^{-3}	1.8	1.9×10^{-1}	1.2×10^{-3}
Plio-Pleistocene Cement	3.0×10^{-1}	1.0×10^{-2}	1.9	4.0×10^{-2}	1.2×10^{-3}
Cold Creek Gravel	2.5×10^{-1}	5.0×10^{-2}	1.8	1.93×10^{-1}	8.1×10^{-2}
Cold Creek Sand	3.0×10^{-1}	9.0×10^{-2}	2.1	7.9×10^{-2}	1.4×10^{-2}
Ringold Gravel	2.7×10^{-1}	7.0×10^{-2}	1.8	3.61×10^{-2}	2.0×10^{-3}
Ringold Sand	3.0×10^{-1}	2.5×10^{-2}	2.75	9.64×10^{-3}	3.94×10^{-4}
Ringold Silt	3.5×10^{-1}	1.0×10^{-2}	2.1	1.9×10^{-1}	1.3×10^{-4}
Ringold Mud	5.0×10^{-1}	5.0×10^{-3}	2.3	3.0×10^{-2}	5.8×10^{-5}

N.2 RESULTS

N.2.1 Tank Closure Alternatives

N.2.1.1 Past Leaks from Tank Farms and Releases from Cribs and Trenches (Ditches)

Under Tank Closure Alternative 1, the tank farms would be maintained in the current condition indefinitely, but, for the purpose of analysis, are assumed to fail after an institutional control period of 100 years. Potential releases to the aquifer from past leaks under Alternative 1 are indicated in Figures N–13 through N–16.

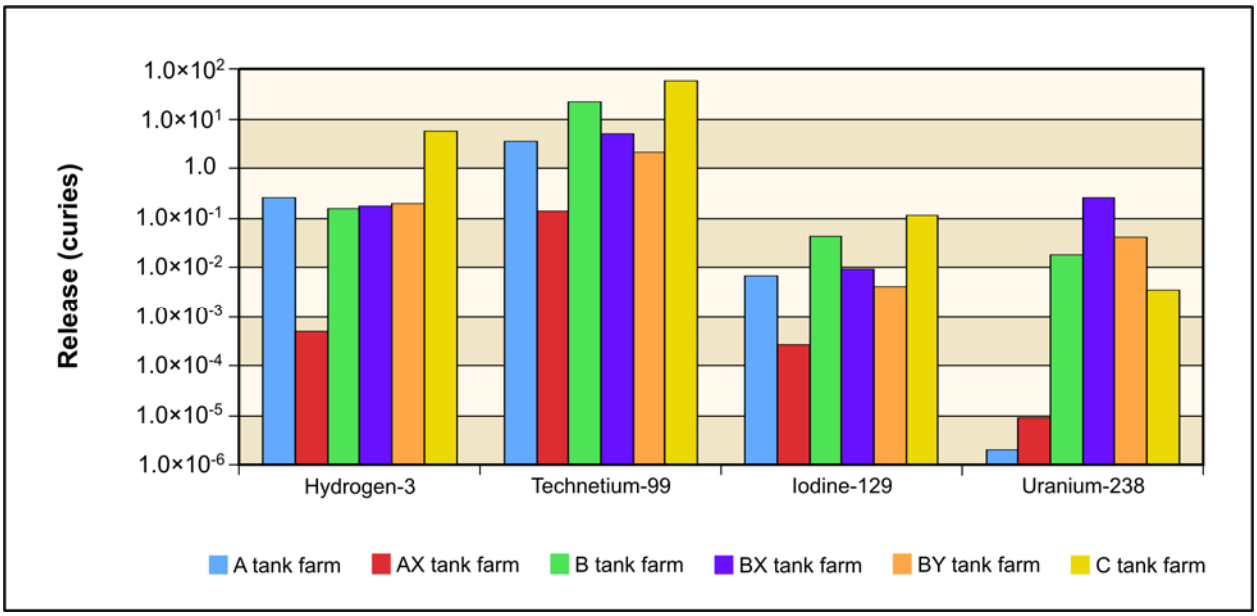


Figure N–13. Tank Closure Alternative 1 Past Leaks from 200-East Area Tank Farms Radiological Release to Aquifer

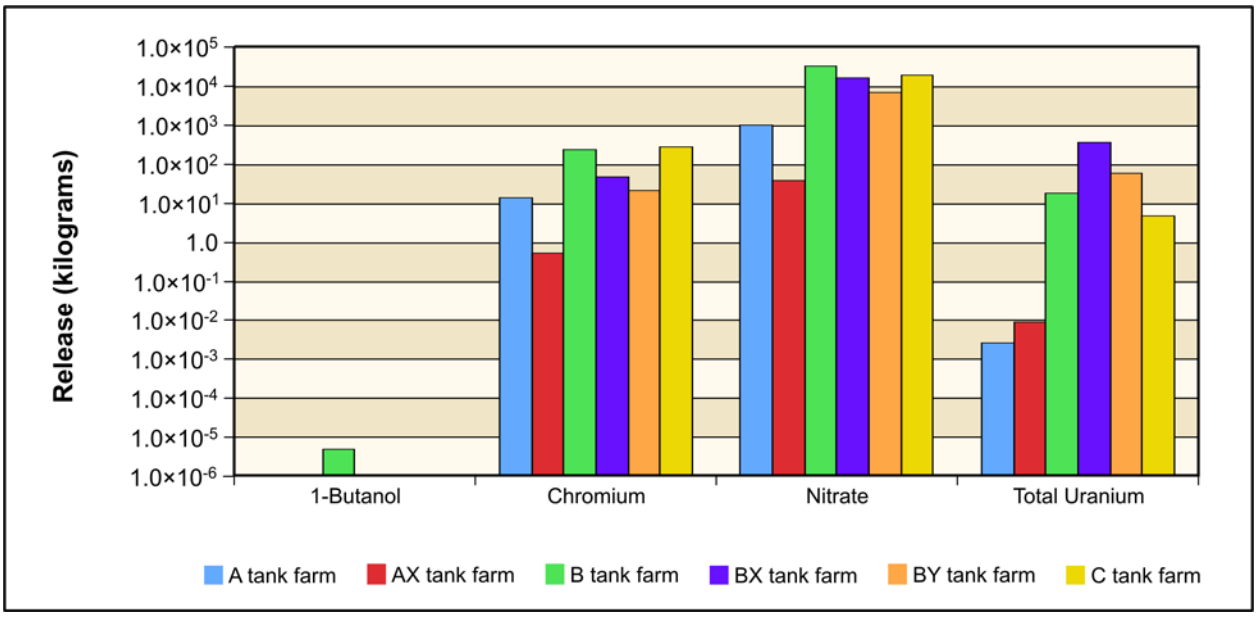


Figure N–14. Tank Closure Alternative 1 Past Leaks from 200-East Area Tank Farms Chemical Release to Aquifer

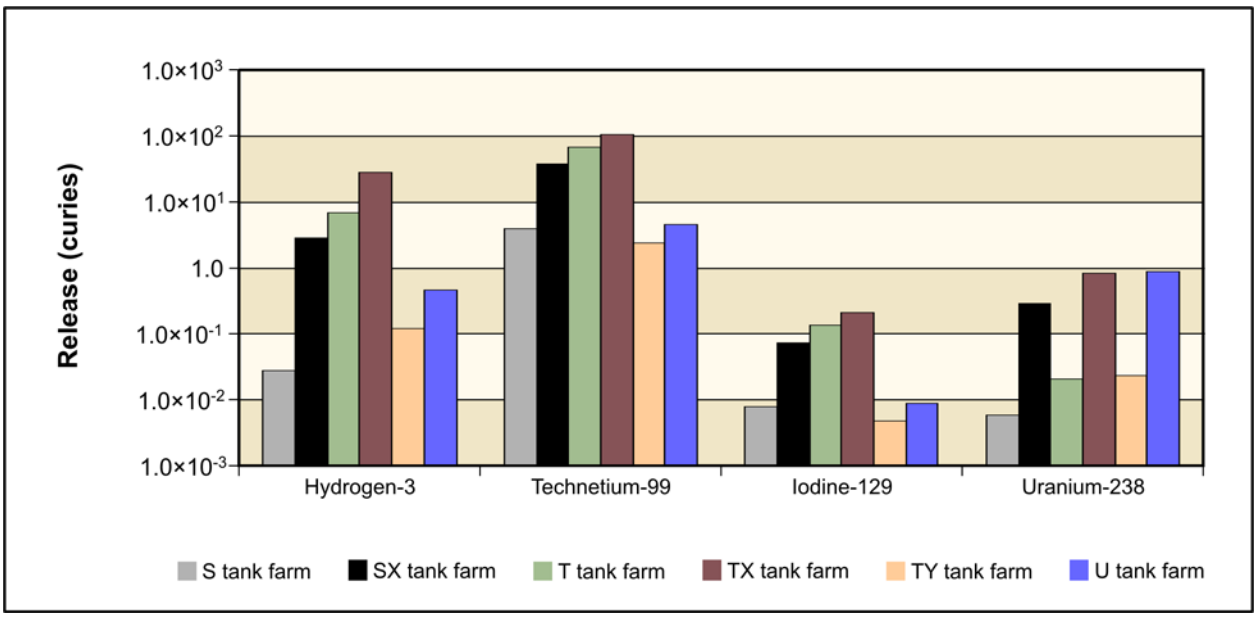


Figure N–15. Tank Closure Alternative 1 Past Leaks from 200-West Area Tank Farms Radiological Release to Aquifer

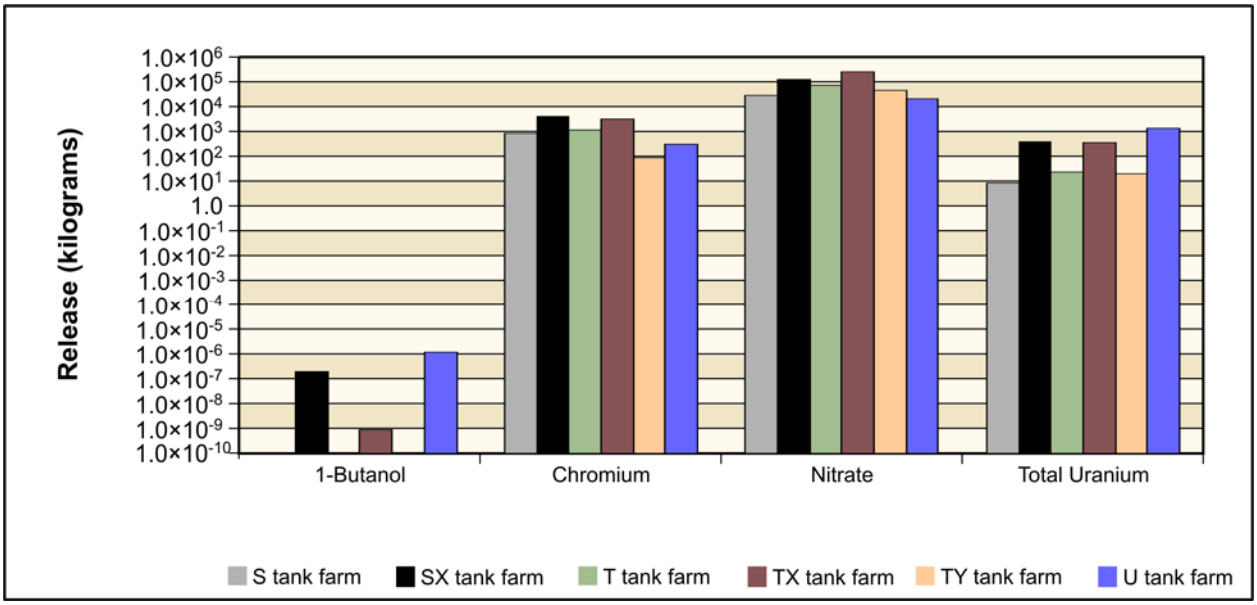


Figure N–16. Tank Closure Alternative 1 Past Leaks from 200-West Area Tank Farms Chemical Release to Aquifer

Under Tank Closure Alternative 2A, tank waste would be retrieved to a volume corresponding to 99 percent retrieval. Potential releases to the aquifer from past leaks under Alternative 2A are indicated in Figures N–17 through N–20.

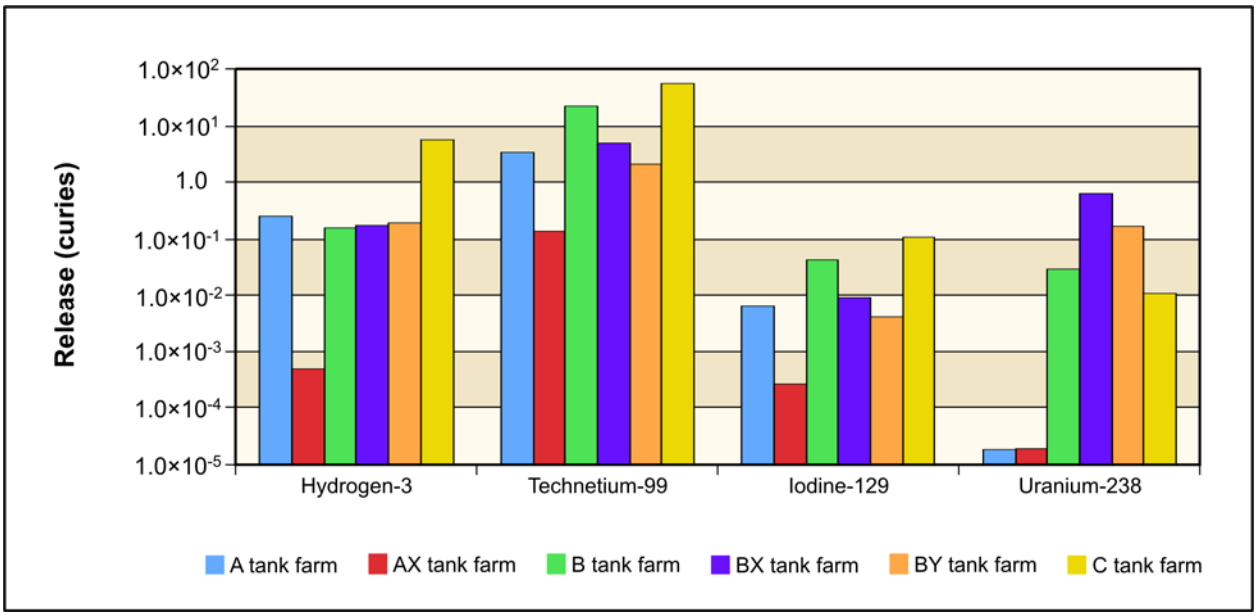


Figure N–17. Tank Closure Alternative 2A Past Leaks from 200-East Area Tank Farms Radiological Release to Aquifer

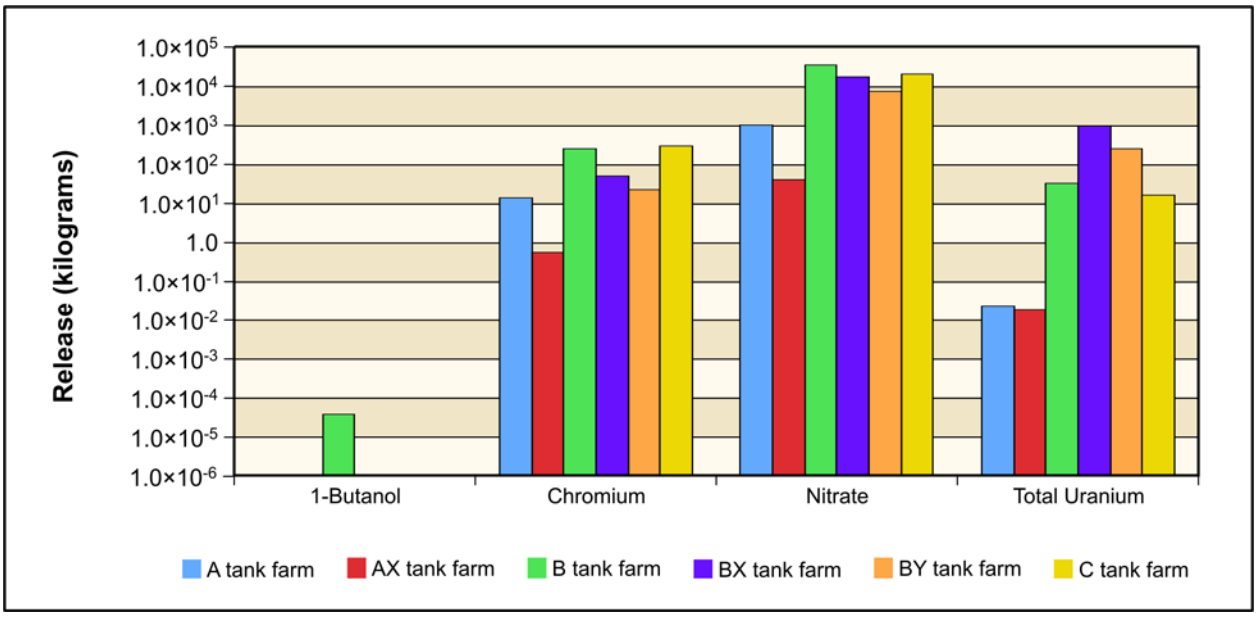


Figure N–18. Tank Closure Alternative 2A Past Leaks from 200-East Area Tank Farms Chemical Release to Aquifer

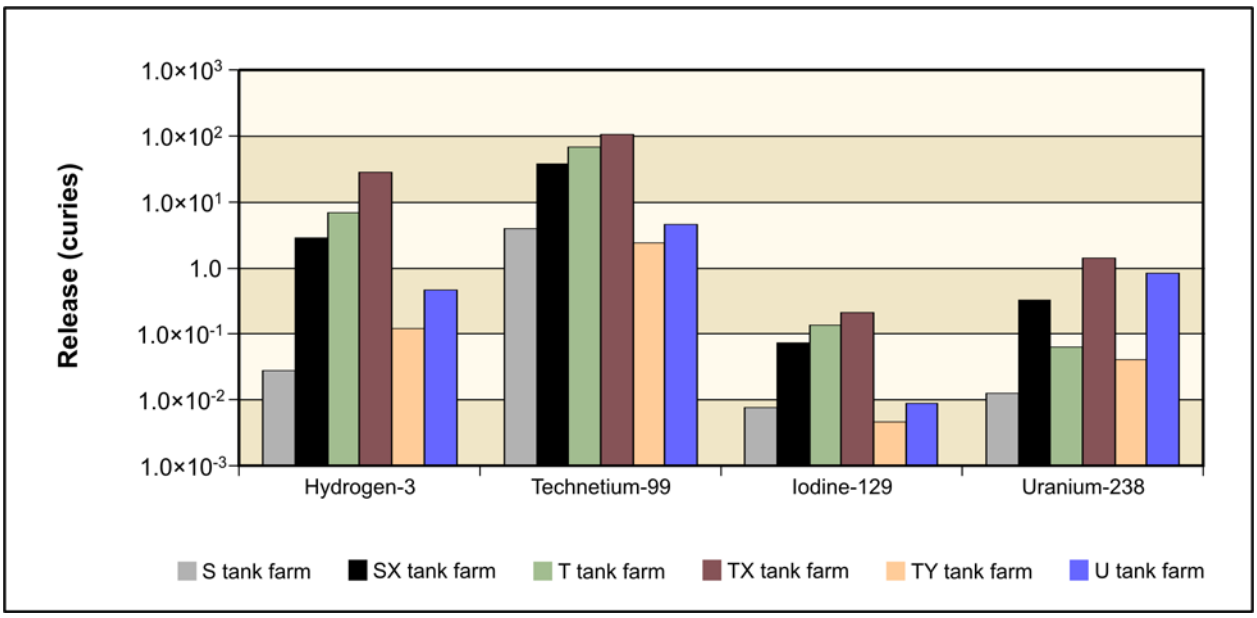


Figure N–19. Tank Closure Alternative 2A Past Leaks from 200-West Area Tank Farms Radiological Release to Aquifer

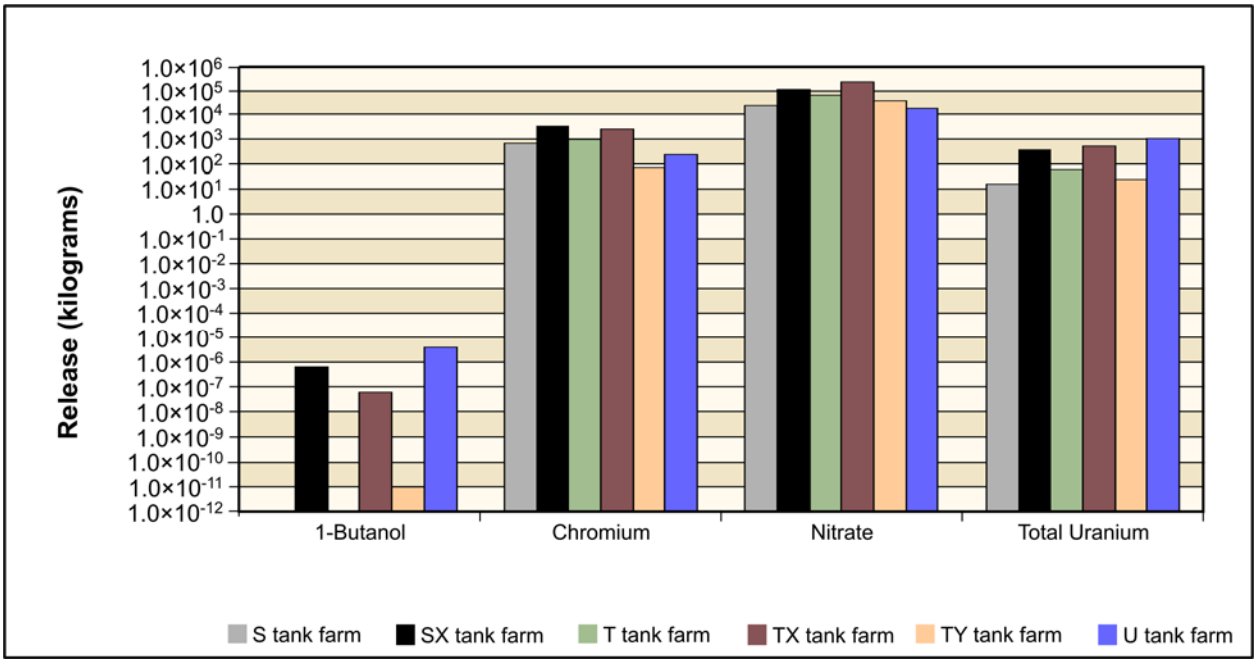


Figure N–20. Tank Closure Alternative 2A Past Leaks from 200-West Area Tank Farms Chemical Release to Aquifer

Activities under Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C would be similar to those of Tank Closure Alternative 2A, with the addition of an engineered modified Resource Conservation and Recovery Act (RCRA) Subtitle C barrier over the tank farms and six sets of adjacent cribs and trenches (ditches). Potential releases to the aquifer from past leaks under Alternatives 2B, 3A, 3B, 3C, and 6C are indicated in Figures N–21 through N–24.

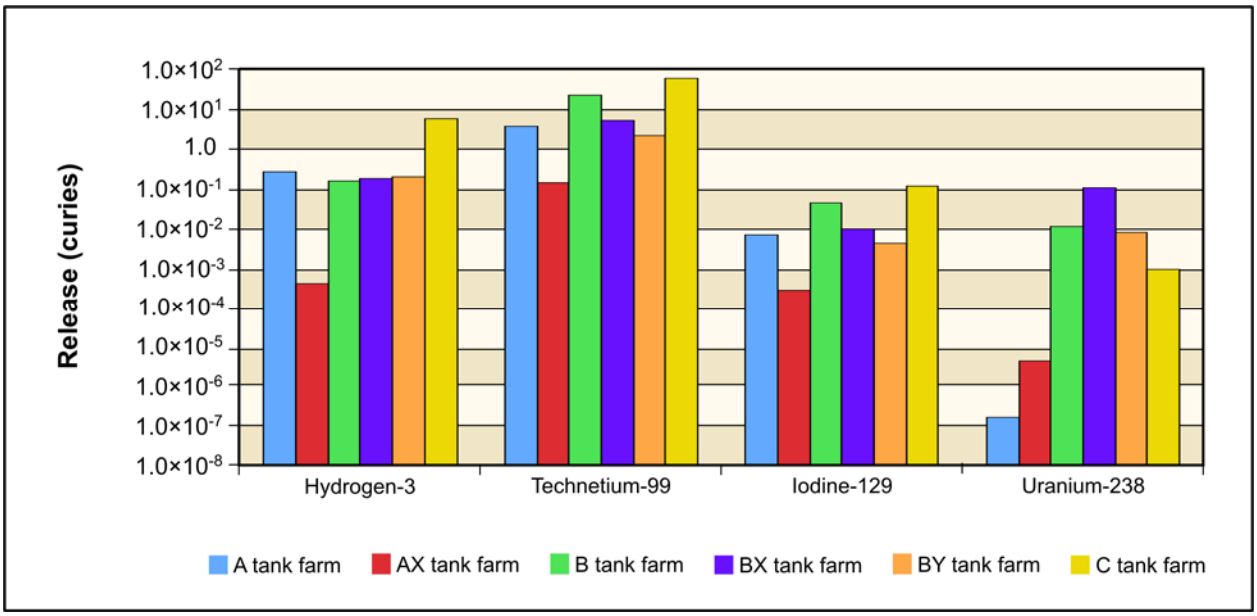


Figure N–21. Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C Past Leaks from 200-East Area Tank Farms Radiological Release to Aquifer

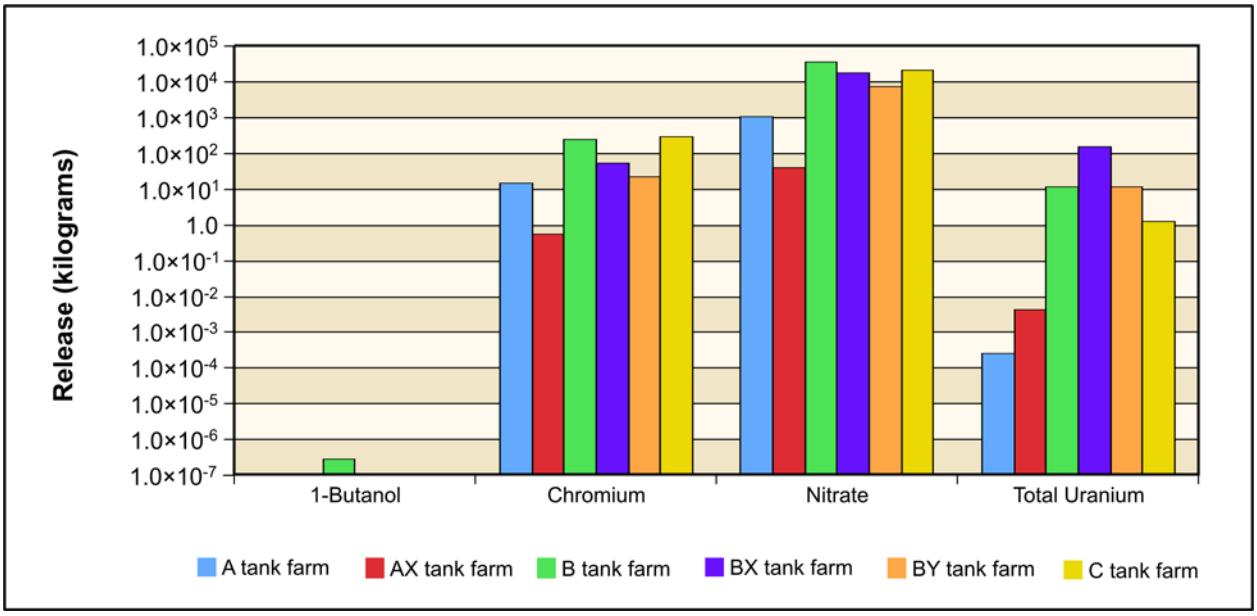


Figure N–22. Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C Past Leaks from 200-East Area Tank Farms Chemical Release to Aquifer

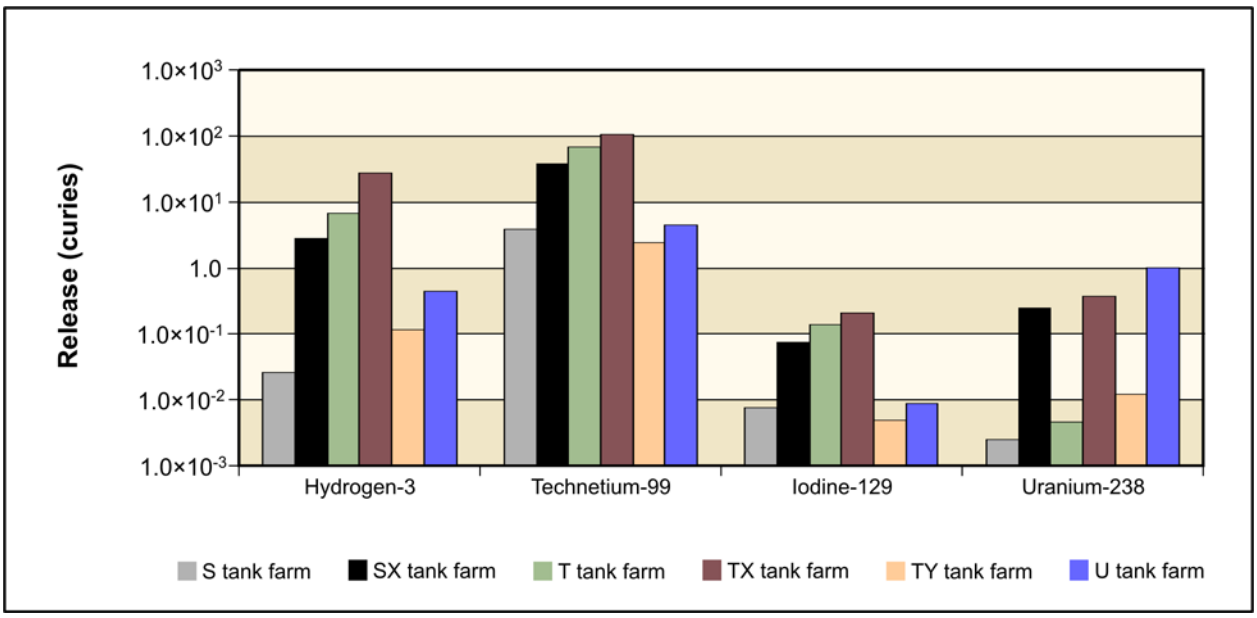


Figure N–23. Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C Past Leaks from 200-West Area Tank Farms Radiological Release to Aquifer

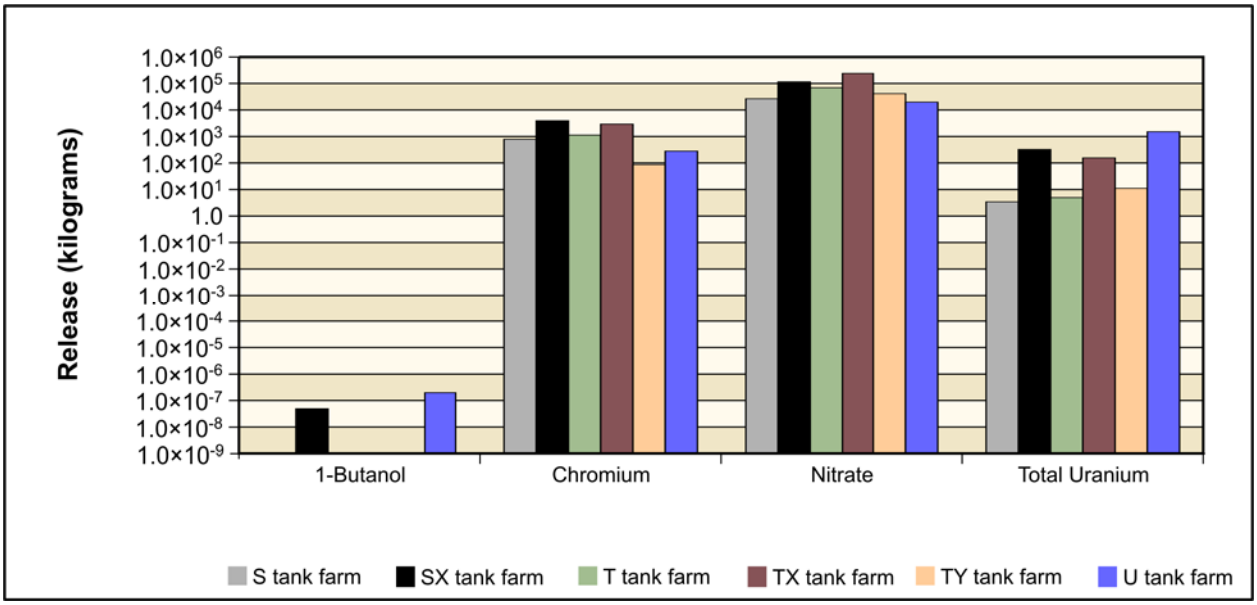


Figure N–24. Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C Past Leaks from 200-West Area Tank Farms Chemical Release to Aquifer

Under Tank Closure Alternative 4, tank waste would be retrieved to a volume corresponding to 99.9 percent retrieval. Except for the BX and SX tank farms, residual material in tanks would be stabilized in place, and the tank farms and adjacent cribs and trenches (ditches) would be covered with an engineered modified RCRA Subtitle C barrier. The BX and SX tank farms would be clean closed by removing soils to a depth of 3 meters (10 feet) below the tank base. Where necessary, deep soil excavation would also be conducted to remove contamination plumes within the soil column. Potential releases to the aquifer from past leaks under Alternative 4 are indicated in Figures N–25 through N–28.

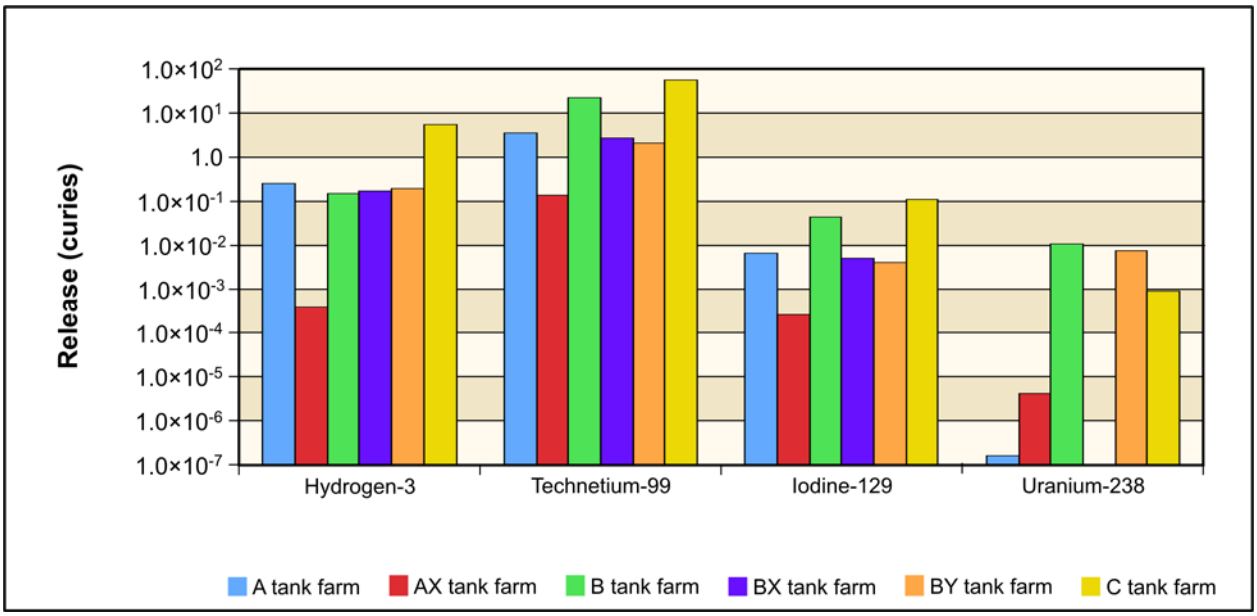


Figure N–25. Tank Closure Alternative 4 Past Leaks from 200-East Area Tank Farms Radiological Release to Aquifer

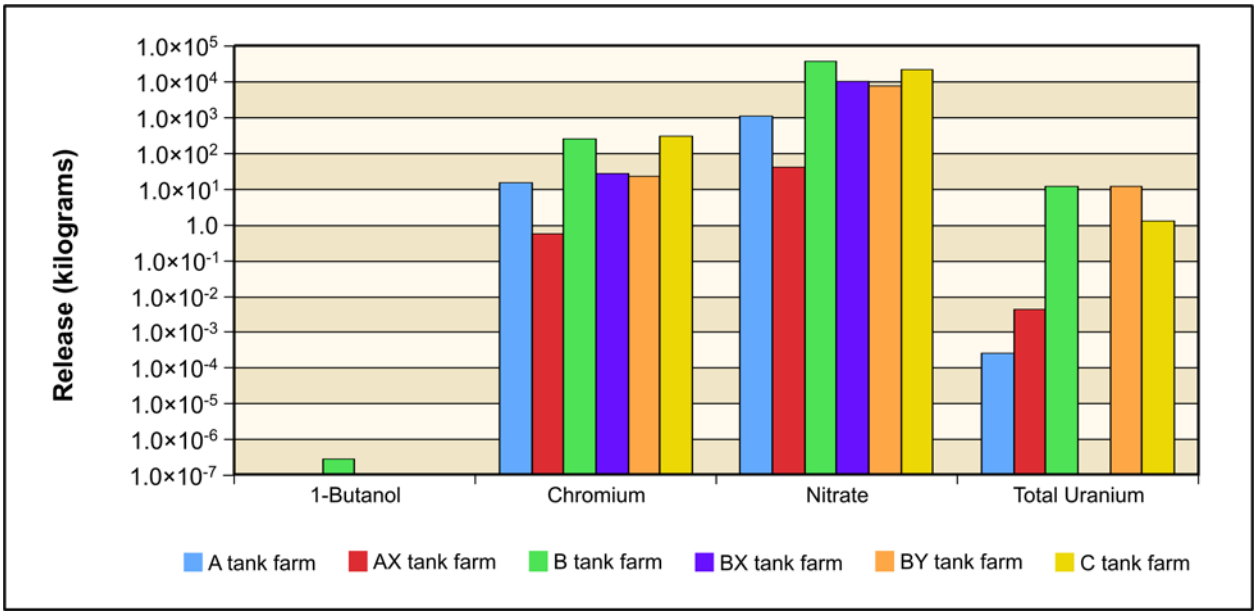


Figure N–26. Tank Closure Alternative 4 Past Leaks from 200-East Area Tank Farms Chemical Release to Aquifer

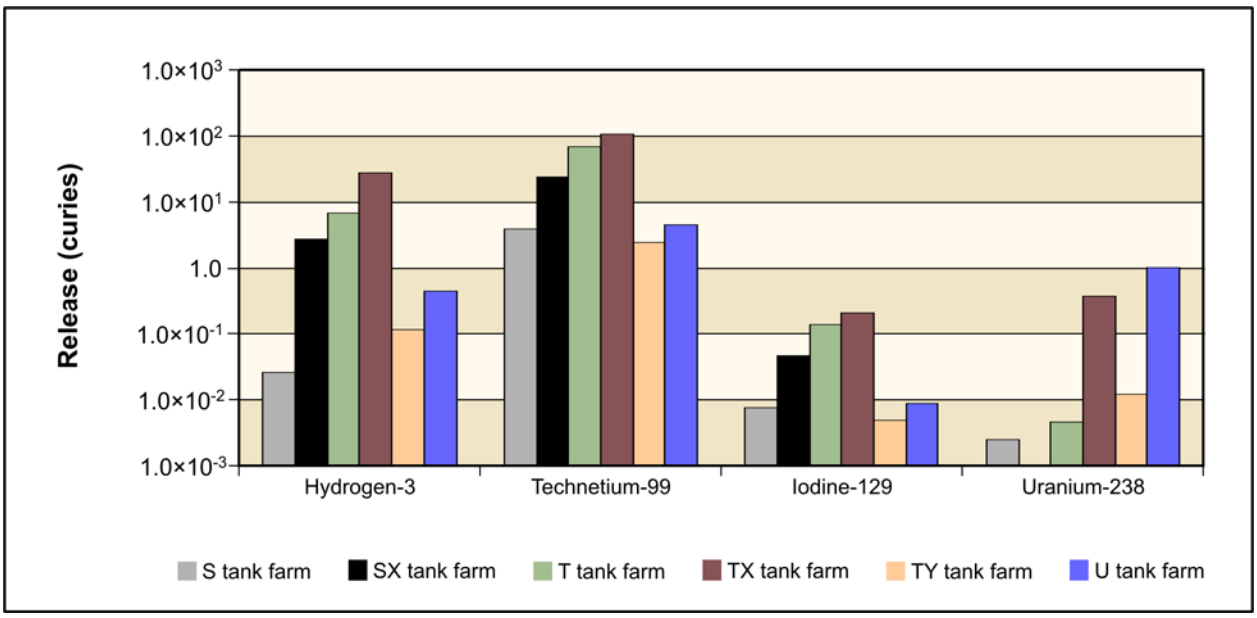


Figure N–27. Tank Closure Alternative 4 Past Leaks from 200-West Area Tank Farms Radiological Release to Aquifer

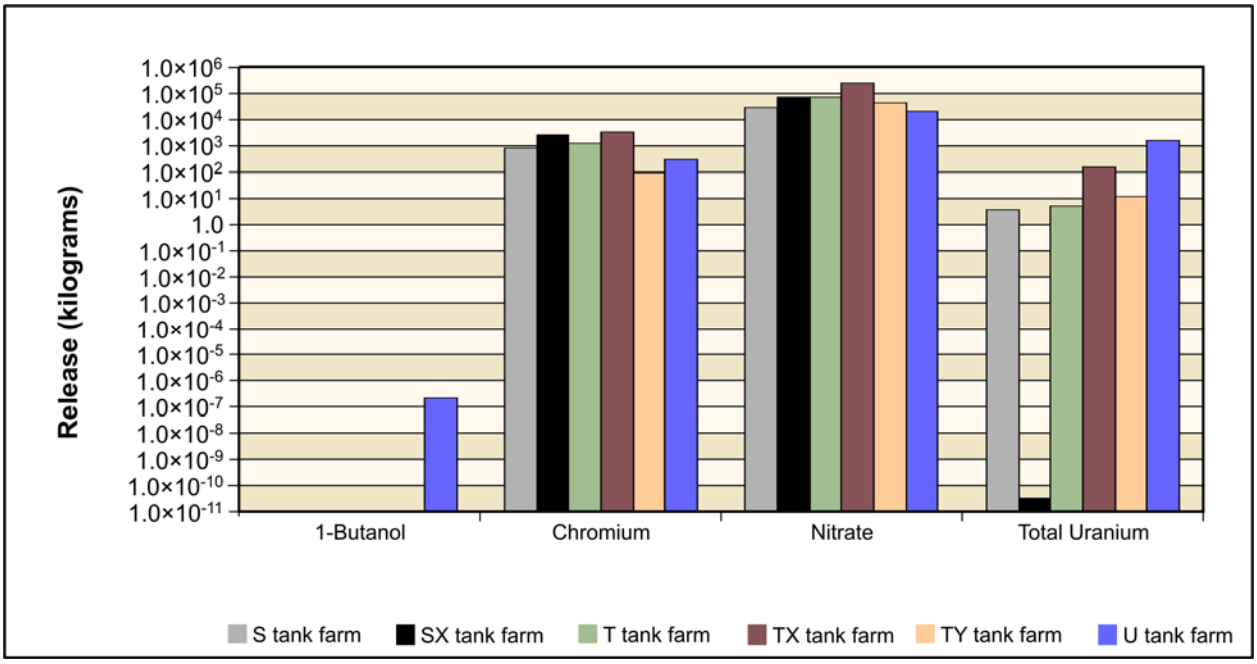


Figure N–28. Tank Closure Alternative 4 Past Leaks from 200-West Area Tank Farms Chemical Release to Aquifer

Under Tank Closure Alternative 5, the tank farms and adjacent cribs and trenches (ditches) would be covered with a Hanford barrier. Potential releases to the aquifer from past leaks under Alternative 5 are indicated in Figures N–29 through N–32.

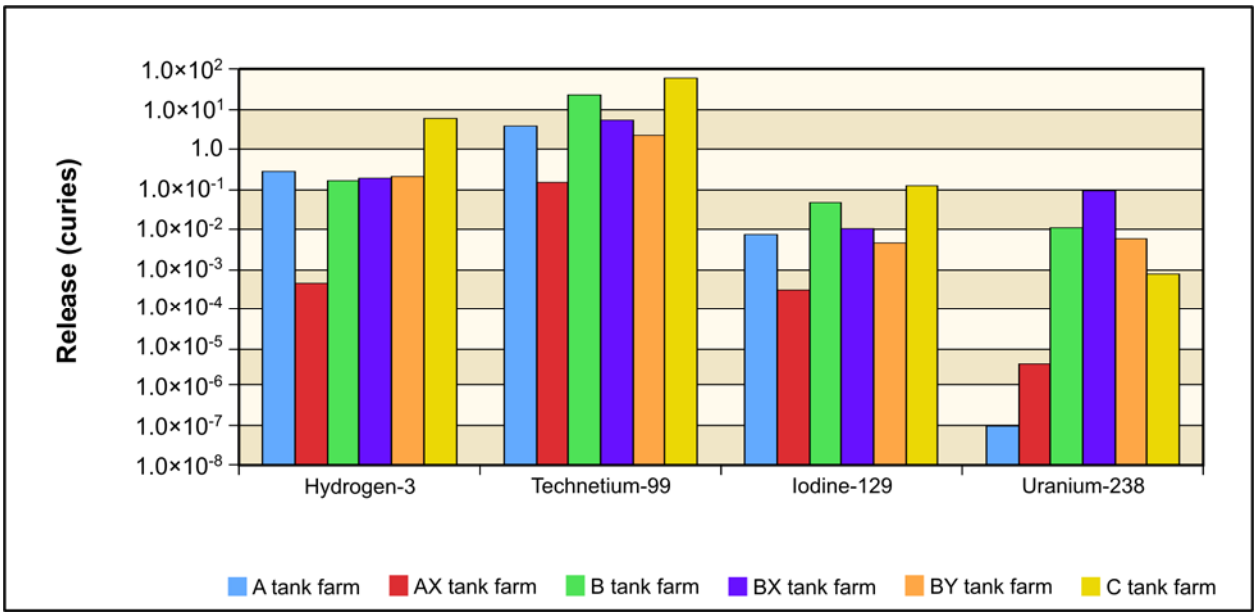


Figure N–29. Tank Closure Alternative 5 Past Leaks from 200-East Area Tank Farms Radiological Release to Aquifer

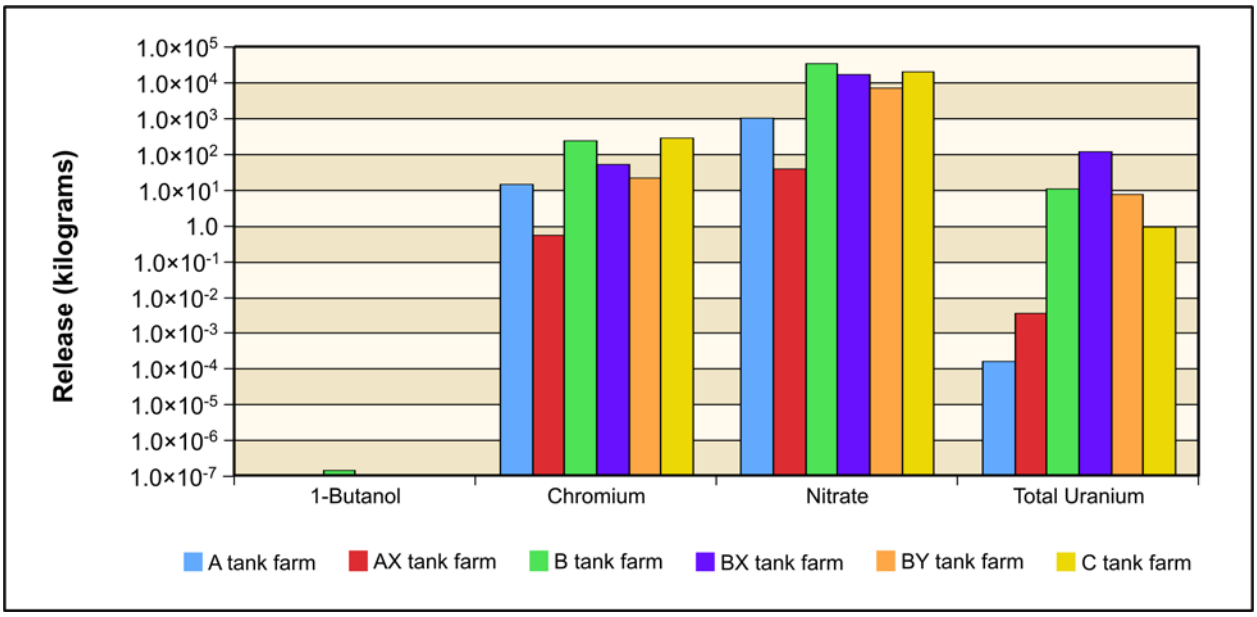


Figure N–30. Tank Closure Alternative 5 Past Leaks from 200-East Area Tank Farms Chemical Release to Aquifer

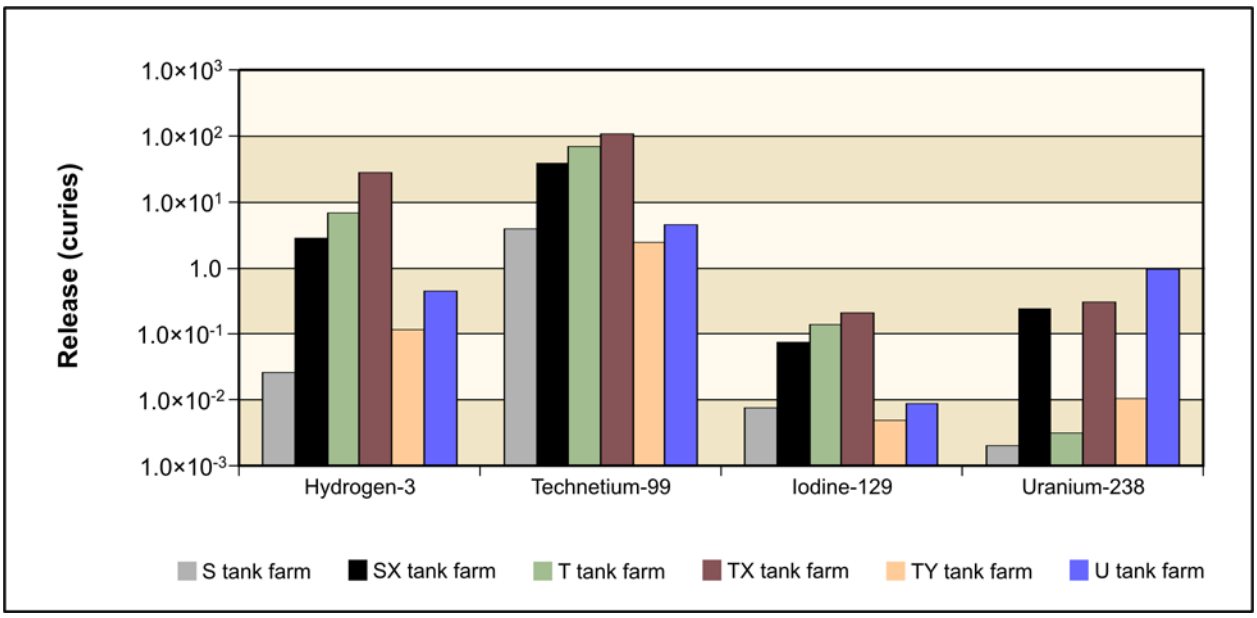


Figure N–31. Tank Closure Alternative 5 Past Leaks from 200-West Area Tank Farms Radiological Release to Aquifer

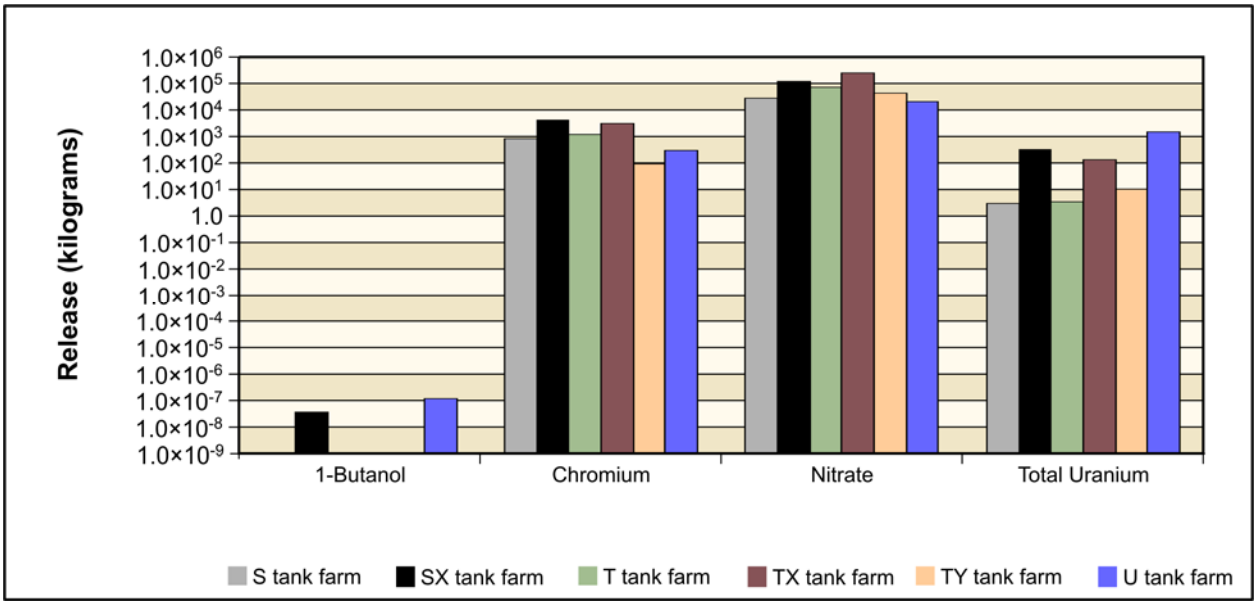


Figure N–32. Tank Closure Alternative 5 Past Leaks from 200-West Area Tank Farms Chemical Release to Aquifer

Under Tank Closure Alternative 6A, Base and Option Cases, all tank farms would be clean closed by removing soils to a depth of 3 meters (10 feet) below the tank base. Where necessary, deep soil excavation would also be conducted to remove contamination plumes within the soil column. The adjacent cribs and trenches (ditches) would be covered with an engineered modified RCRA Subtitle C barrier. Potential releases to the aquifer from past leaks under Alternative 6A, Base and Option Cases, are indicated in Figures N–33 through N–36.

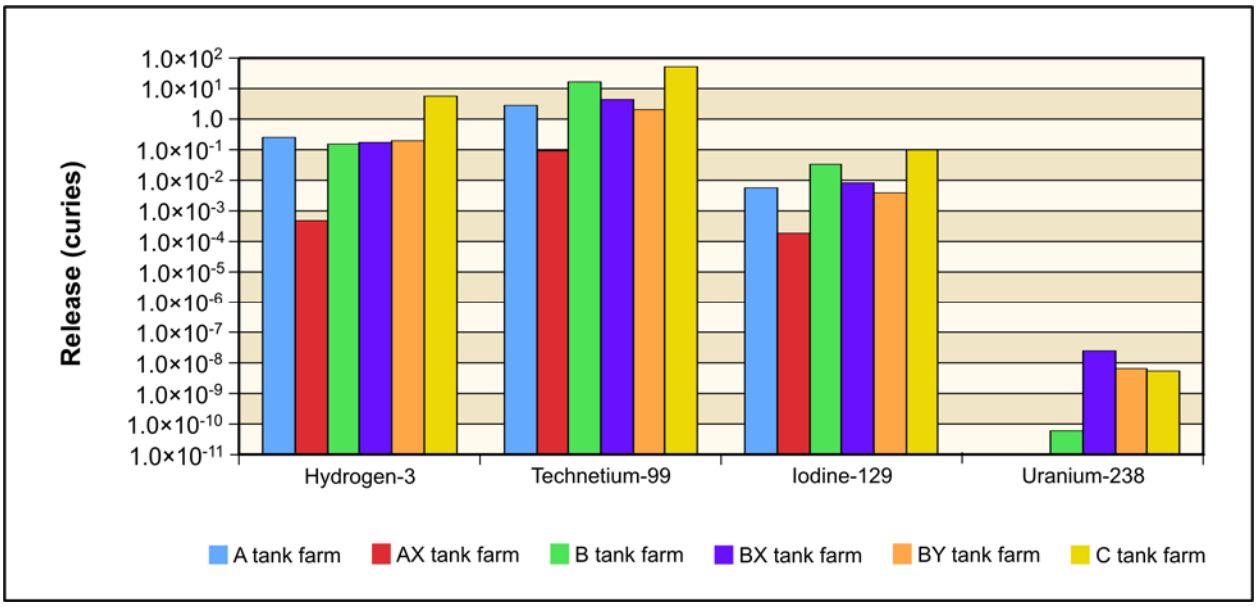


Figure N–33. Tank Closure Alternative 6A, Base and Option Cases, Past Leaks from 200-East Area Tank Farms Radiological Release to Aquifer

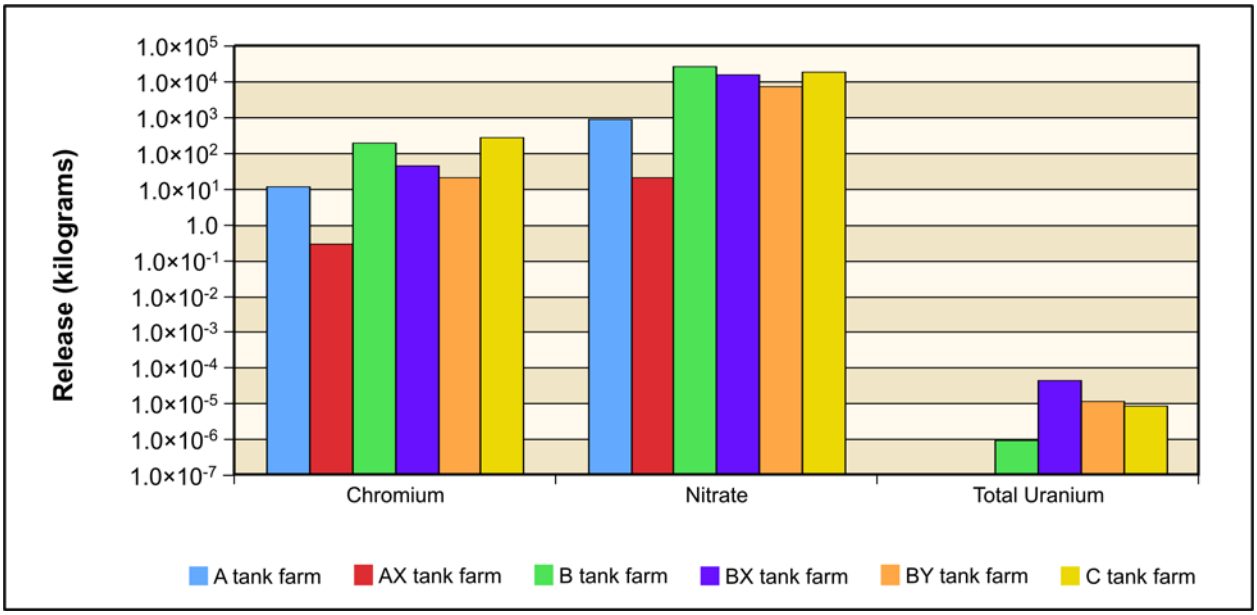


Figure N–34. Tank Closure Alternative 6A, Base and Option Cases, Past Leaks from 200-East Area Tank Farms Chemical Release to Aquifer

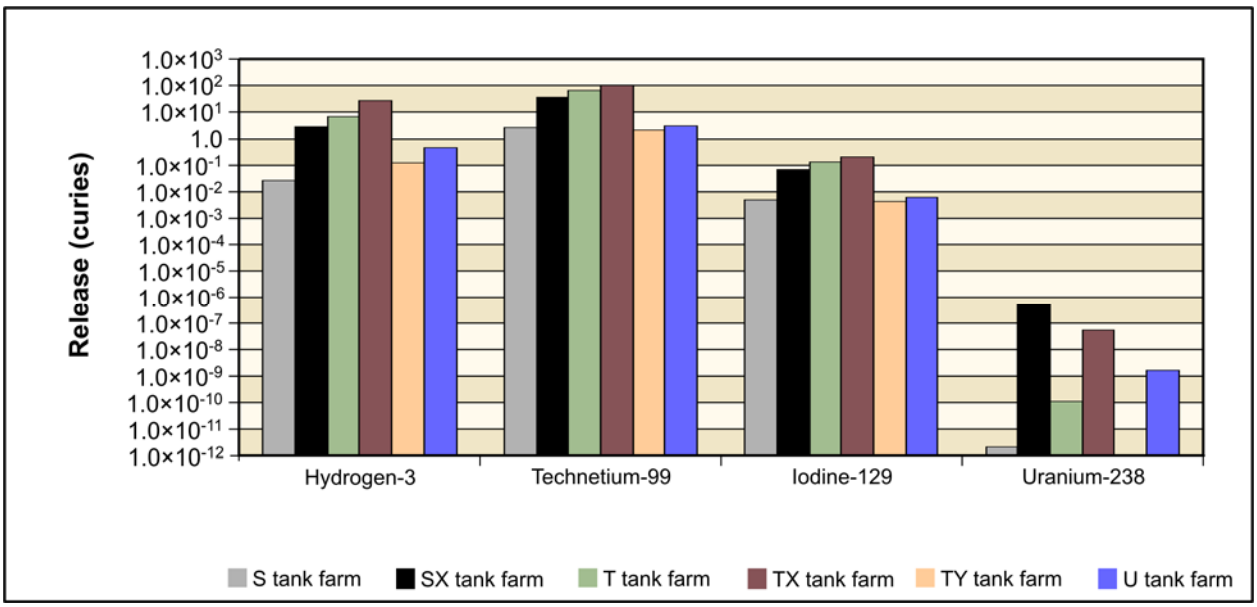


Figure N–35. Tank Closure Alternative 6A, Base and Option Cases, Past Leaks from 200-West Area Tank Farms Radiological Release to Aquifer

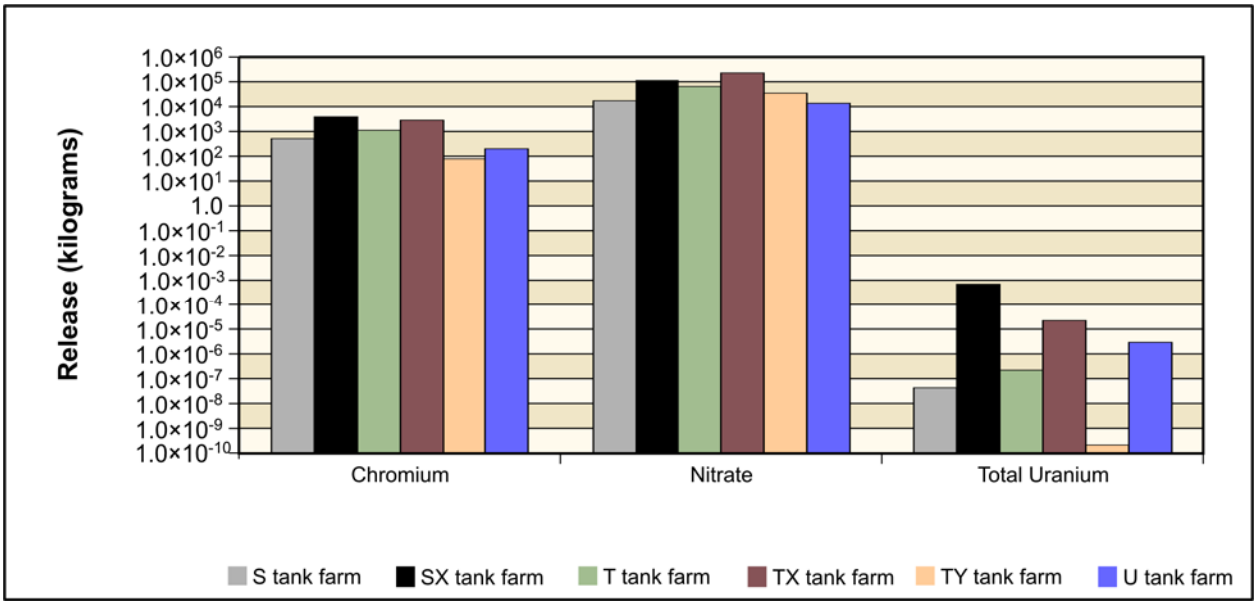


Figure N–36. Tank Closure Alternative 6A, Base and Option Cases, Past Leaks from 200-West Area Tank Farms Chemical Release to Aquifer

Tank Closure Alternative 6B, Base and Option Cases, resembles Tank Closure Alternative 6A, Base and Option Cases, except that waste retrieval and processing would proceed at a faster rate and closure would occur at an earlier date. All tank farms would be clean closed. For the Base Case, the adjacent cribs and trenches (ditches) would be covered with an engineered modified RCRA Subtitle C barrier, and for the Option Case, the adjacent cribs and trenches (ditches) would be clean closed. Potential releases to the aquifer from past leaks under Alternative 6B, Base and Option Cases, are indicated in Figures N–37 through N–40.

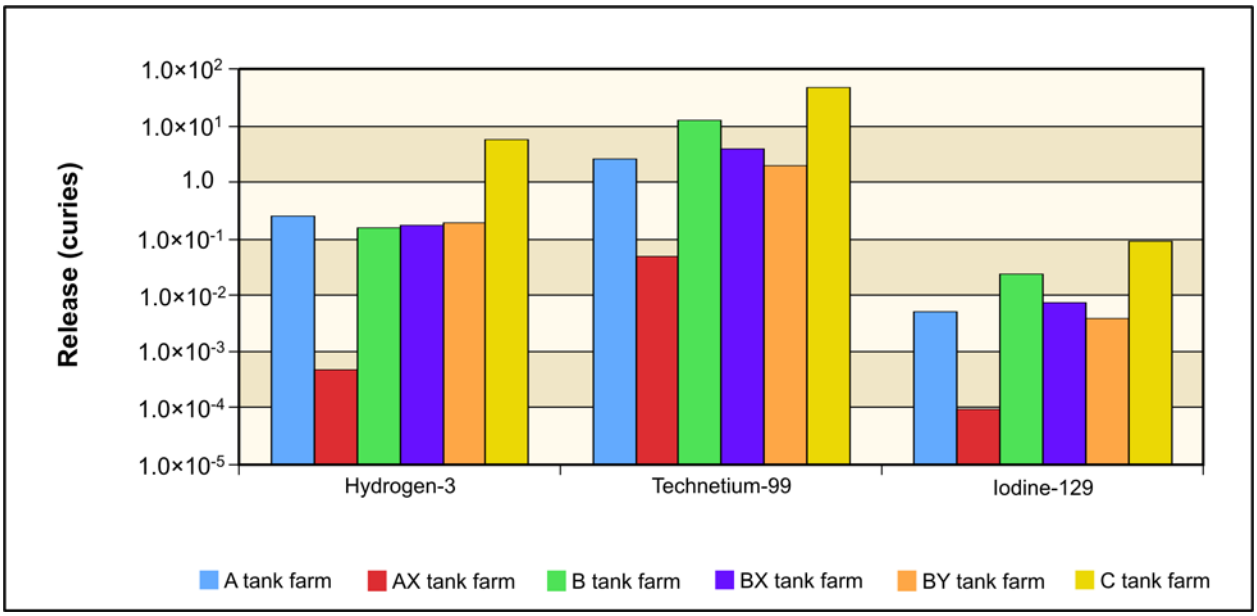


Figure N–37. Tank Closure Alternative 6B, Base and Option Cases, Past Leaks from 200-East Area Tank Farms Radiological Release to Aquifer

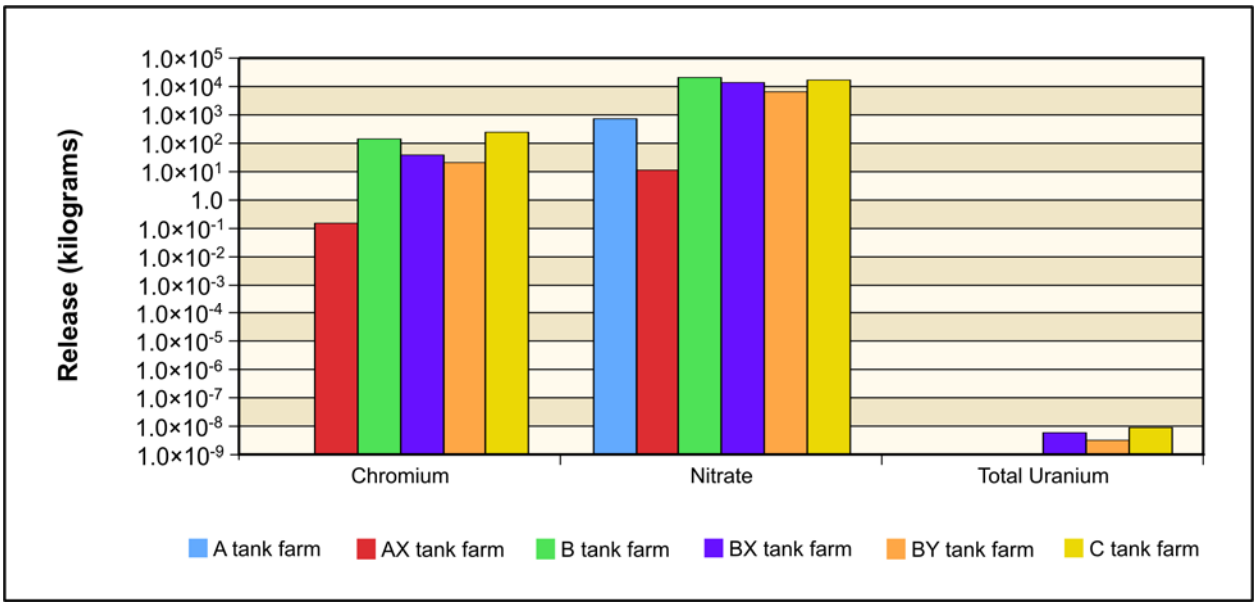


Figure N–38. Tank Closure Alternative 6B, Base and Option Cases, Past Leaks from 200-East Area Tank Farms Chemical Release to Aquifer

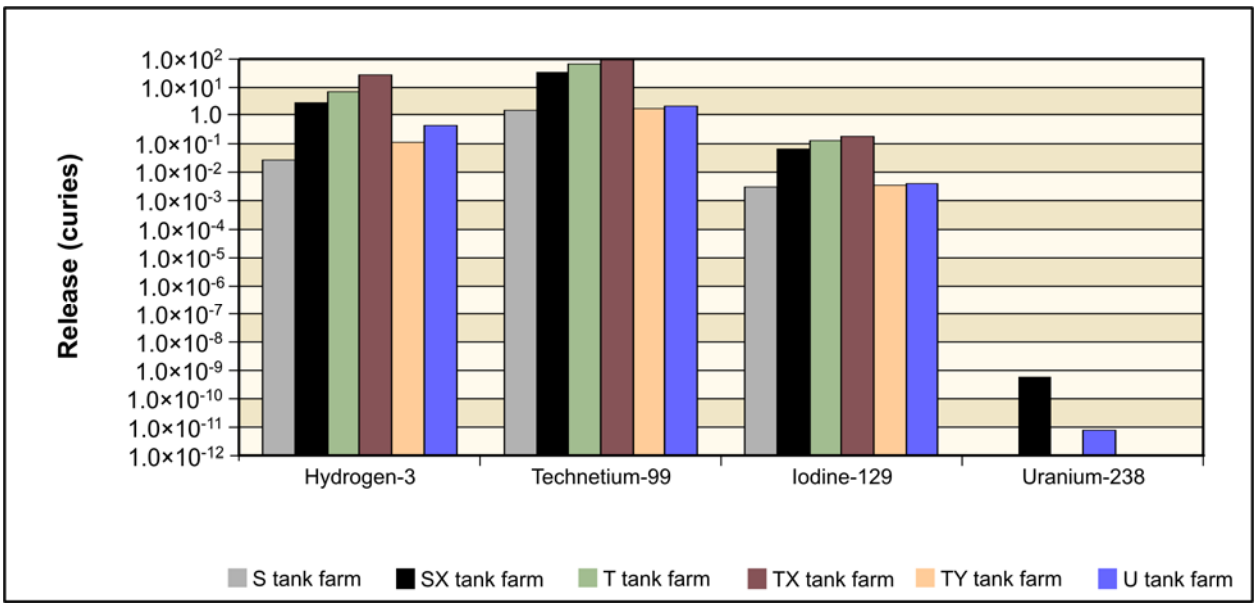


Figure N–39. Tank Closure Alternative 6B, Base and Option Cases, Past Leaks from 200-West Area Tank Farms Radiological Release to Aquifer

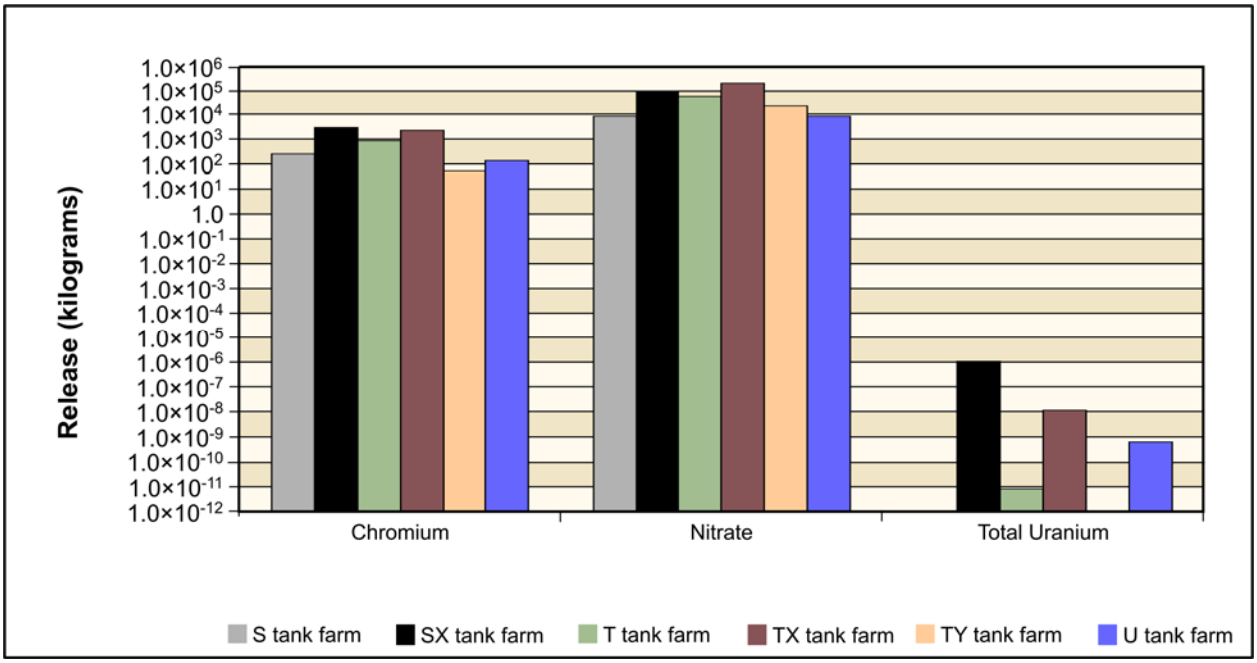


Figure N–40. Tank Closure Alternative 6B, Base and Option Cases, Past Leaks from 200-West Area Tank Farms Chemical Release to Aquifer

Under Tank Closure Alternative 1, the cribs and trenches (ditches) associated with the tank farms would be maintained in the current condition indefinitely, but, for the purpose of analysis, are assumed to fail after an institutional control period of 100 years (i.e., in calendar year 2108). Potential releases to the aquifer from cribs and trenches (ditches) under Alternative 1 are indicated in Figures N–41 and N–42.

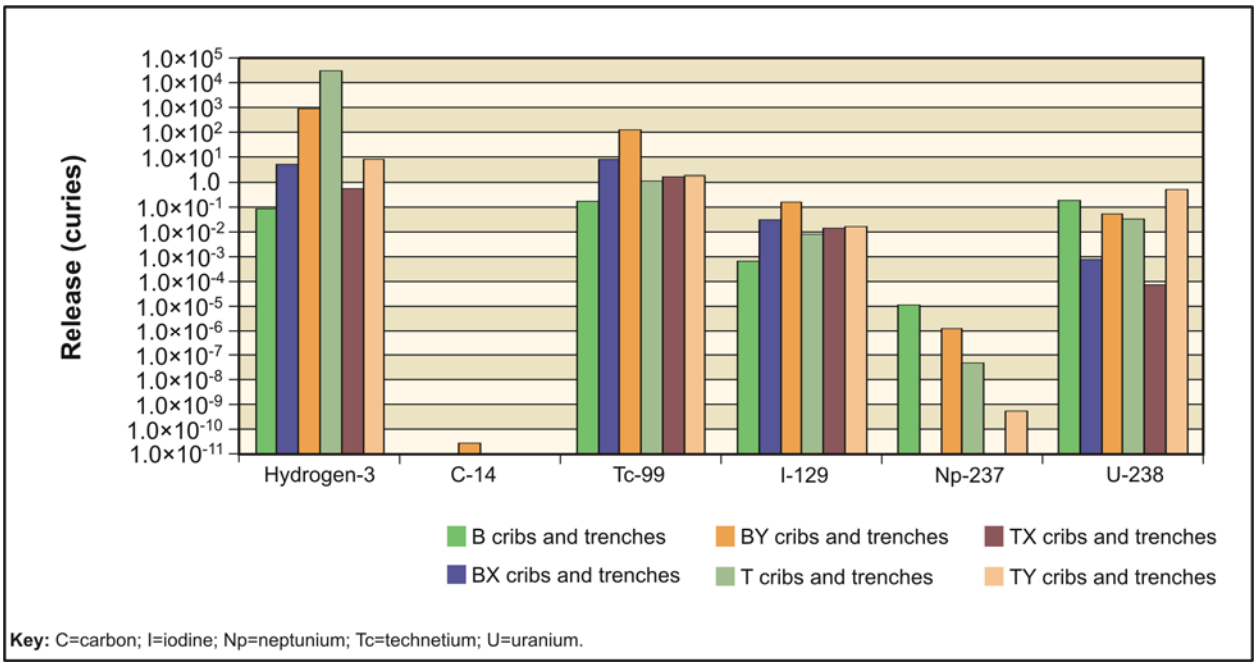


Figure N–41. Tank Closure Alternative 1, Cribs and Trenches (Ditches) Radiological Release to Aquifer

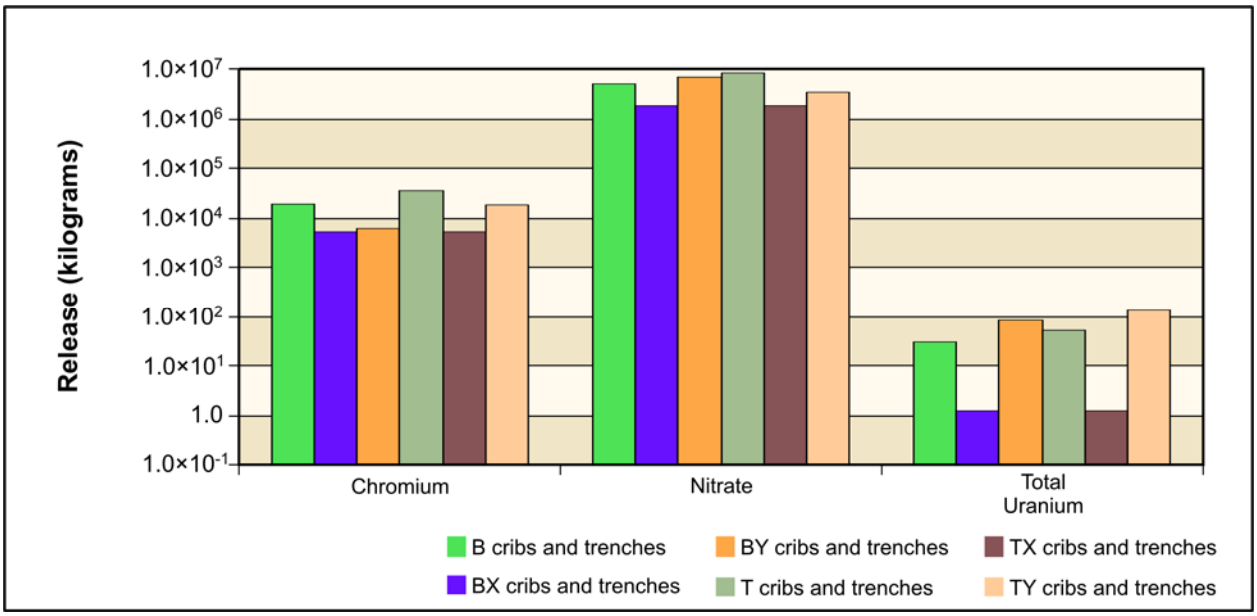


Figure N–42. Tank Closure Alternative 1, Cribs and Trenches (Ditches) Chemical Release to Aquifer

Under Tank Closure Alternative 2A, the cribs and trenches (ditches) associated with the tank farms would be maintained until the end of institutional control period, (i.e., in calendar year 2193). Potential releases to the aquifer from cribs and the trenches (ditches) under Alternative 1 are indicated in Figures N–43 and N–44.

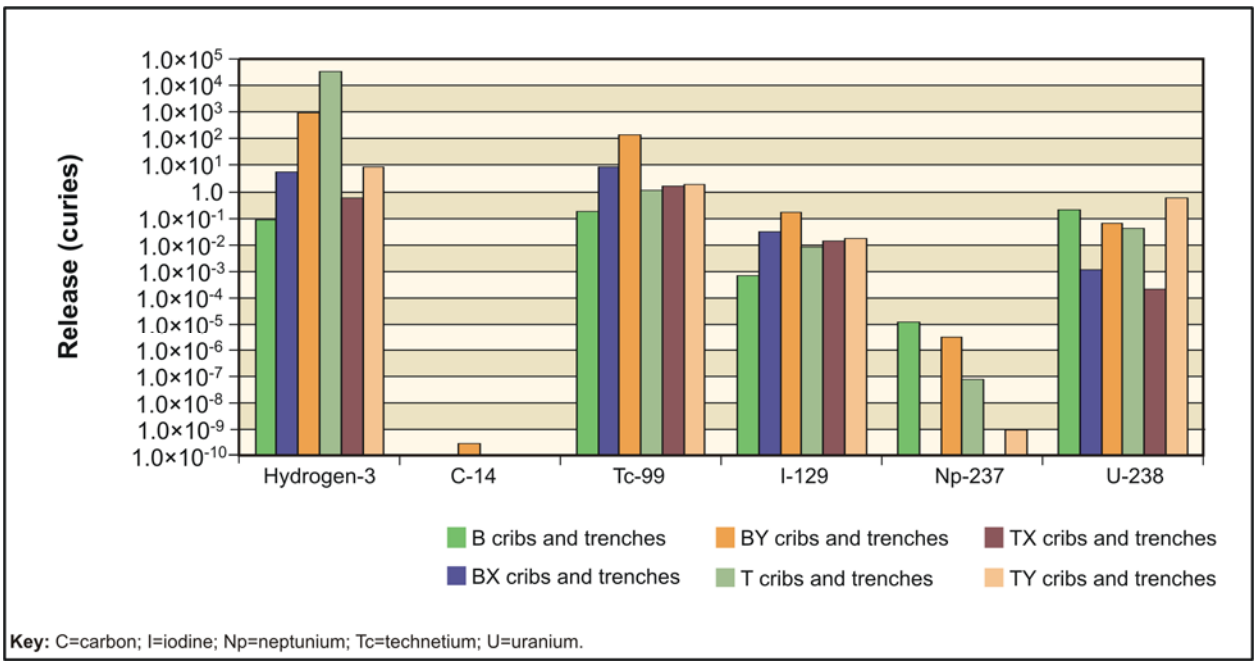


Figure N–43. Tank Closure Alternative 2A, Cribs and Trenches (Ditches) Radiological Release to Aquifer

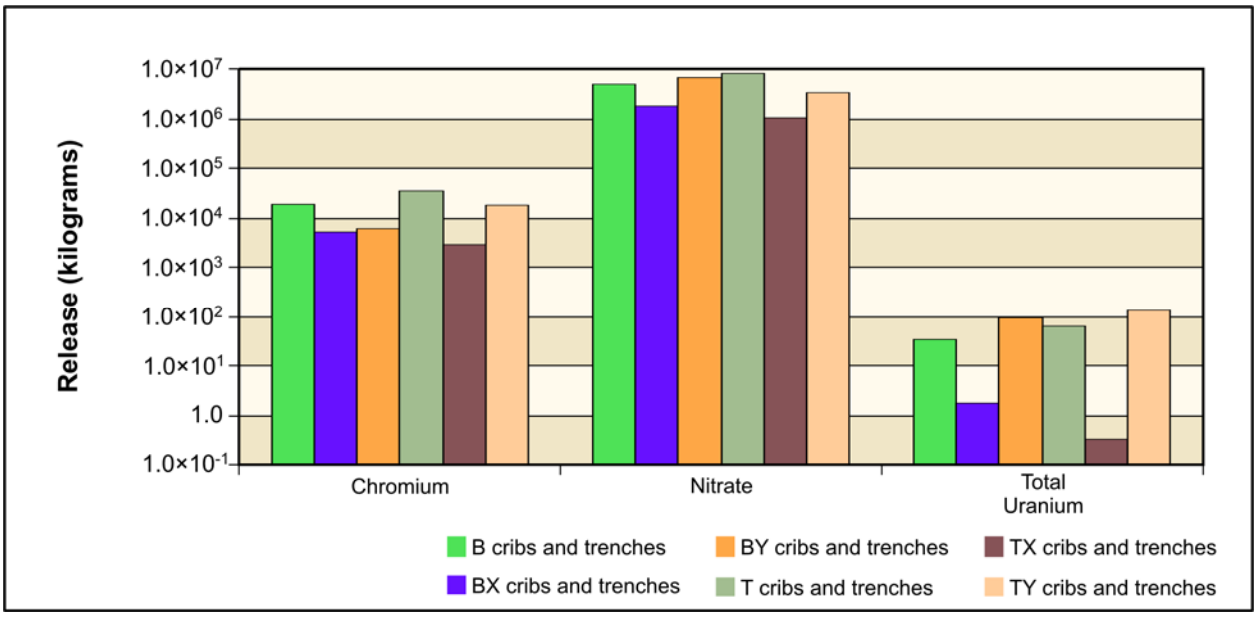


Figure N–44. Tank Closure Alternative 2A, Cribs and Trenches (Ditches) Chemical Release to Aquifer

Activities under Tank Closure Alternatives 2B, 3A, 3B, 3C, 4, 5, 6A (Base Case), 6B (Base Case), and 6C would be similar to those of Tank Closure Alternative 2A, with the addition of an engineered modified RCRA Subtitle C barrier over six sets of adjacent cribs and trenches (ditches). Potential releases to the aquifer from cribs and trenches (ditches) under Alternatives 2B, 3A, 3B, 3C, 4, 5, 6A (Base Case), 6B (Base Case), and 6C are indicated in Figures N–45 through N–46.

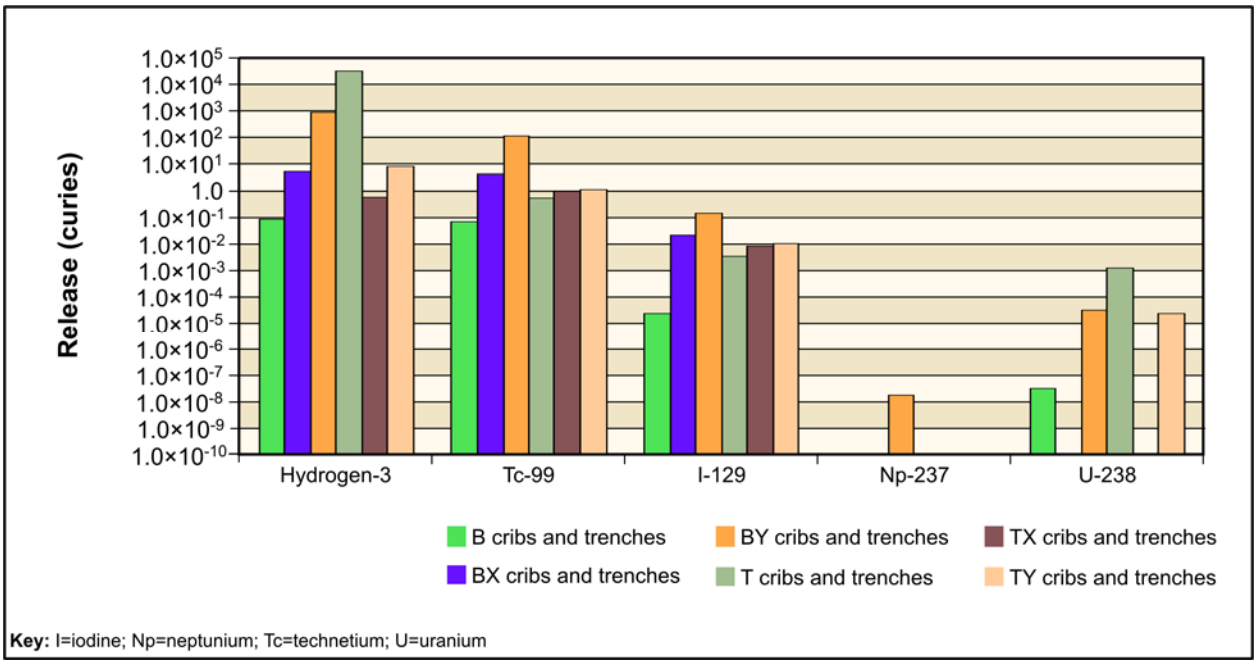


Figure N–45. Tank Closure Alternatives 2B, 3A, 3B, 3C, 4, 5, 6A (Base Case), 6B (Base Case) and 6C, Cribs and Trenches (Ditches) Radiological Release to Aquifer

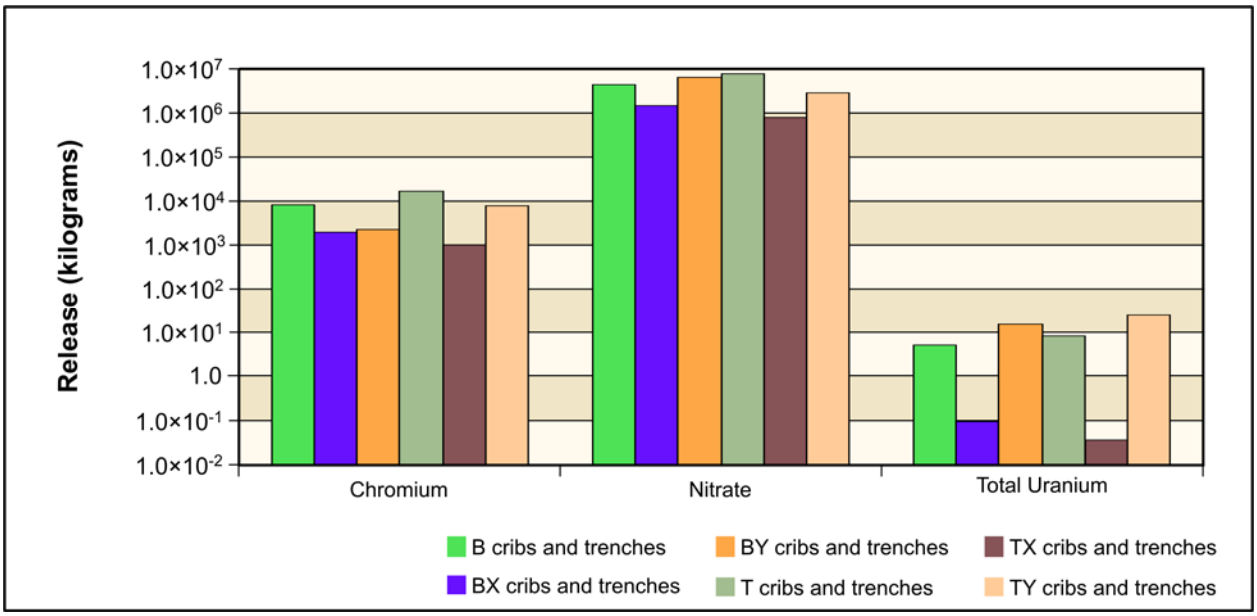


Figure N–46. Tank Closure Alternatives 2B, 3A, 3B, 3C, 4, 5, 6A (Base Case), 6B (Base Case) and 6C, Cribs and Trenches (Ditches) Chemical Release to Aquifer

Under Tank Closure Alternative 6A, Option Case, deep soil excavation would also be conducted to remove contamination plumes within the soil column where necessary. The adjacent cribs and trenches (ditches) would be covered with an engineered modified RCRA Subtitle C barrier. Potential releases to the aquifer from past leaks under Alternative 6A, Option Case, are indicated in Figures N–47 through N–48.

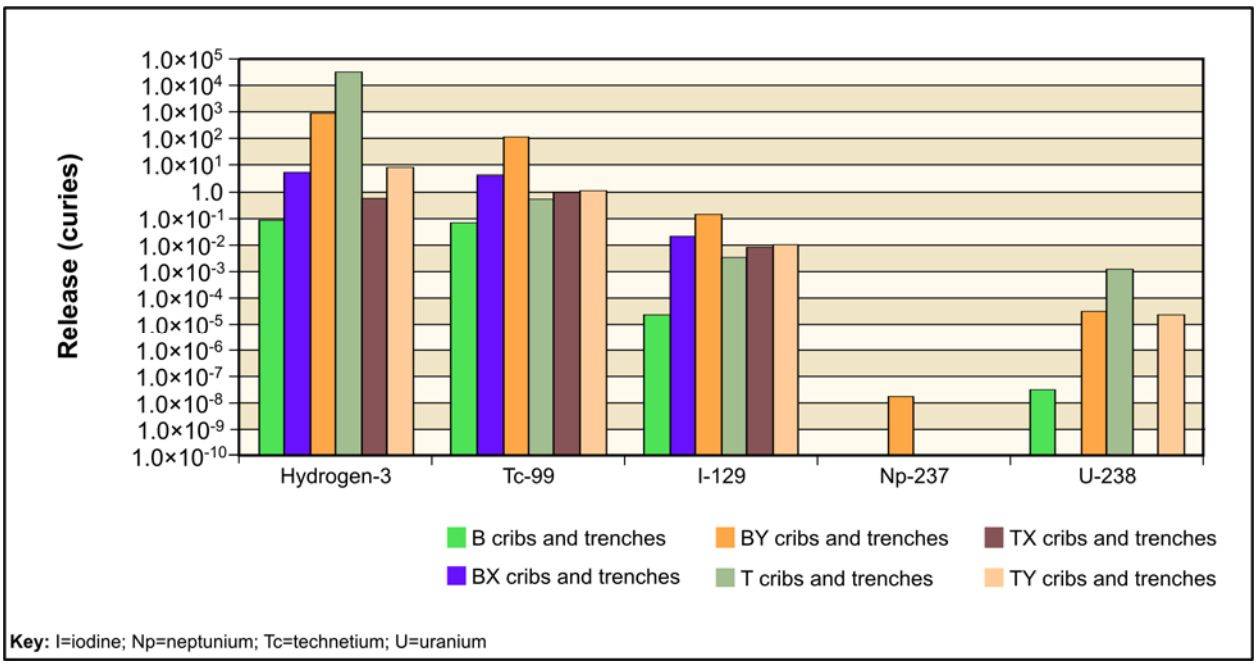


Figure N–47. Tank Closure Alternative 6A, Option Case, Cribs and Trenches (Ditches) Radiological Release to Aquifer

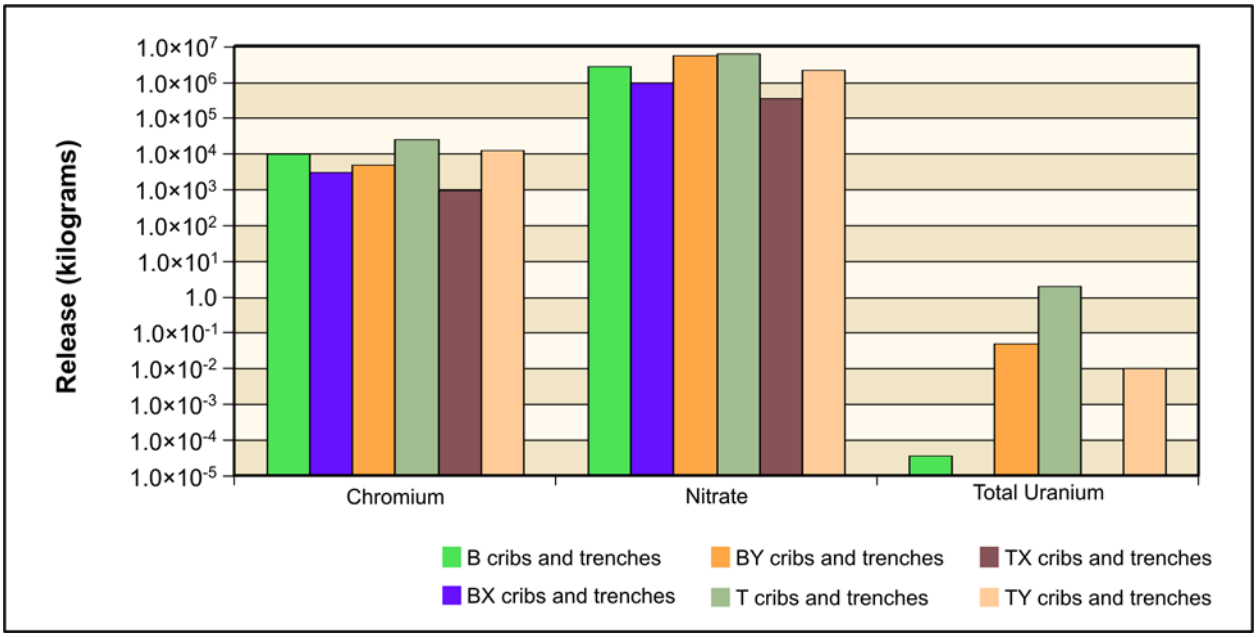


Figure N–48. Tank Closure Alternative 6A, Option Case, Cribs and Trenches (Ditches) Chemical Release to Aquifer

Tank Closure Alternative 6B, Option Case, resembles Tank Closure Alternative 6A, Option Case, except that waste retrieval and processing would proceed at a faster rate and closure would occur at an earlier date. Potential releases to the aquifer from cribs and trenches (ditches) under Alternative 6B, Option Case, are indicated in Figures N–49 through N–50.

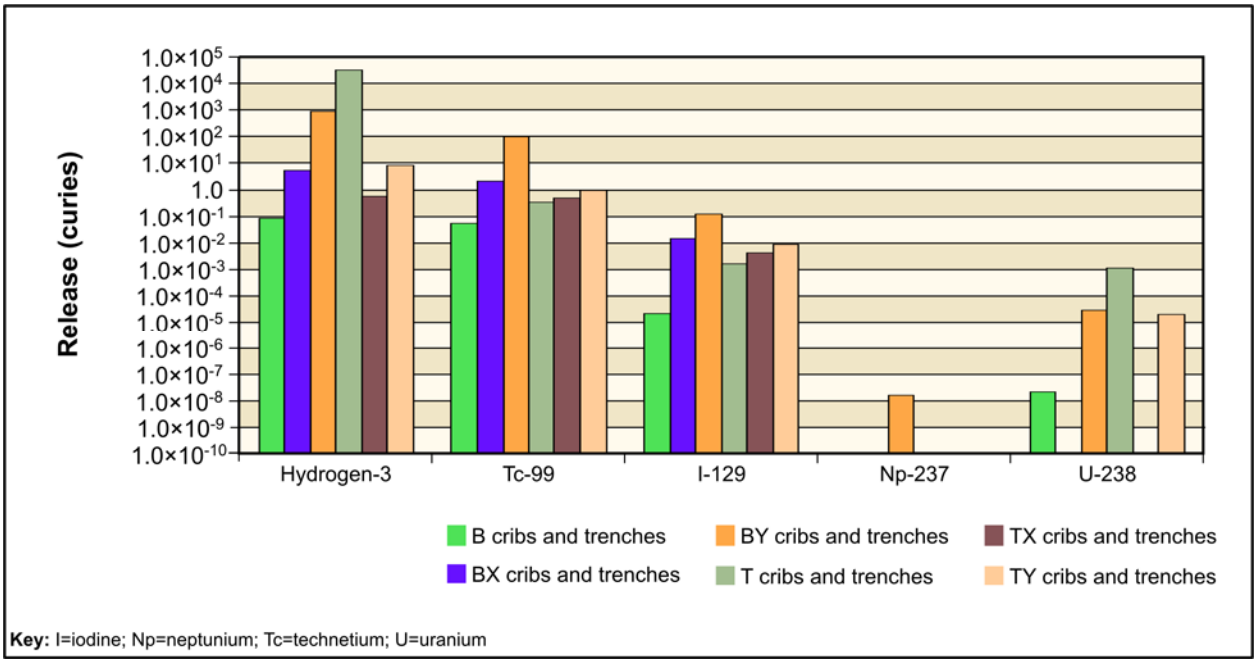


Figure N–49. Tank Closure Alternative 6B, Option Case, Cribs and Trenches (Ditches) Radiological Release to Aquifer

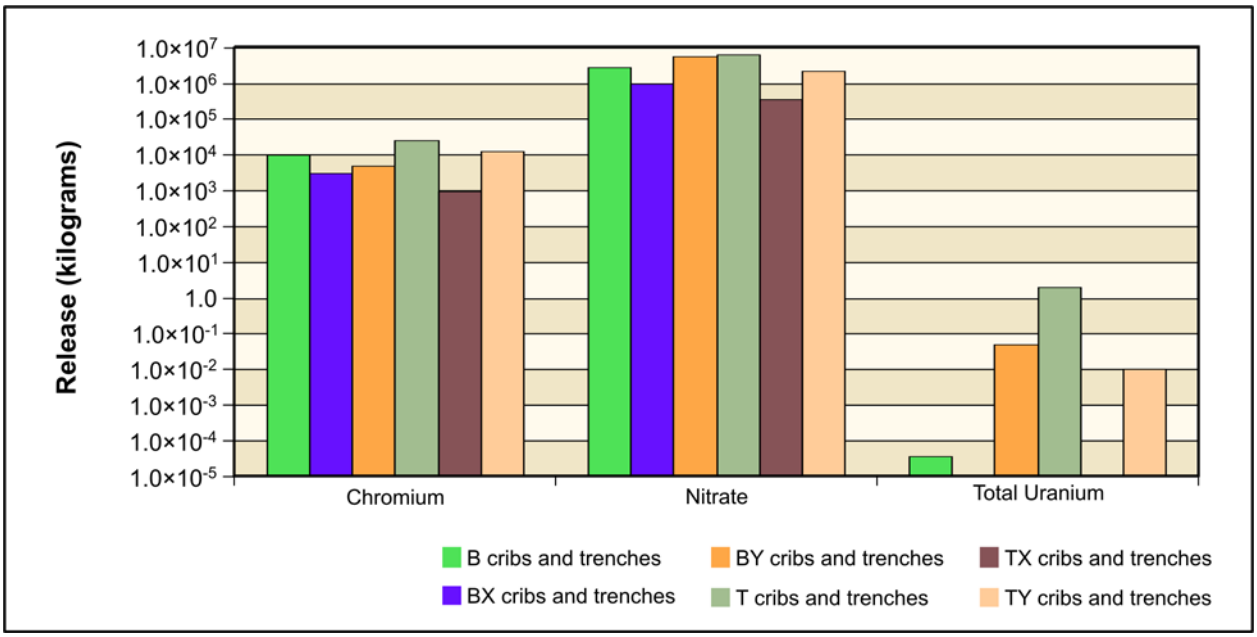


Figure N–50. Tank Closure Alternative 6B, Option Case, Cribs and Trenches (Ditches) Chemical Release to Aquifer

N.2.1.2 Release from Other Sources in the Tank Farms

Releases from other sources related to the HLW tanks, including tank residuals, retrieval leaks, and ancillary equipment, were analyzed together. The amount of constituent released to the aquifer is related to the activities under each Tank Closure alternative. Under Tank Closure Alternatives 6A and 6B, all tank farms would be closed to a clean state by removing the tanks, ancillary equipment, and soil to a depth of 3 meters (10 feet) below the tank base. Where necessary, deep soil excavation would also be conducted to remove contamination plumes within the soil column. Therefore, releases from other sources related to the HLW tanks were not analyzed.

Under Tank Closure Alternative 1, tank farms would be maintained in the current condition indefinitely but, for the purpose of analysis, are assumed to fail after an institutional control period of 100 years. At this time, the salt cake in single-shell tanks is assumed available for leaching into the vadose zone, and the liquid contents of double-shell tanks are assumed to be discharged directly to the vadose zone. Figures N–51 through N–56 indicate the constituent release estimated under Tank Closure Alternative 1.

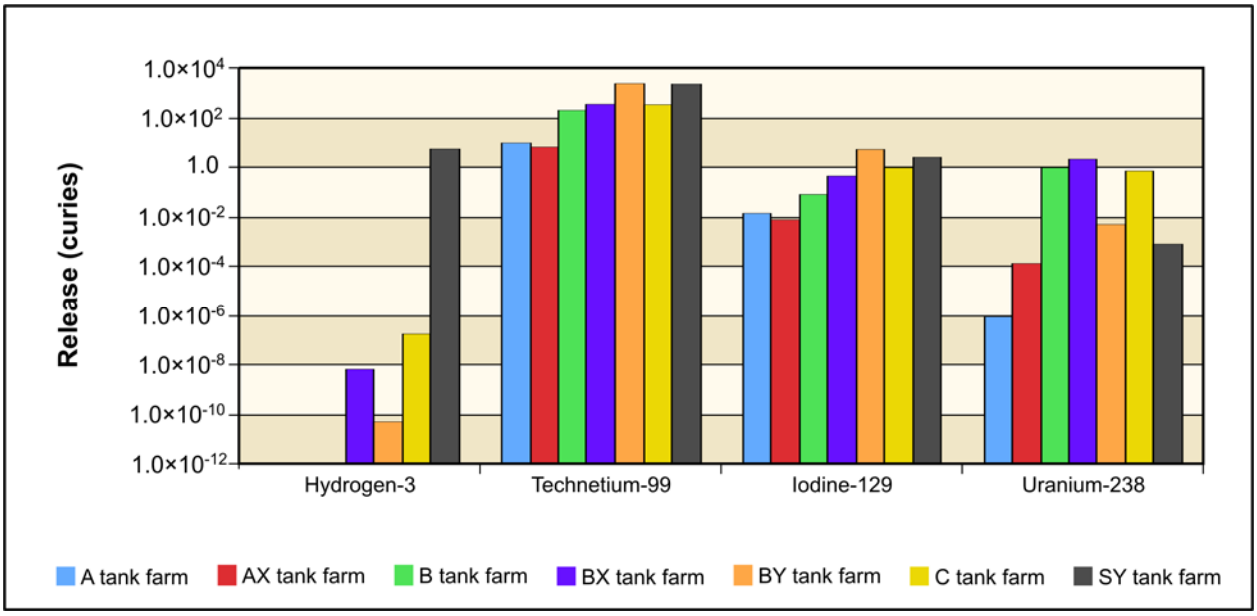


Figure N–51. Tank Closure Alternative 1 Other Sources from Tank Farms A, AX, B, BX, BY, C, and SY Radiological Release to Aquifer

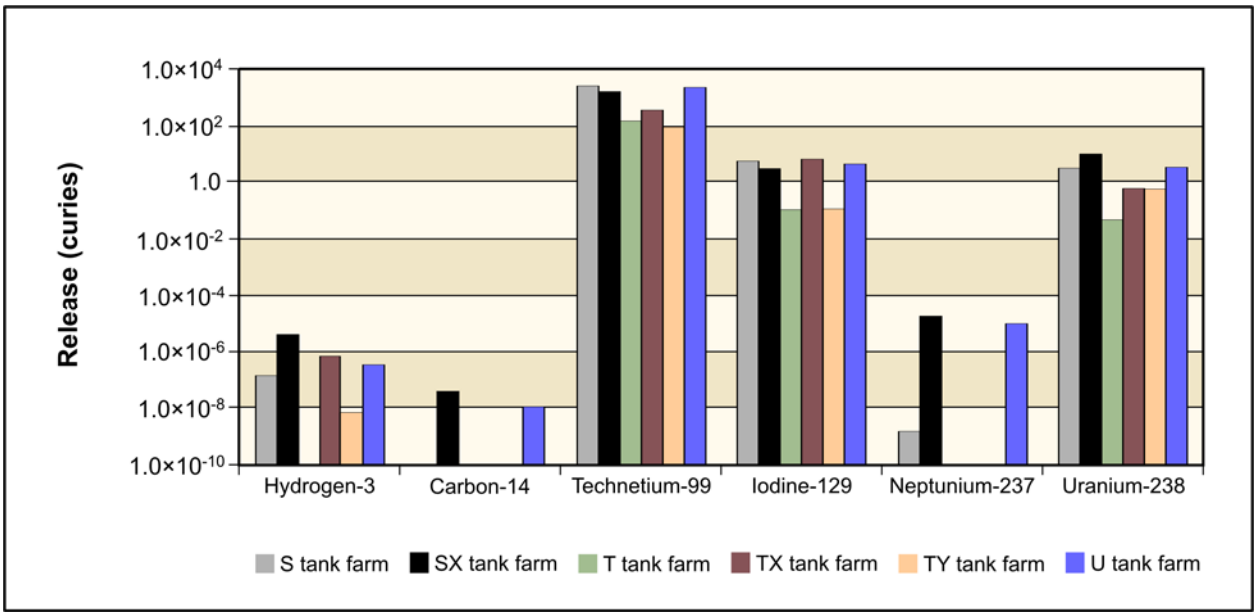


Figure N–52. Tank Closure Alternative 1 Other Sources from Tank Farms S, SX, T, TX, TY, and U Radiological Release to Aquifer

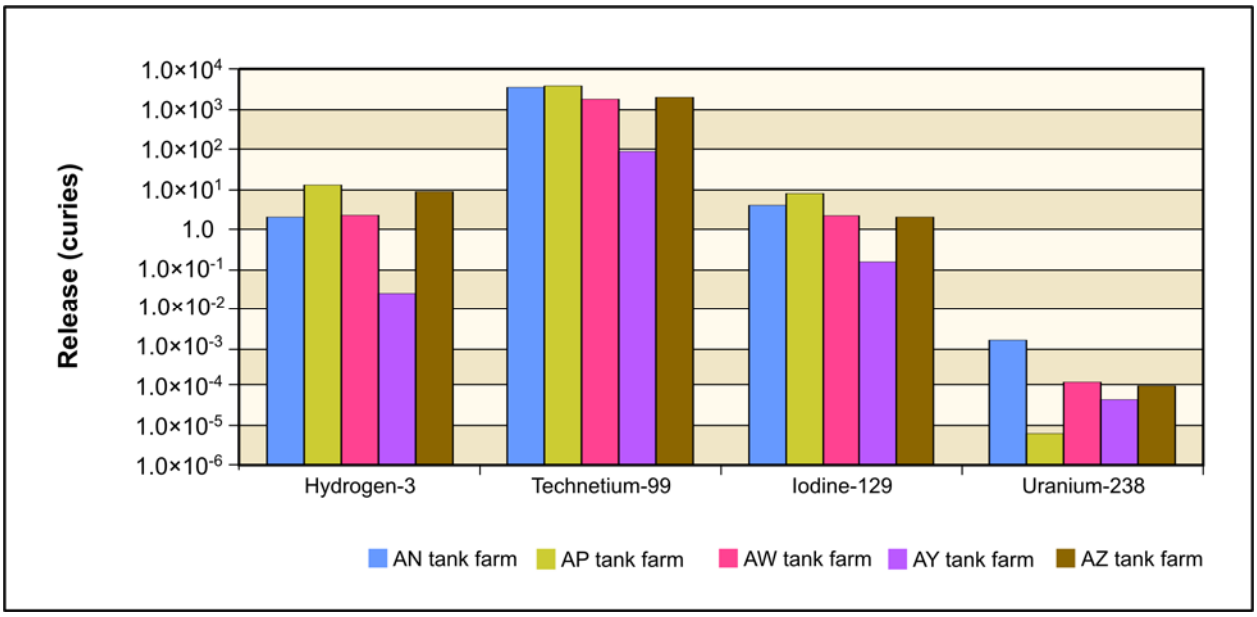


Figure N–53. Tank Closure Alternative 1 Other Sources from Tank Farms AN, AP, AW, AY and AZ Radiological Release to Aquifer

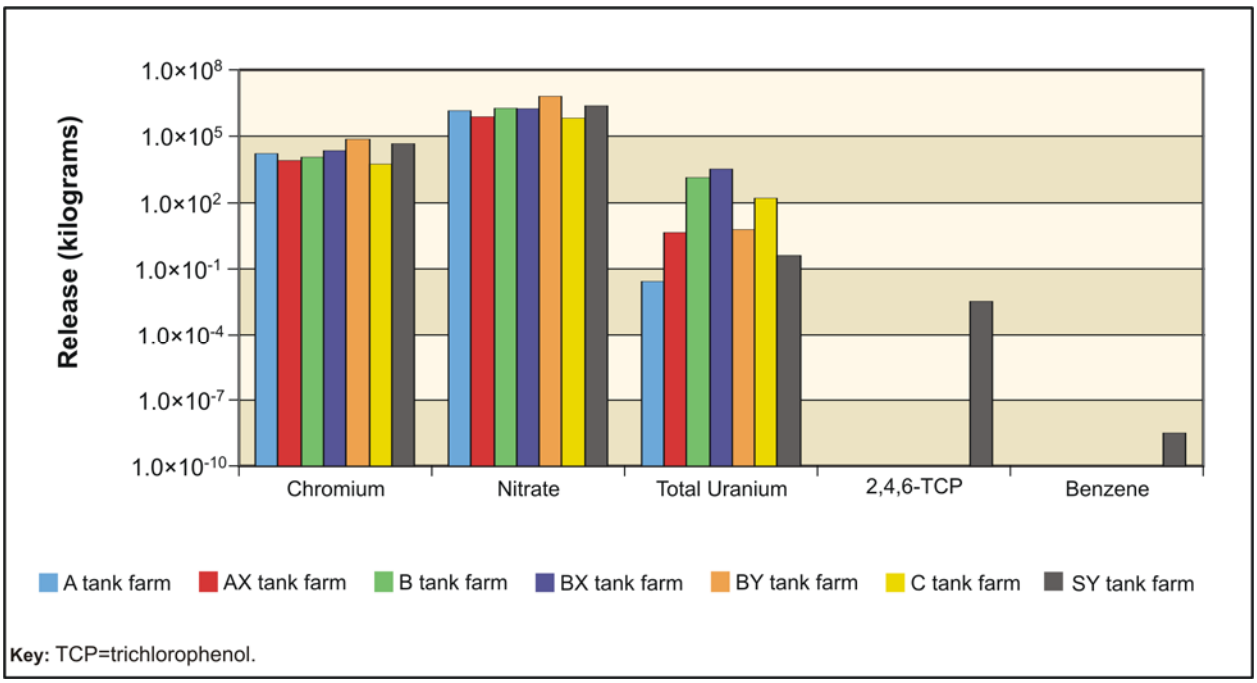


Figure N–54. Tank Closure Alternative 1 Other Sources from Tank Farms A, AX, B, BX, BY, C, and SY Chemical Release to Aquifer

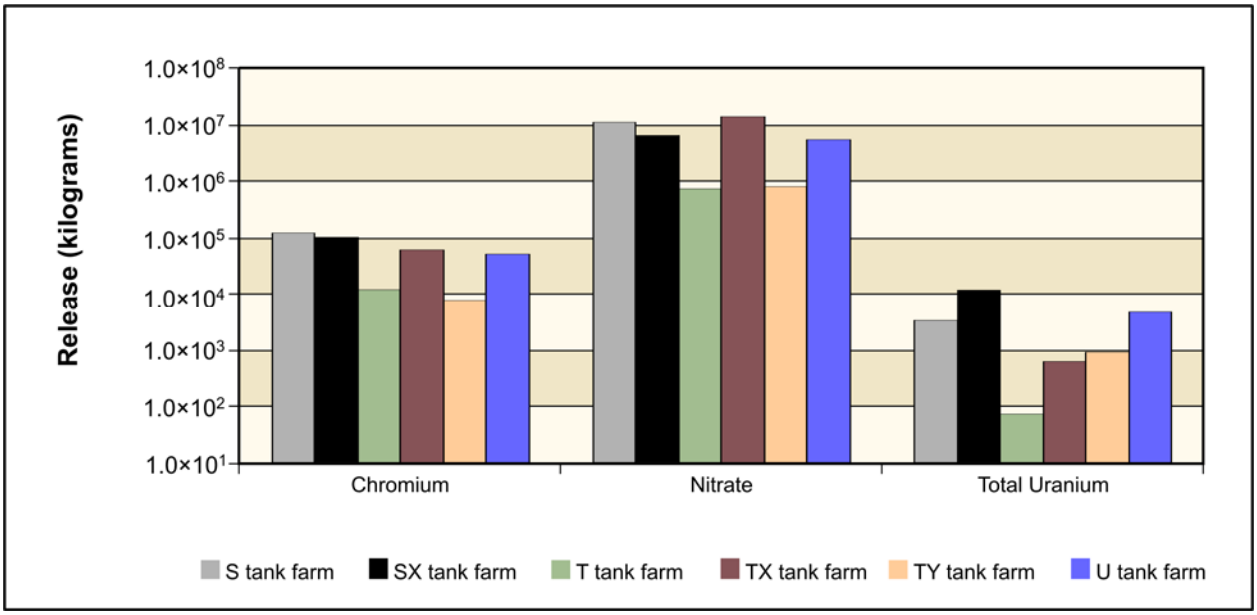


Figure N–55. Tank Closure Alternative 1 Other Sources from Tank Farms S, SX, T, TX, TY, and U Chemical Release to Aquifer

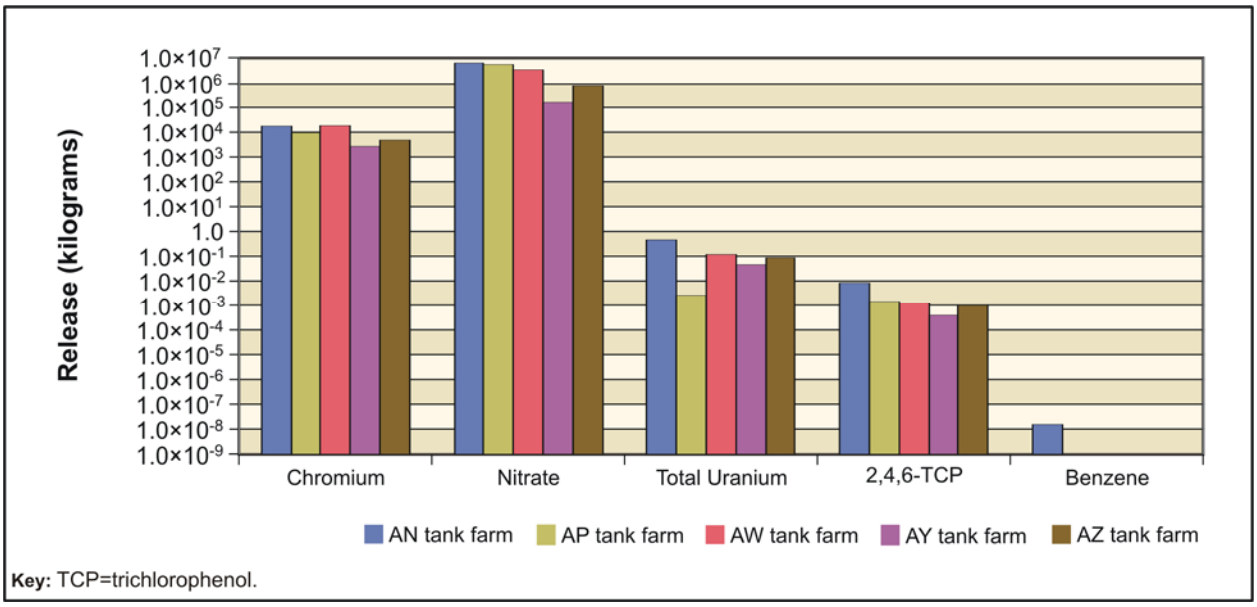


Figure N–56. Tank Closure Alternative 1 Other Sources from Tank Farms AN, AP, AW, AY, and AZ Chemical Release to Aquifer

Under Tank Closure Alternative 2A, tank waste would be retrieved to a volume corresponding to 99 percent retrieval, but residual material in tanks would not be stabilized. After an institutional control period of 100 years, the salt cake in tanks would presumably be available for dissolution in infiltrating water. Potential releases to the aquifer under Tank Closure Alternative 2A are indicated in Figures N–57 through N–62.

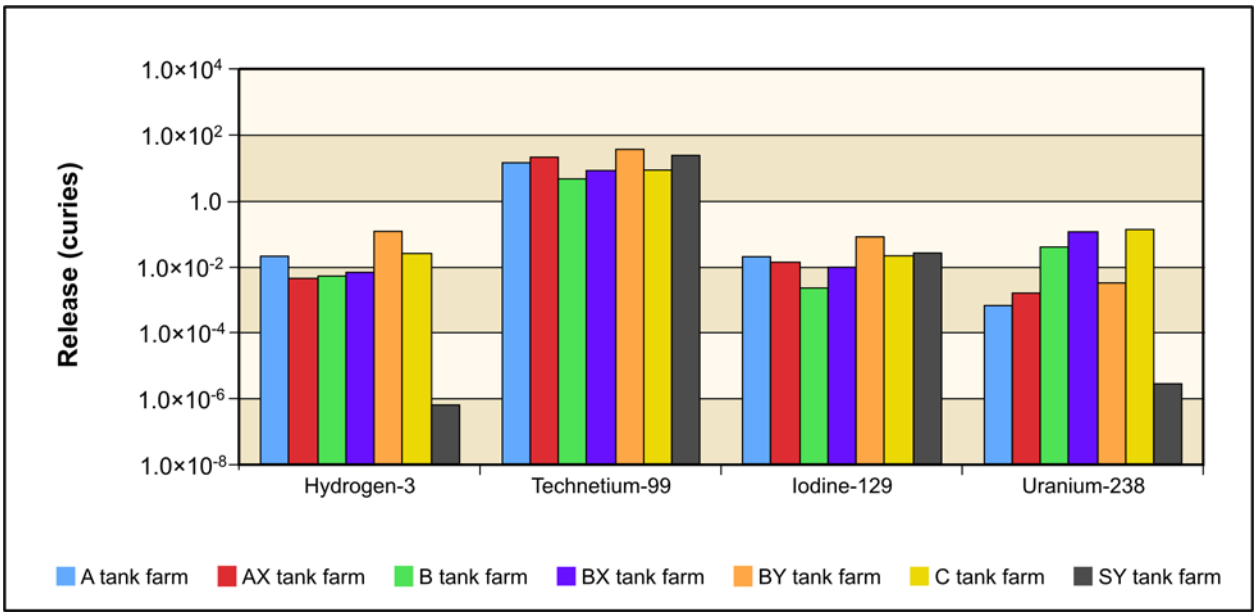


Figure N–57. Tank Closure Alternative 2A Other Sources from Tank Farms A, AX, B, BX, BY, C, and SY Radiological Release to Aquifer

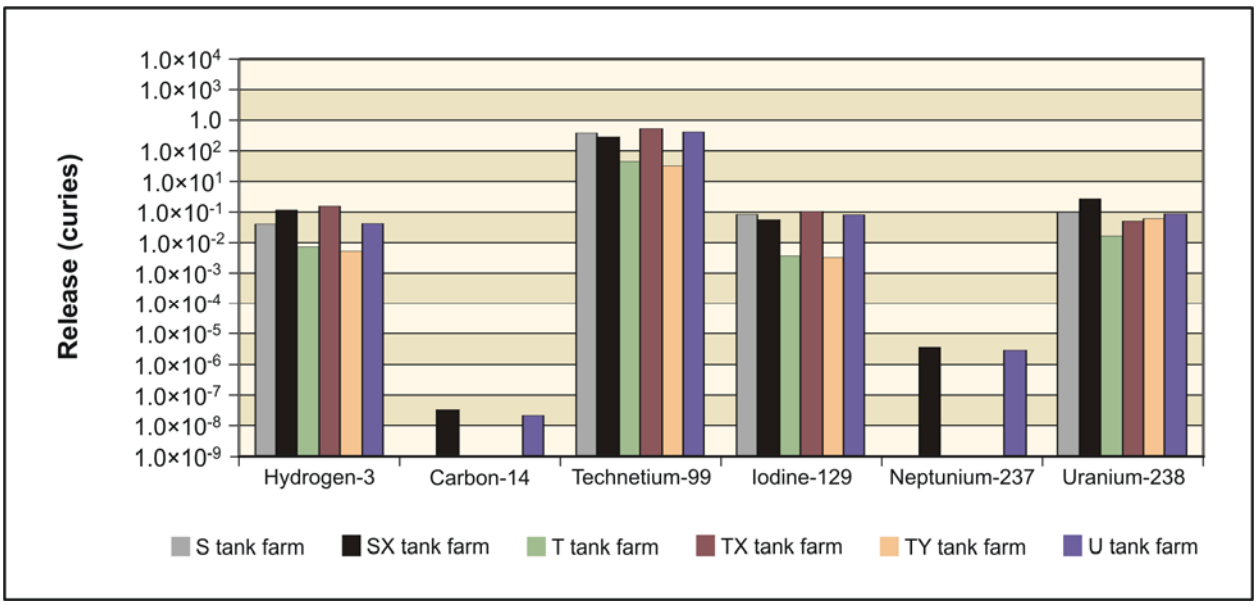


Figure N–58. Tank Closure Alternative 2A Other Sources from Tank Farms S, SX, T, TX, TY, and U Radiological Release to Aquifer

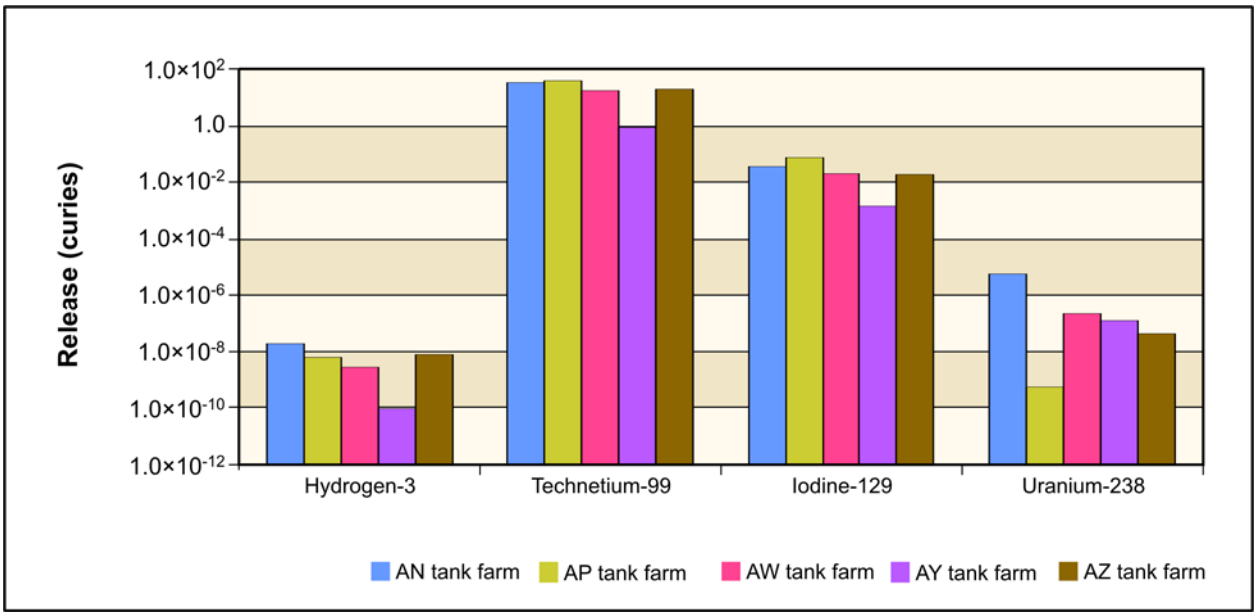


Figure N–59. Tank Closure Alternative 2A Other Sources from Tank Farms AN, AP, AW, AY, and AZ Radiological Release to Aquifer

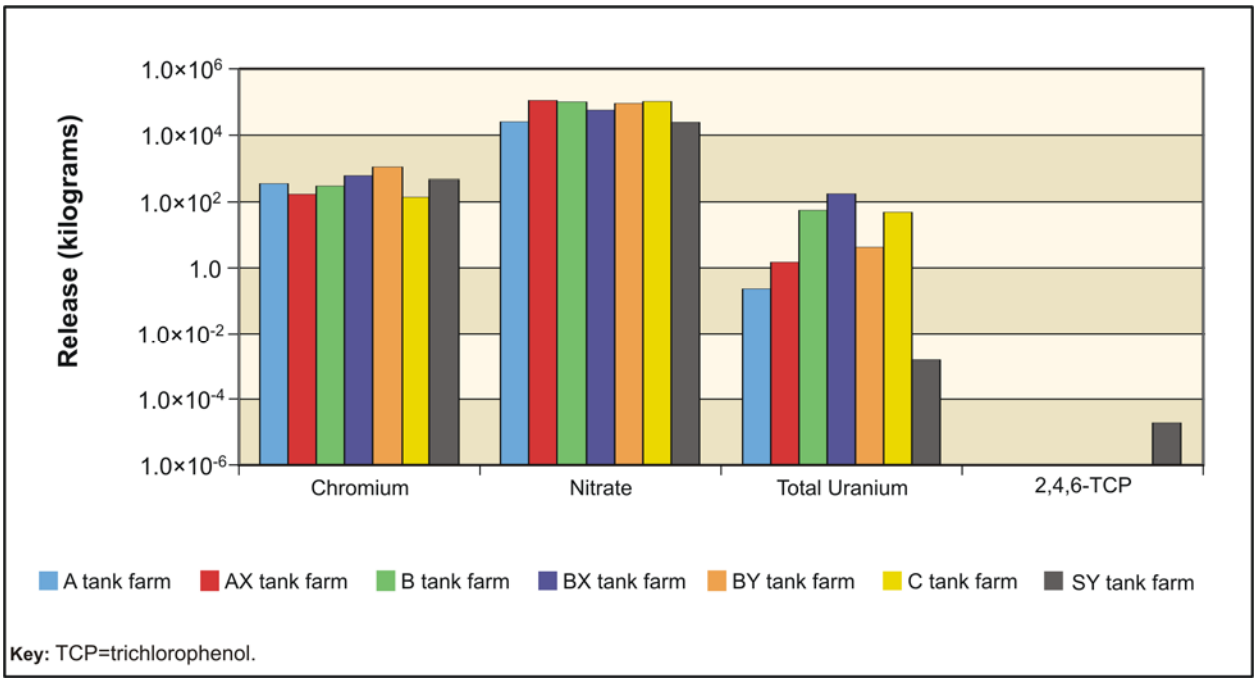


Figure N–60. Tank Closure Alternative 2A Other Sources from Tank Farms A, AX, B, BX, BY, C, and SY Chemical Release to Aquifer

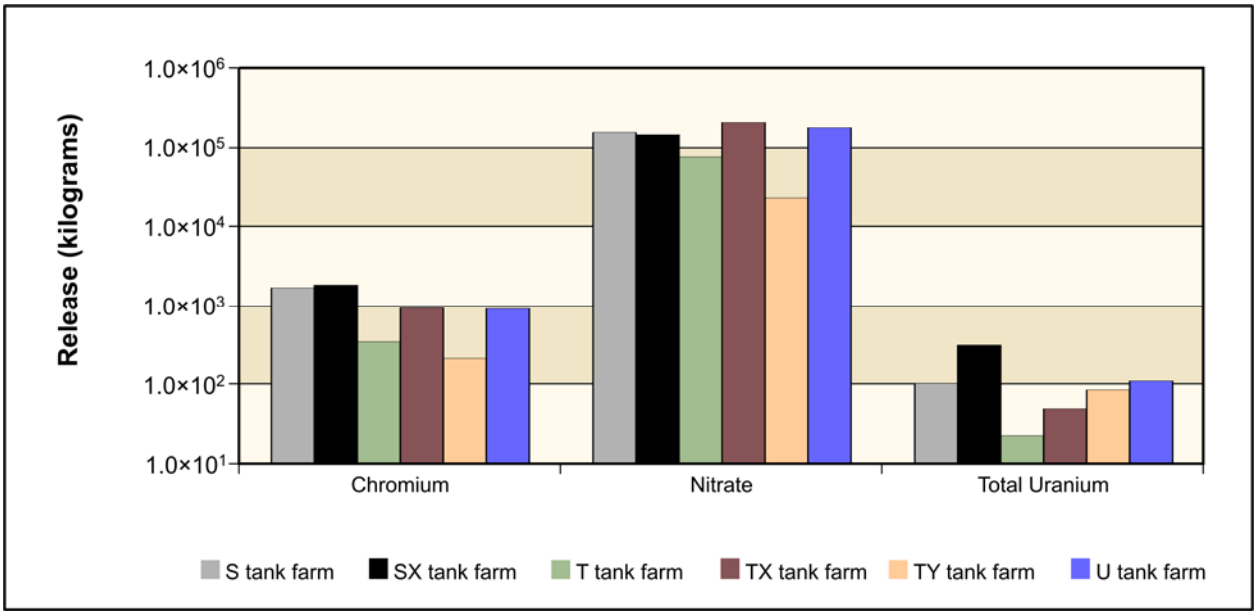


Figure N–61. Tank Closure Alternative 2A Other Sources from Tank Farms S, SX, T, TX, TY, and U Chemical Release to Aquifer

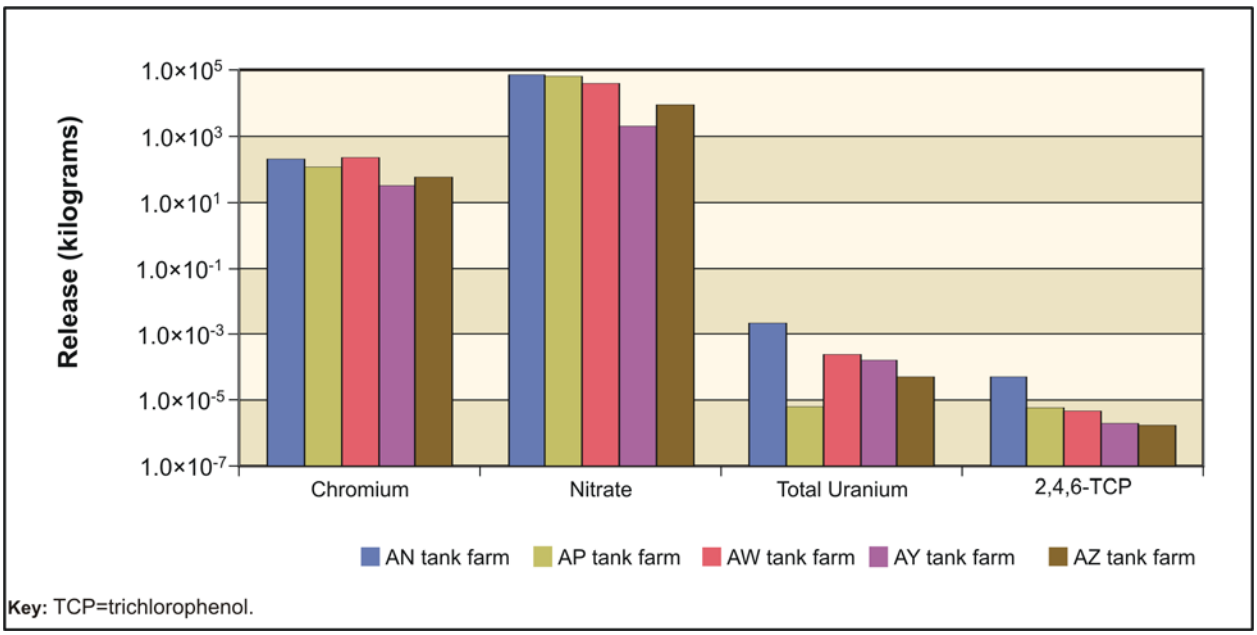


Figure N–62. Tank Closure Alternative 2A Other Sources from Tank Farms AN, AP, AW, AY, and AZ Chemical Release to Aquifer

Activities under Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C would be similar to those of Tank Closure Alternative 2A, except that residual material in tanks would be stabilized in place. Soil would be removed down to 4.6 meters (15 feet) for the BX and SX tank farms and replaced with clean soil from onsite sources. Potential releases to the aquifer under Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C are indicated in Figures N–63 through N–68.

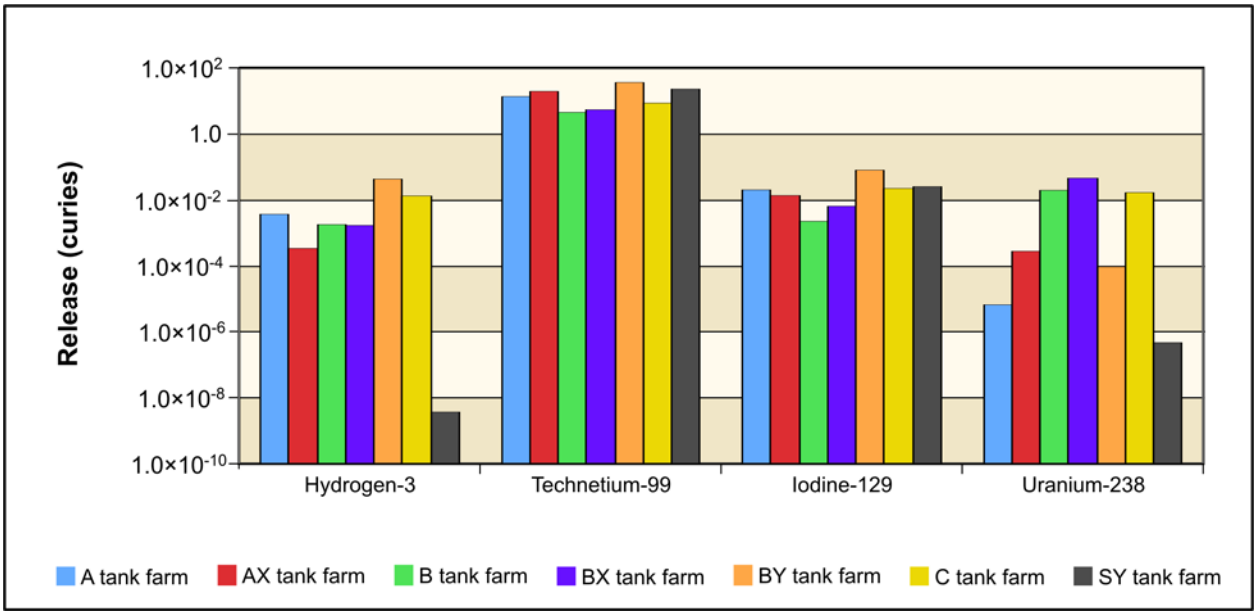


Figure N–63. Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C Other Sources from Tank Farms A, AX, B, BX, BY, C, and SY Radiological Release to Aquifer

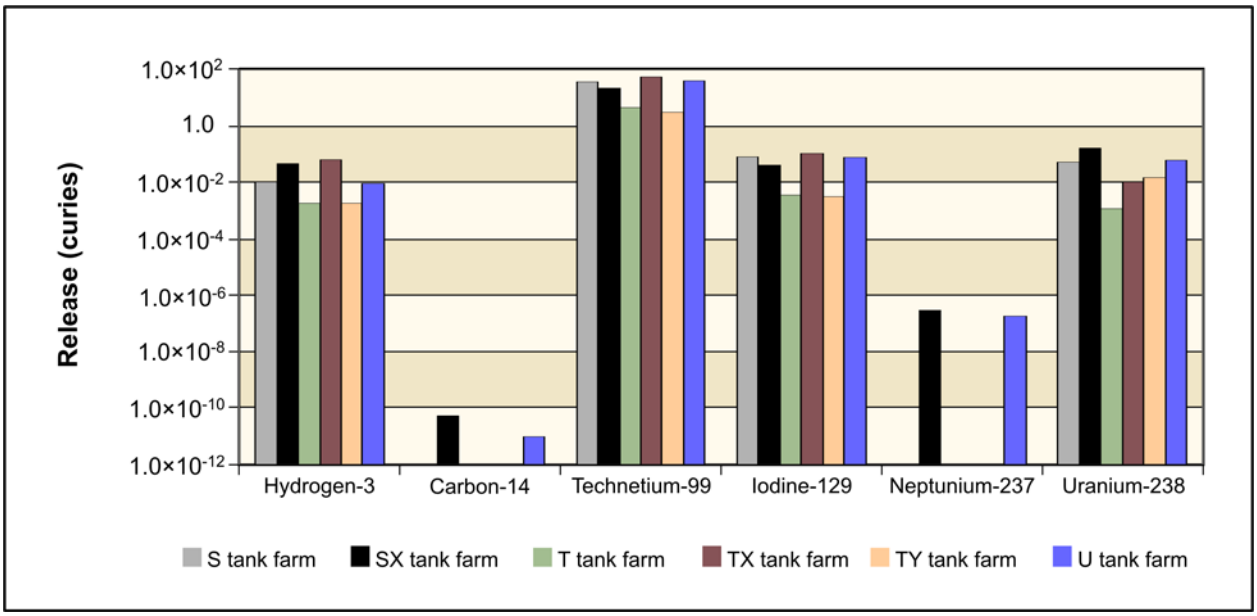


Figure N–64. Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C Other Sources from Tank Farms S, SX, T, TX, TY, and U Radiological Release to Aquifer

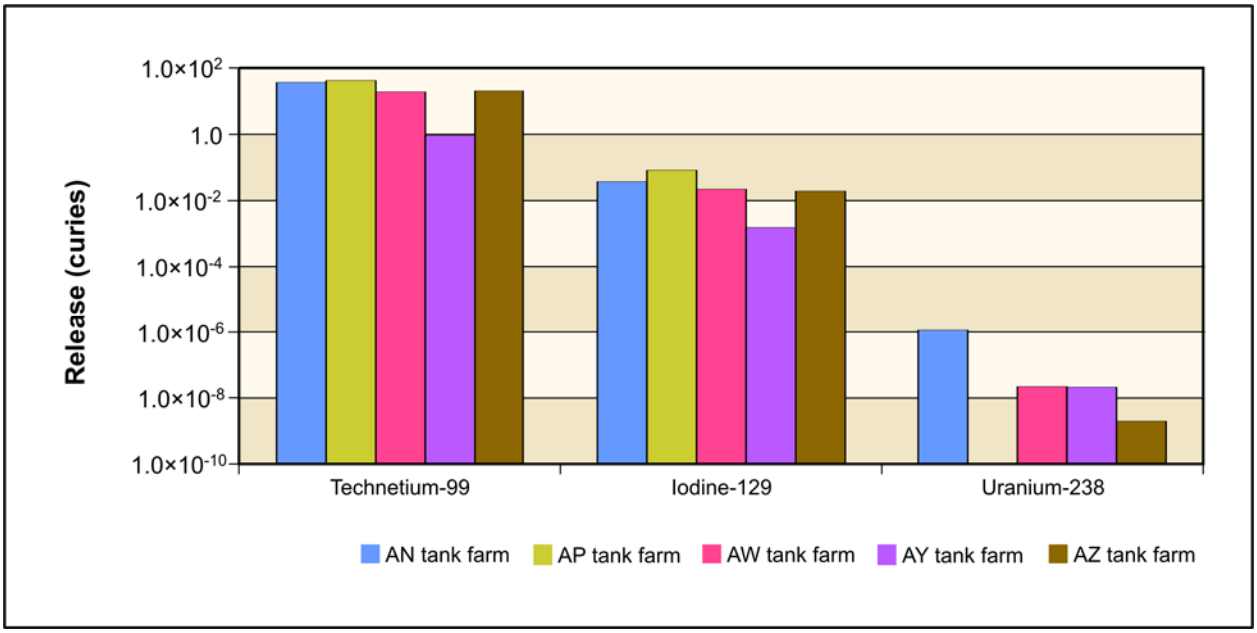


Figure N–65. Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C Other Sources from Tank Farms AN, AP, AW, AY, and AZ Radiological Release to Aquifer

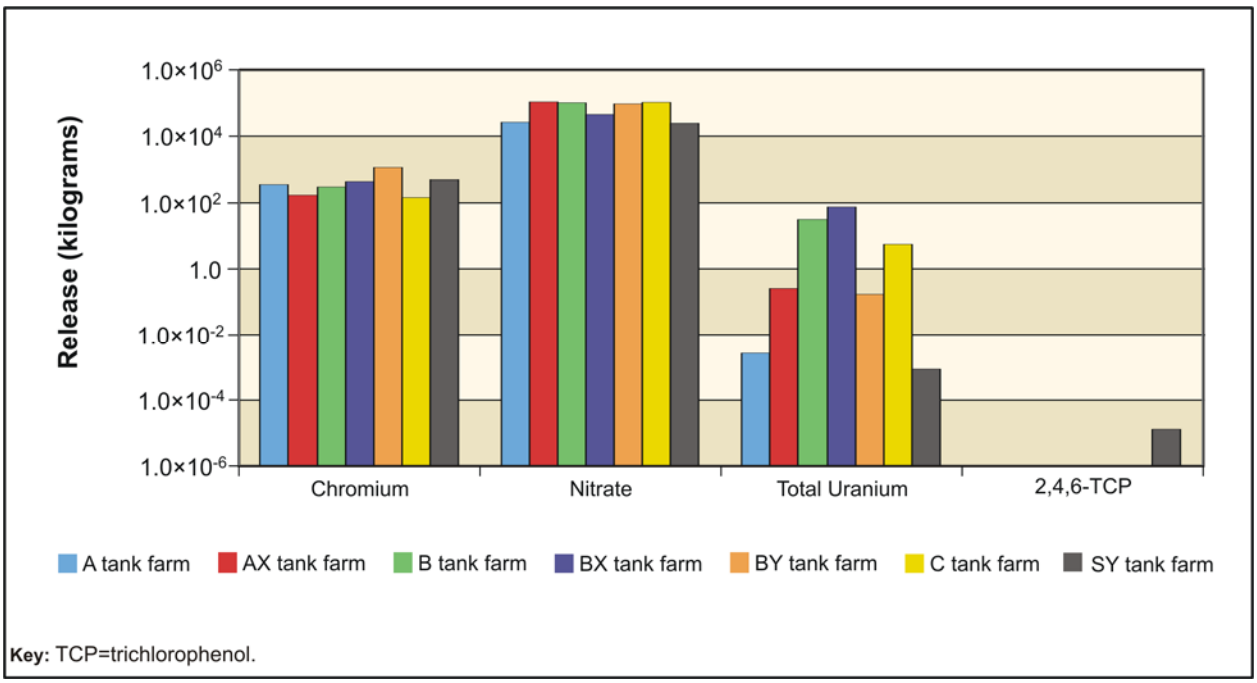


Figure N–66. Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C Other Sources from Tank Farms A, AX, B, BX, BY, C, and SY Chemical Release to Aquifer

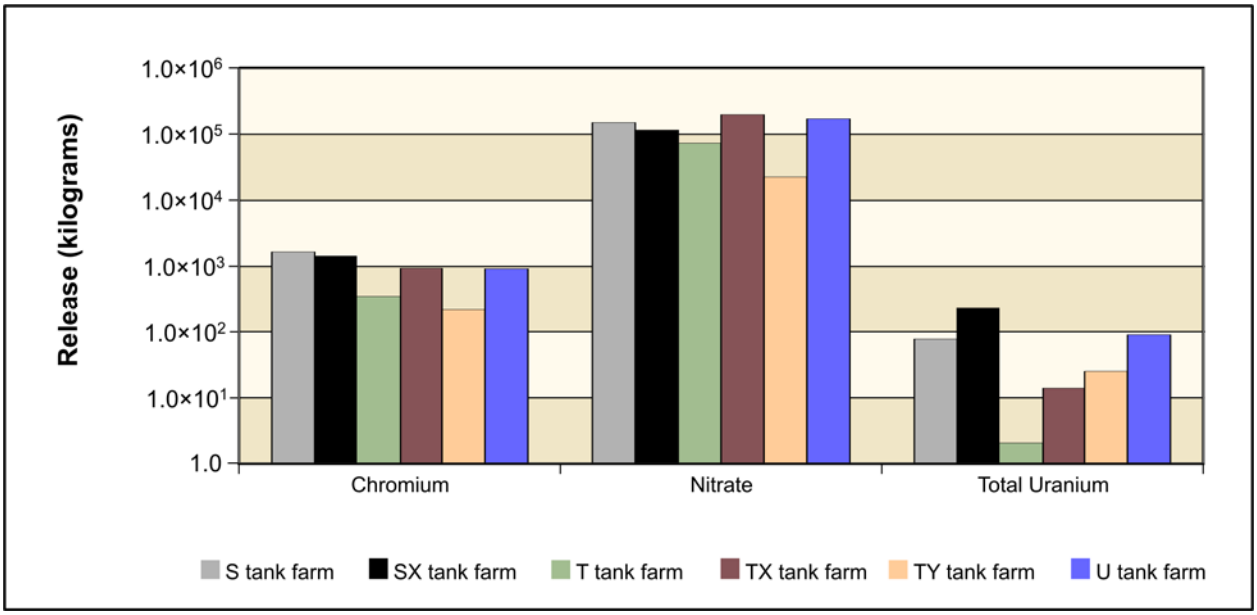


Figure N–67. Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C Other Sources from Tank Farms S, SX, T, TX, TY, and U Chemical Release to Aquifer

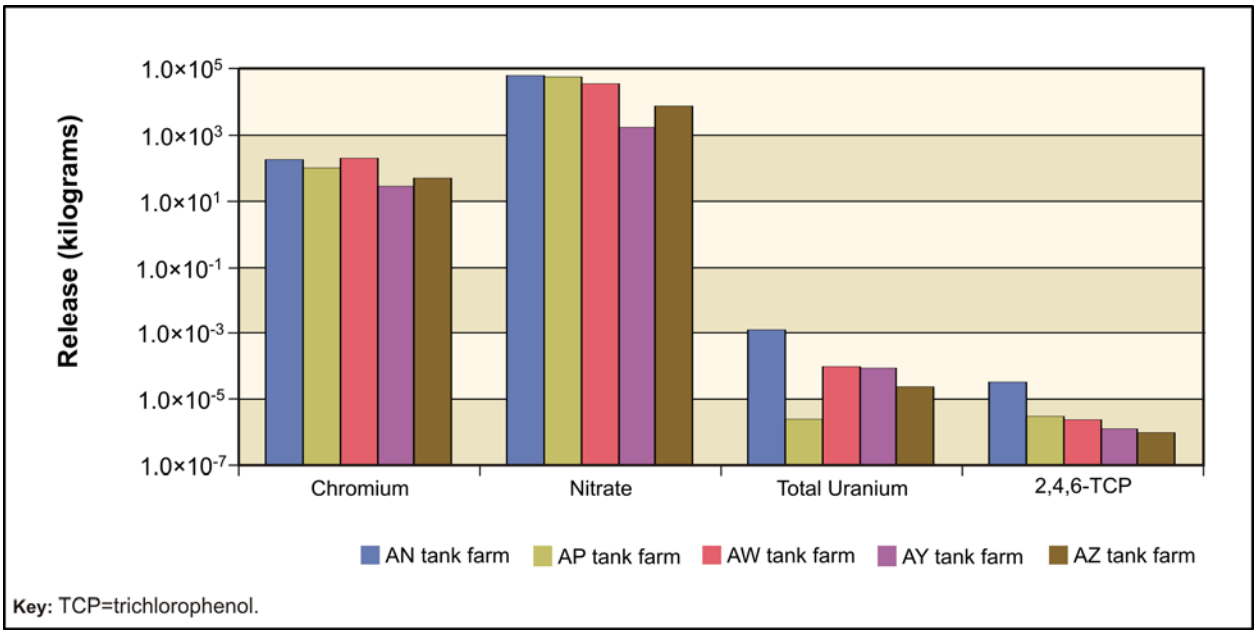


Figure N–68. Tank Closure Alternatives 2B, 3A, 3B, 3C, and 6C Other Sources from Tank Farms AN, AP, AW, AY, and AZ Chemical Release to Aquifer

Under Tank Closure Alternative 4, tank waste would be retrieved to a volume corresponding to 99.9 percent retrieval. Except for the BX and SX tank farms, residual material in tanks would be stabilized in place, and the tank farms and adjacent cribs and trenches (ditches) would be covered with an engineered modified RCRA Subtitle C barrier. The BX and SX tank farms would be closed to a clean state by removing the tanks, ancillary equipment, and soils to a depth of 3 meters (10 feet) below the tank base. Where necessary, deep soil excavation would also be conducted to remove contamination plumes within the soil column. Potential releases to the aquifer under Tank Closure Alternative 4 are indicated in Figures N–69 through N–74.

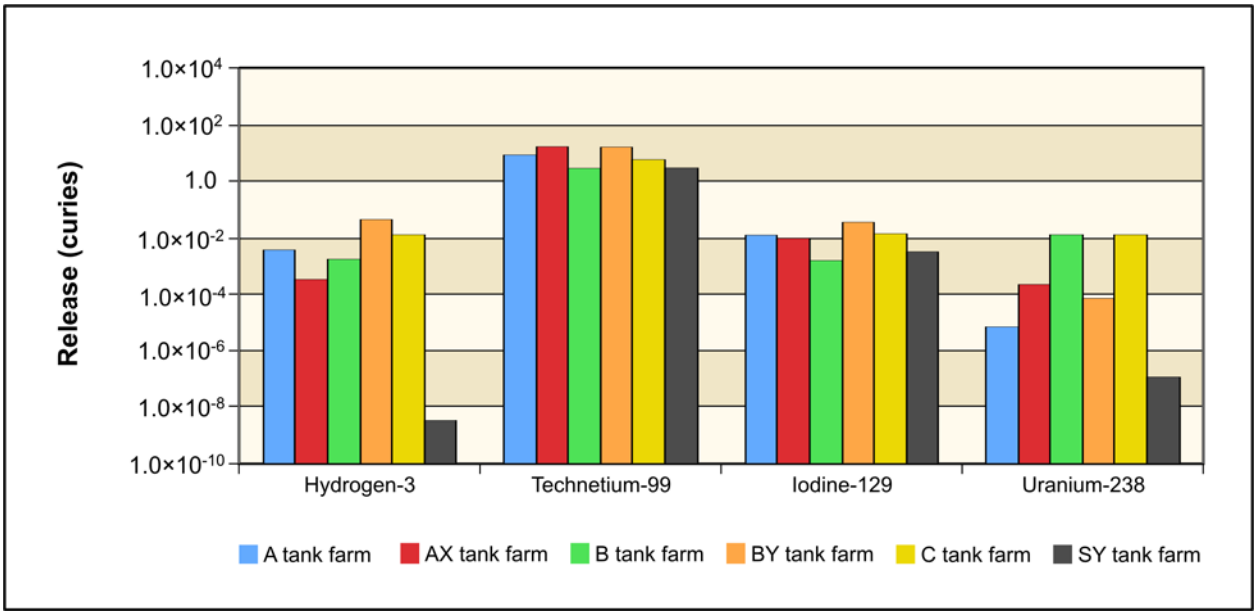


Figure N–69. Tank Closure Alternative 4 Other Sources from Tank Farms A, AX, BX, BY, C, and SY Radiological Release to Aquifer

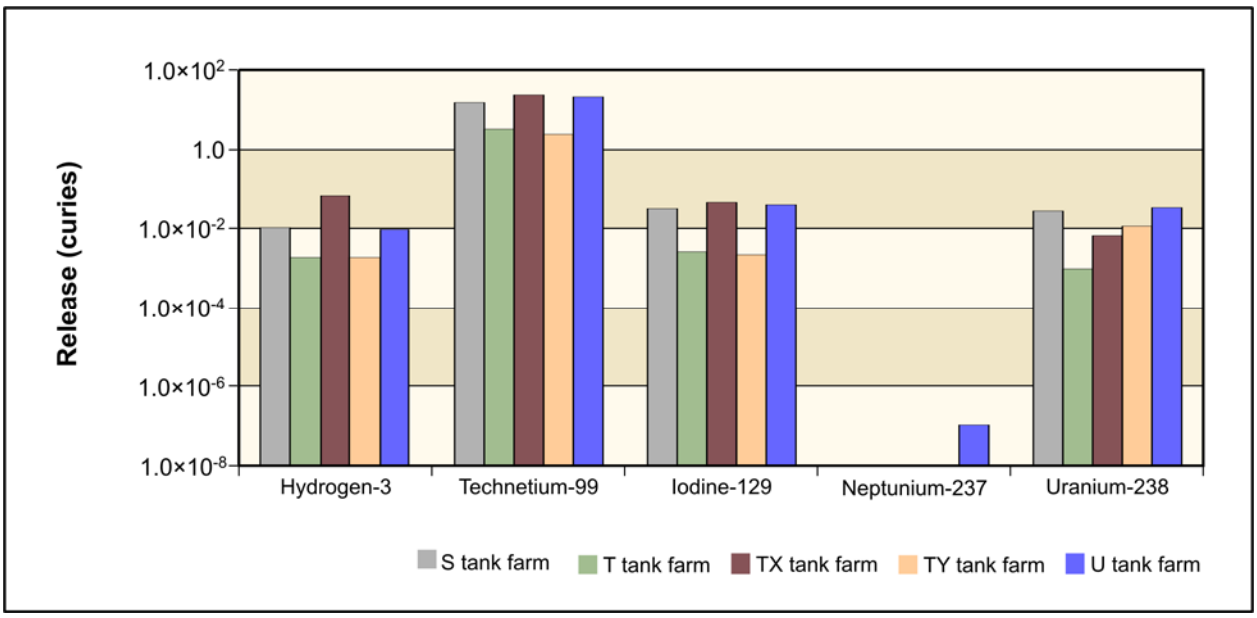


Figure N–70. Tank Closure Alternative 4 Other Sources from Tank Farms S, T, TX, TY, and U Radiological Release to Aquifer

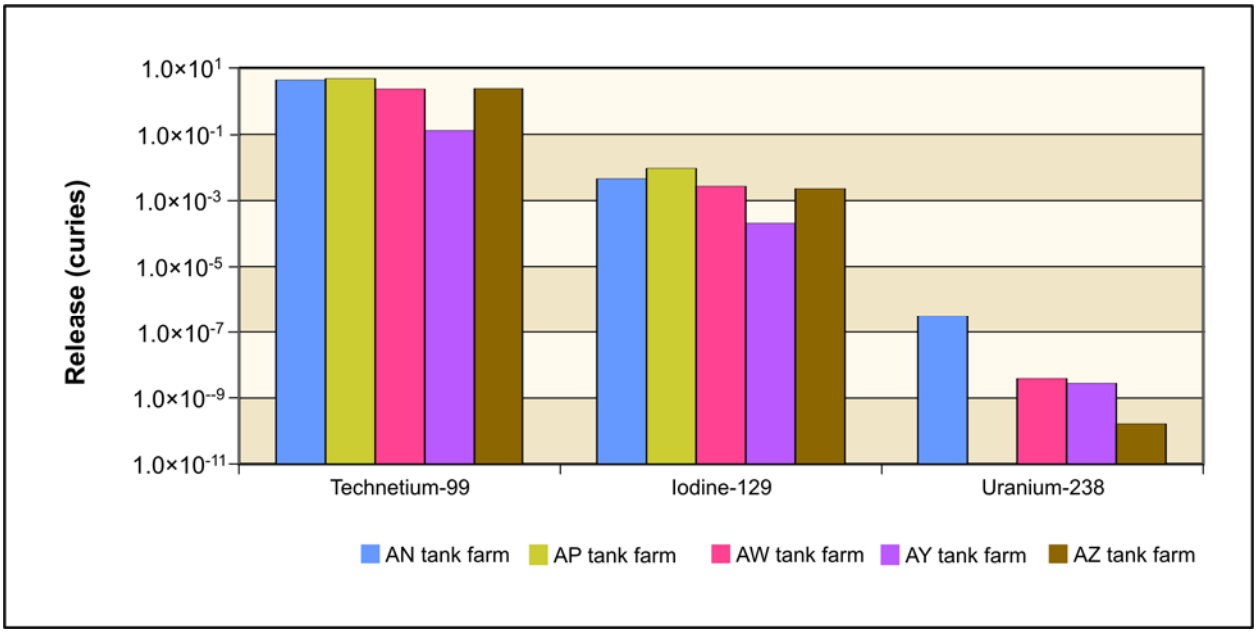


Figure N–71. Tank Closure Alternative 4 Other Sources from Tank Farms AN, AP, AW, AY, and AZ Radiological Release to Aquifer

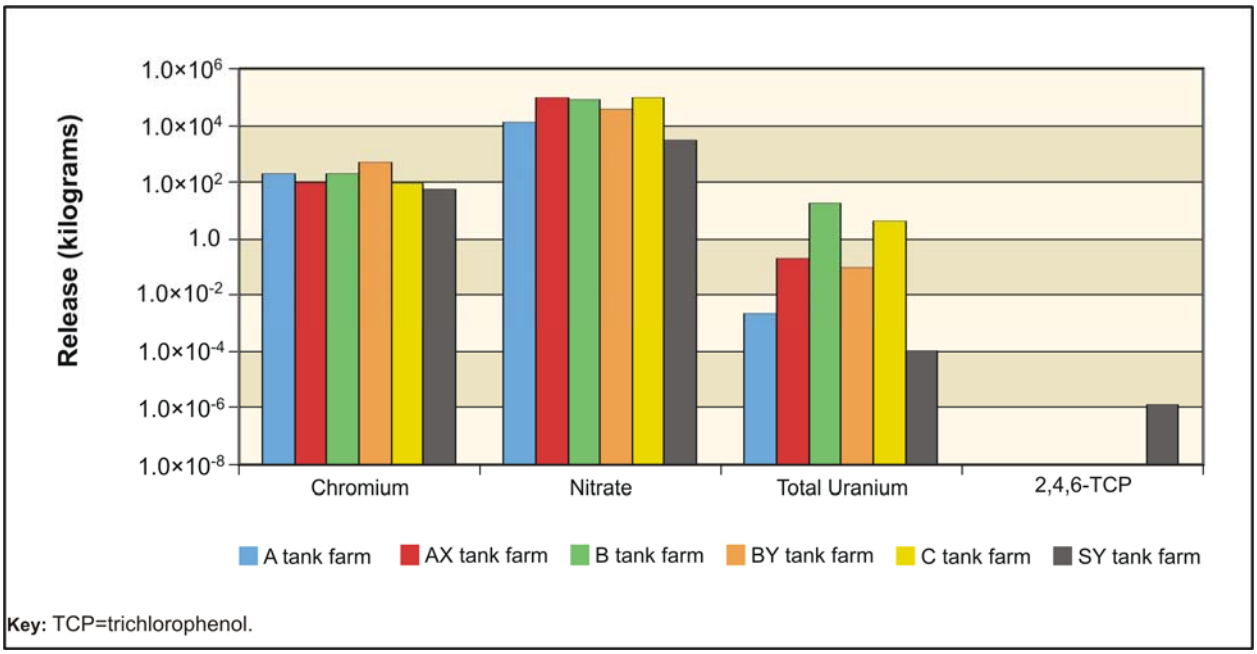


Figure N–72. Tank Closure Alternative 4 Other Sources from Tank Farms A, AX, B, BX, BY, C, and SY Chemical Release to Aquifer

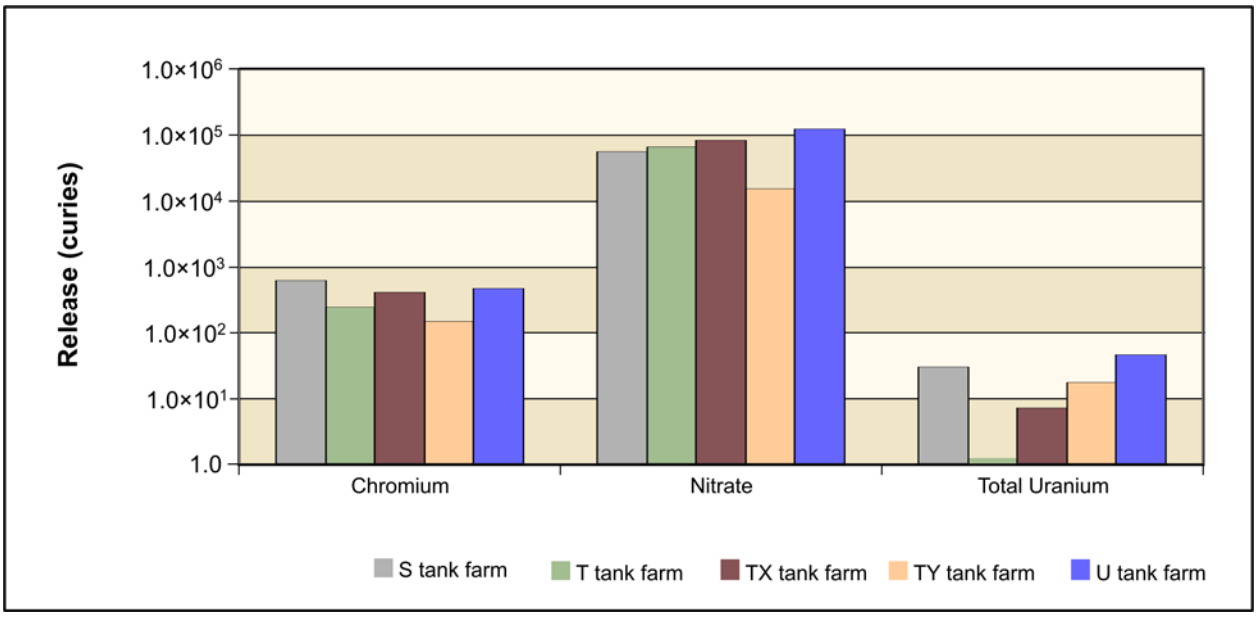


Figure N–73. Tank Closure Alternative 4 Other Sources from Tank Farms S, SX, T, TX, TY, and U Chemical Release to Aquifer

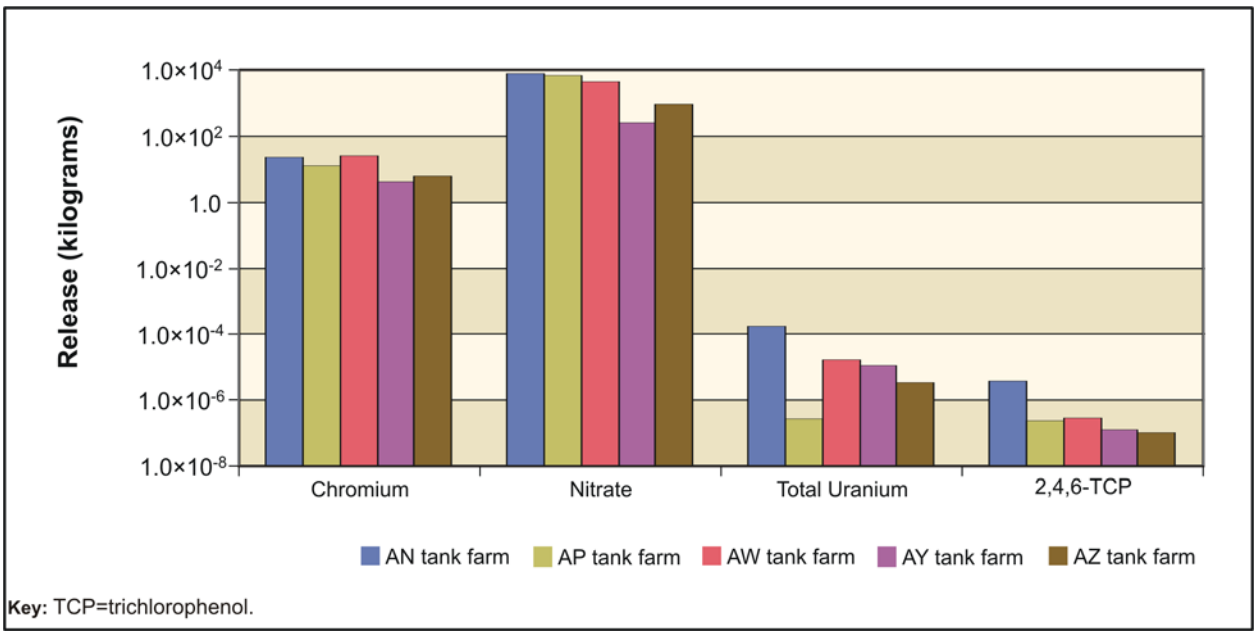


Figure N–74. Tank Closure Alternative 4 Other Sources from Tank Farms AN, AP, AW, AY, and AZ Chemical Release to Aquifer

Under Tank Closure Alternative 5, tank waste would be retrieved to a volume corresponding to 90 percent retrieval, residual material in tanks would be stabilized in place, and the tank farms and adjacent cribs and trenches (ditches) would be covered with a Hanford barrier. Potential releases to the aquifer under Tank Closure Alternative 5 are indicated in Figures N–75 through N–80.

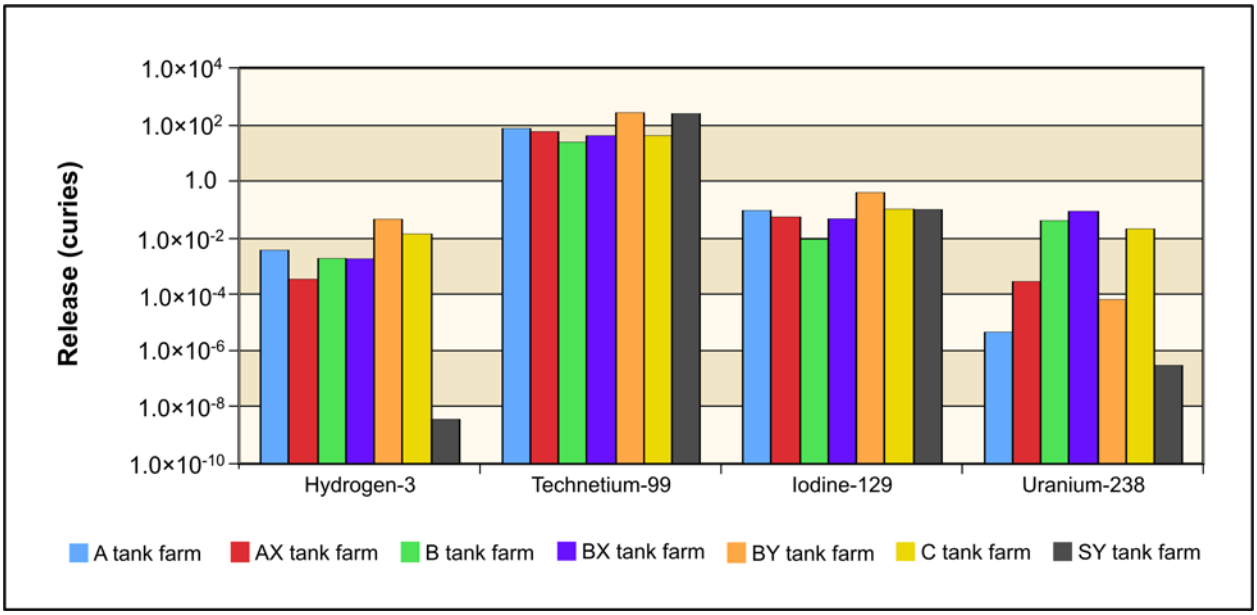


Figure N–75. Tank Closure Alternative 5 Other Sources from Tank Farms A, AX, B, BX, BY, C, and SY Radiological Release to Aquifer

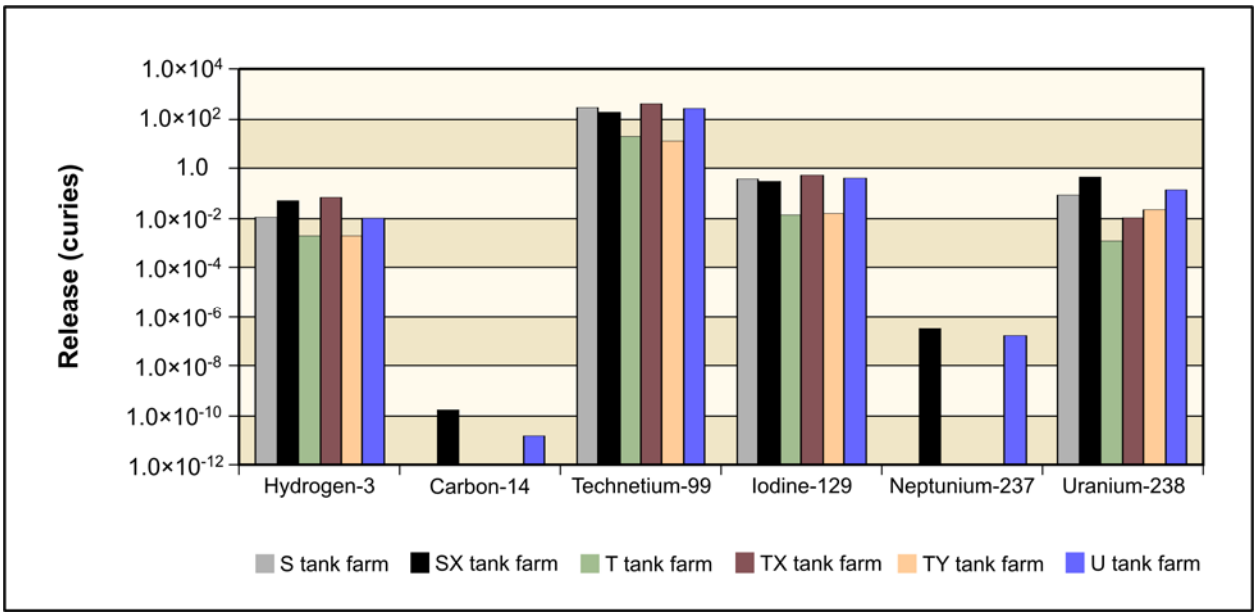


Figure N–76. Tank Closure Alternative 5 Other Sources from Tank Farms S, SX, T, TX, TY, and U Radiological Release to Aquifer

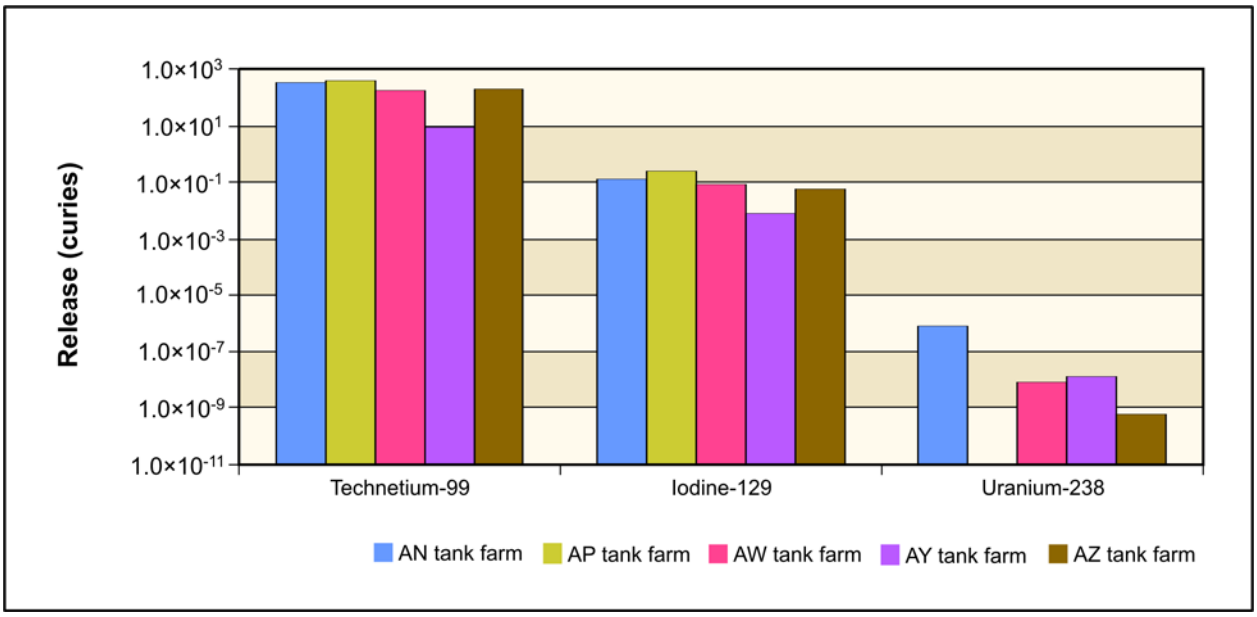


Figure N–77. Tank Closure Alternative 5 Other Sources from Tank Farms AN, AP, AW, AY, and AZ Radiological Release to Aquifer

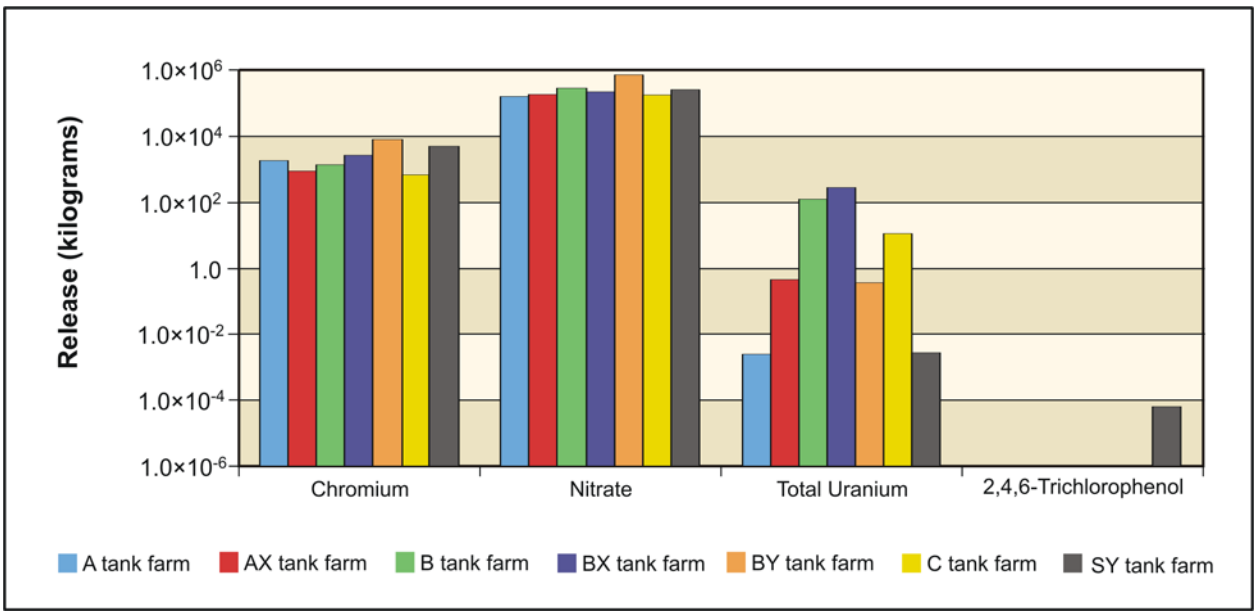


Figure N–78. Tank Closure Alternative 5 Other Sources from Tank Farms A, AX, B, BX, BY, C, and SY Chemical Release to Aquifer

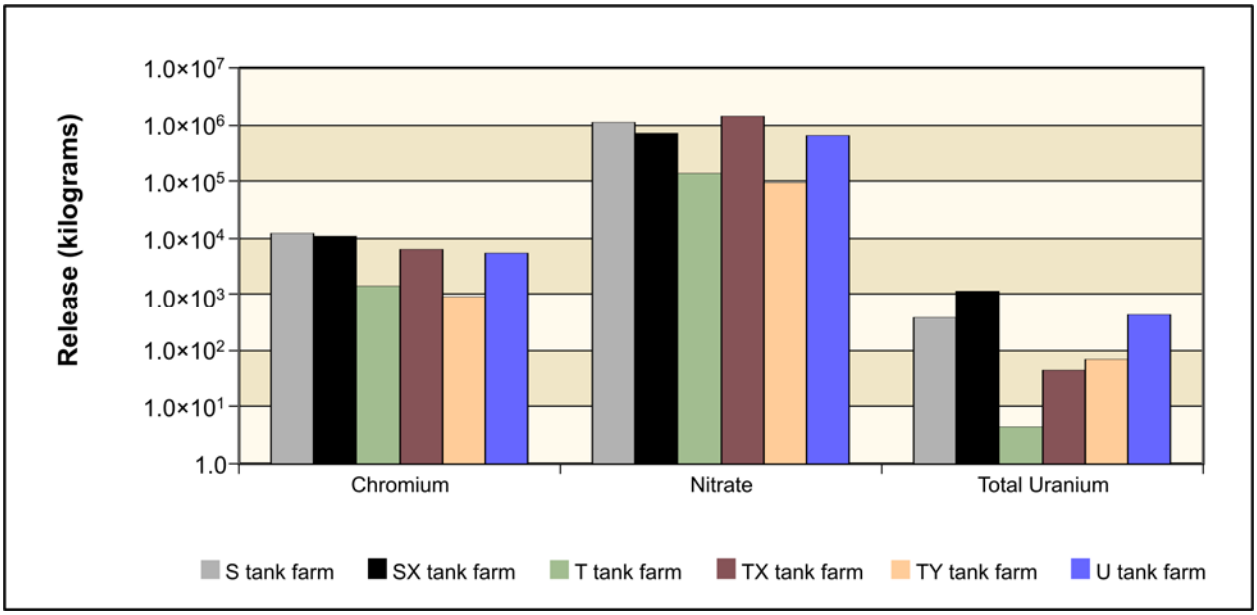


Figure N–79. Tank Closure Alternative 5 Other Sources from Tank Farms S, SX, T, TX, TY, and U Chemical Release to Aquifer

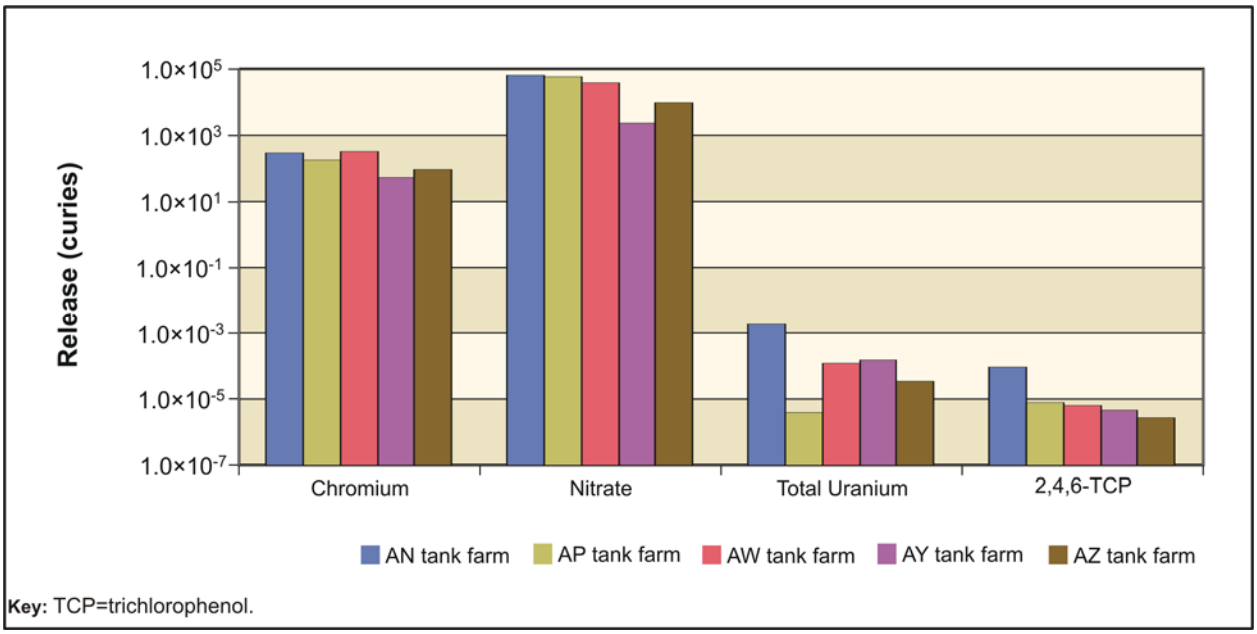


Figure N–80. Tank Closure Alternative 5 Other Sources from Tank Farms AN, AP, AW, AY, and AZ Chemical Release to Aquifer

N.2.2 FFTF Decommissioning Alternatives

N.2.2.1 FFTF Decommissioning Alternative 1: No Action

Under FFTF Decommissioning Alternative 1, only those actions consistent with previous DOE National Environmental Policy Act actions would be completed. Final decommissioning of the Fast Flux Test Facility (FFTF) would not occur. For purpose of analysis, the remaining waste would be available for release to the environment after an institutional control period of 100 years. Potential releases to the aquifer under FFTF Decommissioning Alternative 1 are indicated in Figures N–81 and N–82.

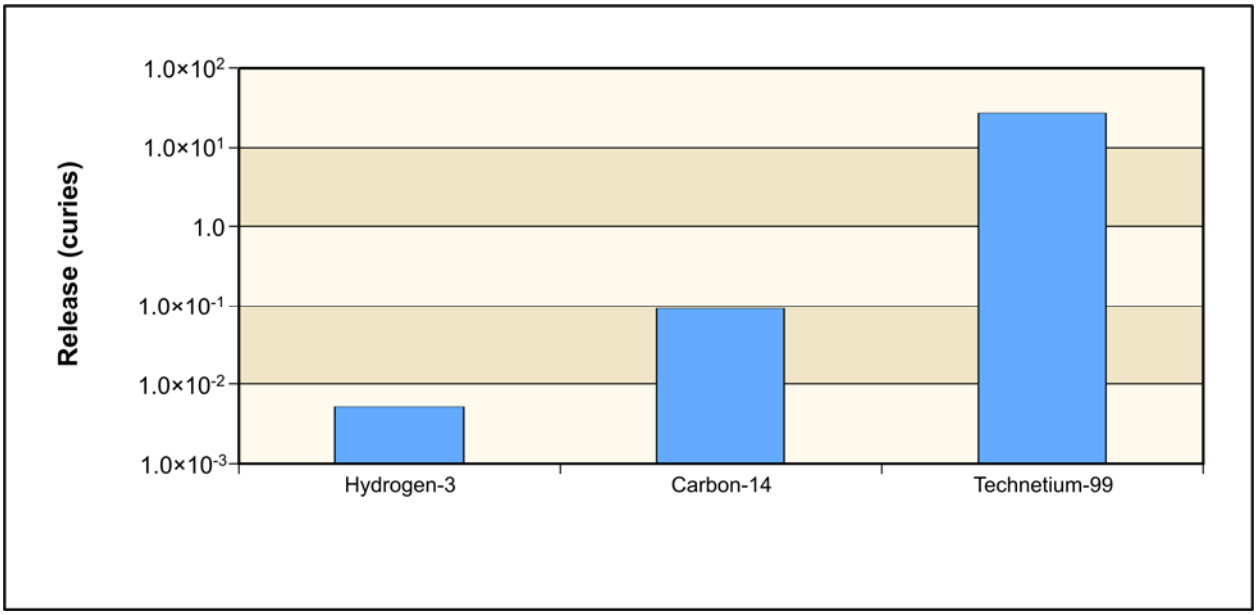


Figure N–81. FFTF Decommissioning Alternative 1 Radiological Release to Aquifer

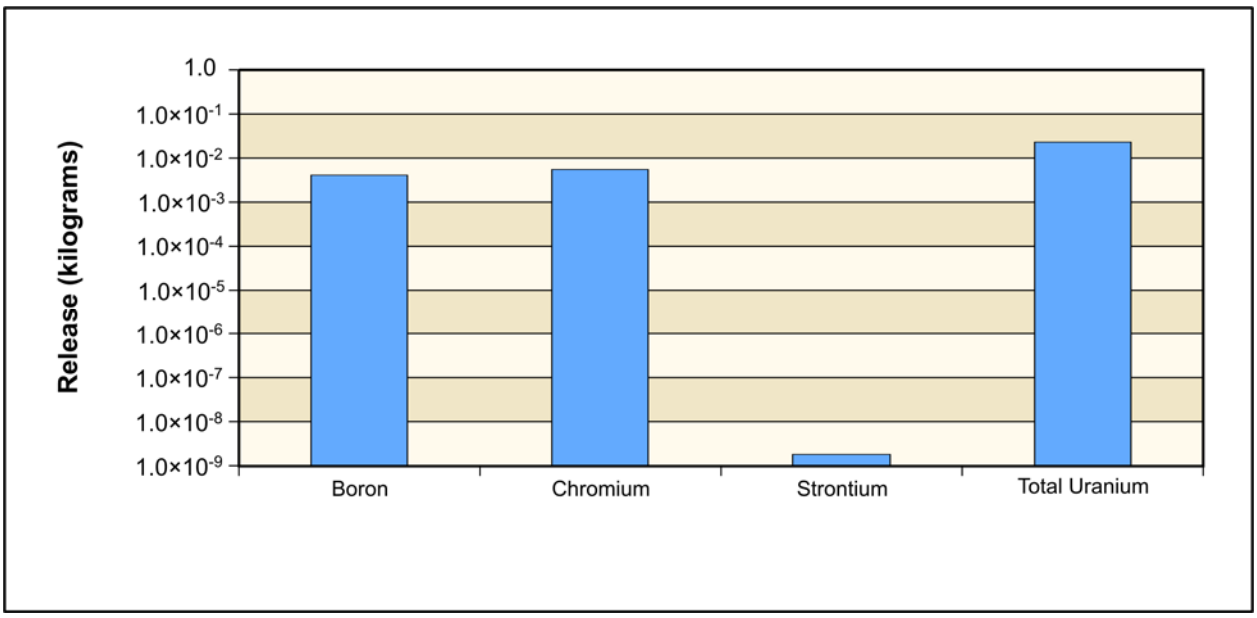


Figure N–82. FFTF Decommissioning Alternative 1 Chemical Release to Aquifer

N.2.2.2 FFTF Decommissioning Alternative 2: Entombment

Under FFTF Decommissioning Alternative 2, all aboveground structures and minimal below-grade structures, equipment, and materials would be removed. An RCRA-compliant barrier would be constructed over the Reactor Containment Building and any other remaining below-grade structures (including the reactor vessel). Potential releases to the aquifer under FFTF Decommissioning Alternative 2 are indicated in Figure N–83.

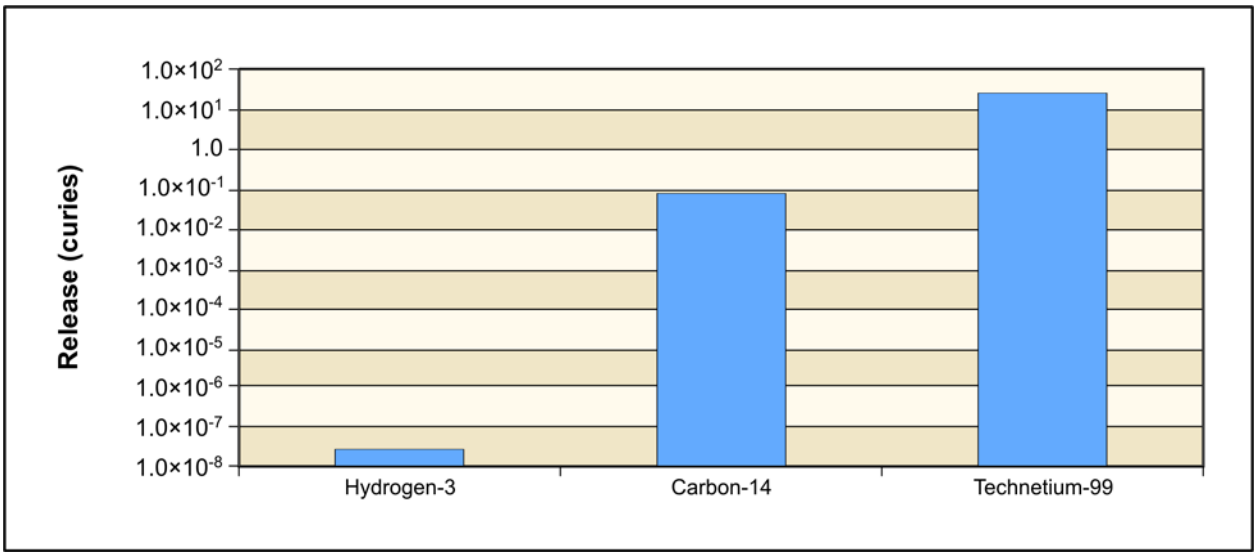


Figure N–83. FFTF Decommissioning Alternative 2 Radiological Release to Aquifer

N.2.2.3 FFTF Decommissioning Alternative 3: Removal

Under FFTF Decommissioning Alternative 3, all aboveground structures and contaminated below-grade structures, equipment, and materials would be removed. Potential releases to the aquifer under FFTF Decommissioning Alternative 3 are indicated in Figure N–84.

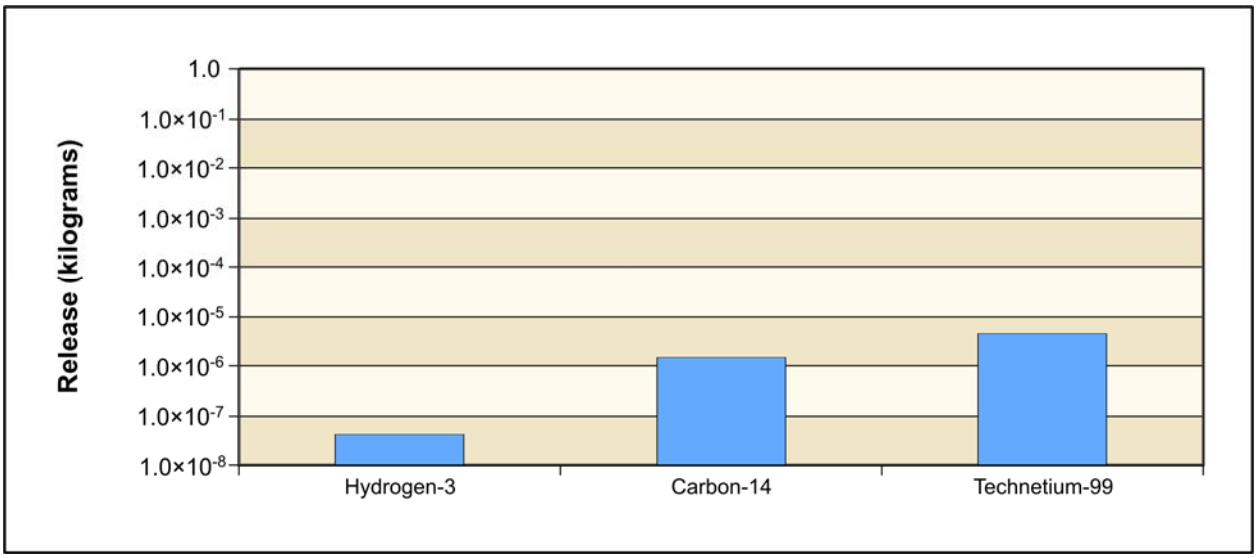


Figure N–84. FFTF Decommissioning Alternative 3 Radiological Release to Aquifer

N.2.3 Waste Management Alternatives

N.2.3.1 Waste Management Alternative 1: No Action

Under Waste Management Alternative 1, only the waste currently generated onsite at Hanford from non–Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) actions would continue to be disposed of in the low-level radioactive waste burial ground 218-W-5, trenches 31 and 34. Although short-term impacts do not address impacts associated with closure activities for this site, for purposes of analysis of long-term impacts, it is assumed that these trenches would be closed using an RCRA-compliant barrier consistent with the closure plans for these burial grounds. As a result, the non-CERCLA waste disposed of in these trenches from 2008 to 2035 would become available for release to the environment. Potential releases to the aquifer under Waste Management Alternative 1 are indicated in Figures N–85 and N–86.

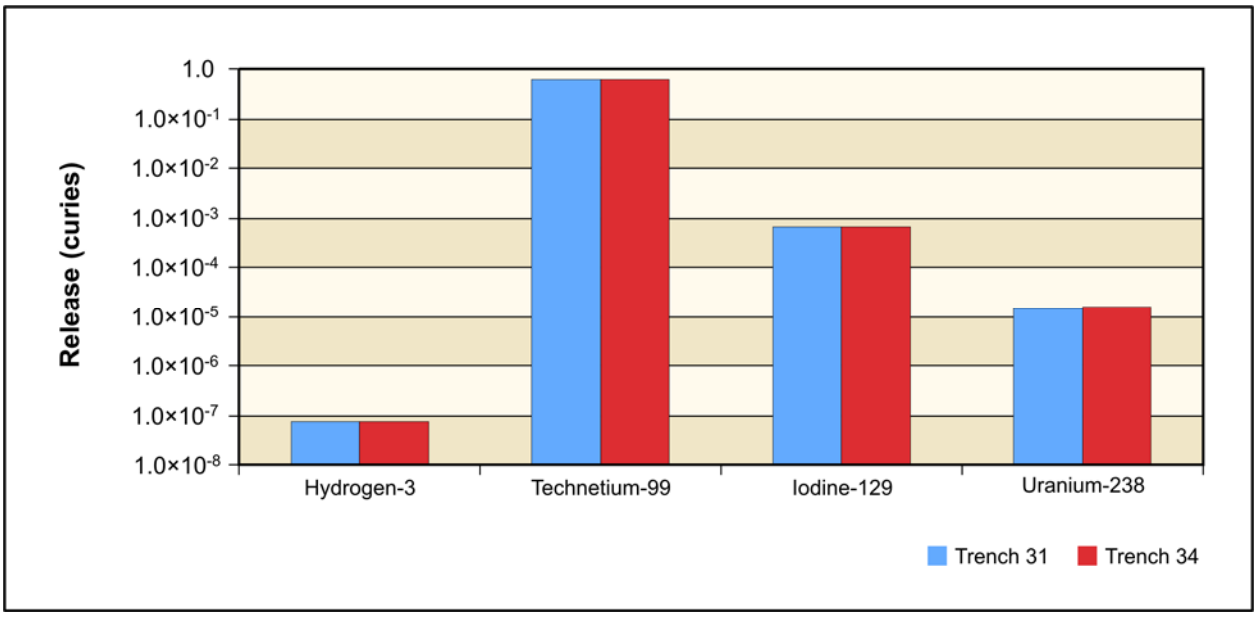


Figure N–85. Waste Management Alternative 1 Radiological Release to Aquifer

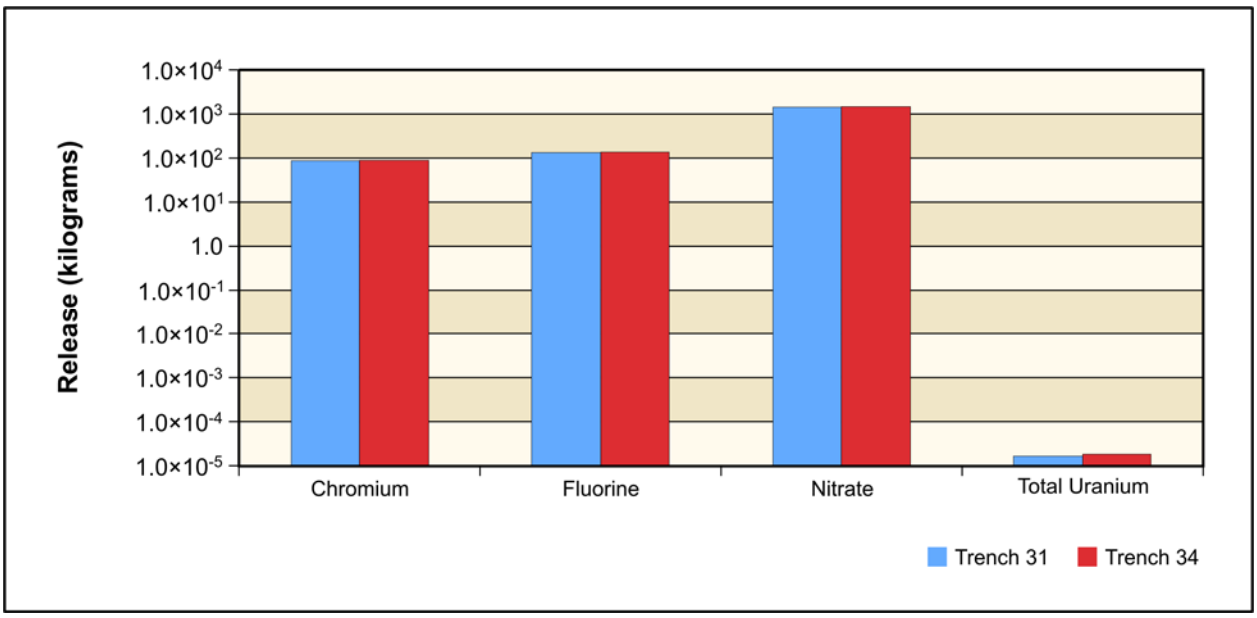


Figure N–86. Waste Management Alternative 1 Chemical Release to Aquifer

N.2.3.2 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only

Under Waste Management Alternative 2, waste from tank treatment operations, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites would be disposed of in an Integrated Disposal Facility (IDF) in the 200-East Area (IDF-East). Waste from tank farm cleanup activities would be disposed of in the River Protection Project Disposal Facility (RPPDF). As a result, the waste disposed of in these two facilities would become available for release to the environment. Because different waste types would result from the Tank Closure action alternatives, three disposal groups were considered to account for the different IDF-East sizes and operational time periods. In addition, within these three disposal groups, subgroups were identified to allow for consideration of the different waste types resulting from the Tank Closure alternatives.

N.2.3.2.1 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only, Disposal Group 1, Subgroup 1-A

Disposal Group 1, Subgroup 1-A, addresses the waste from Tank Closure Alternative 2B, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- Immobilized low-activity waste (ILAW) glass
- Low-activity waste (LAW) melters
- Tank closure secondary waste
- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 2B. Potential releases to the aquifer under Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, are indicated in Figures N–87 and N–88.

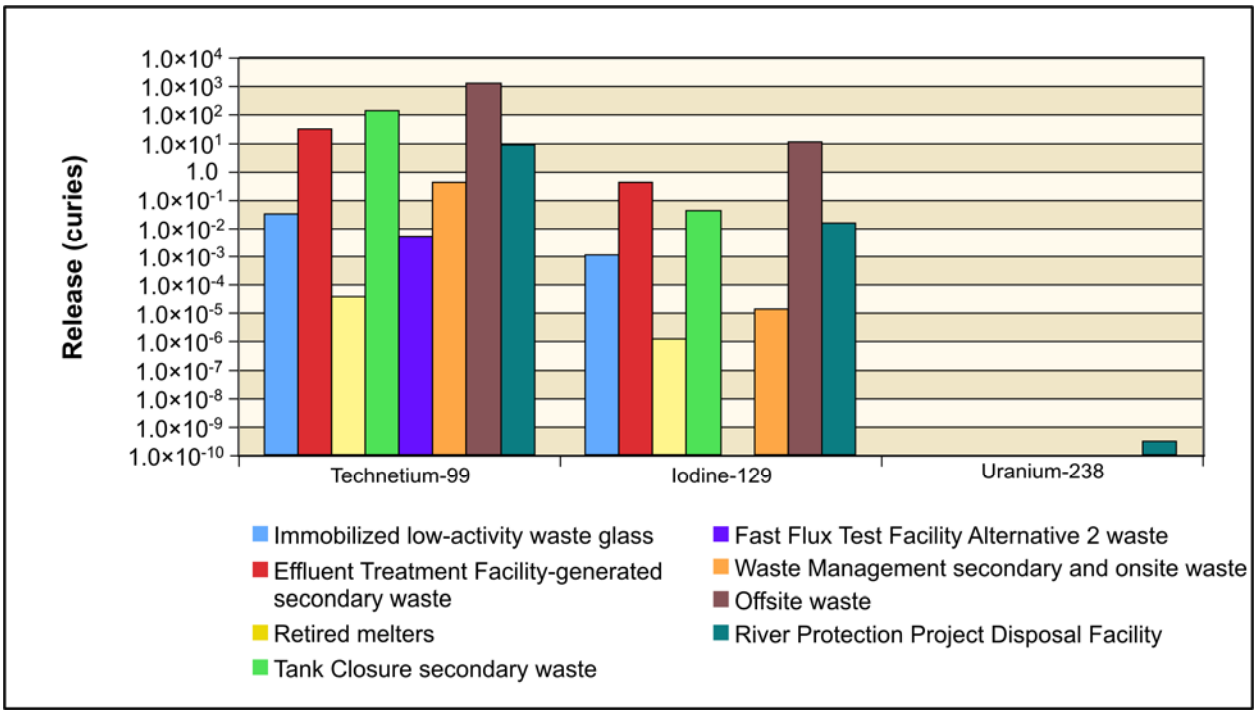


Figure N–87. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, Radiological Release to Aquifer

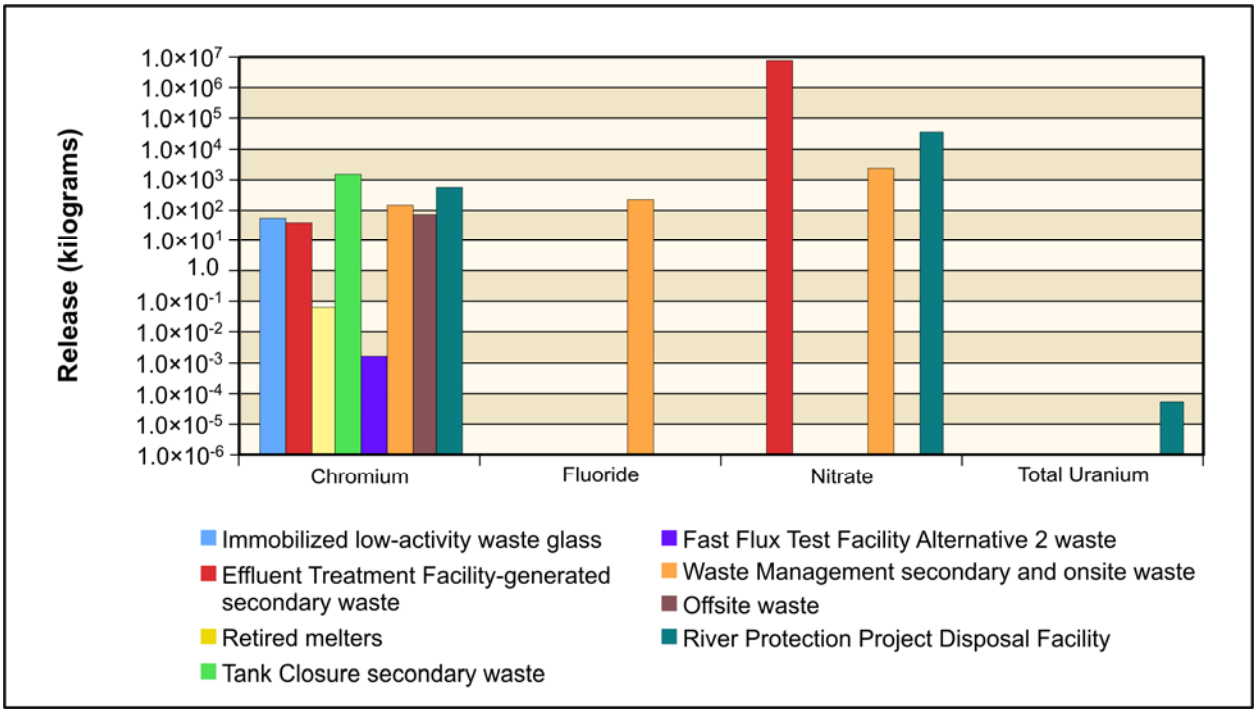


Figure N–88. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, Chemical Release to Aquifer

N.2.3.2.2 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only, Disposal Group 1, Subgroup 1-B

Disposal Group 1, Subgroup 1-B, addresses the waste from Tank Closure Alternative 3A, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Bulk vitrification glass
- Tank closure secondary waste
- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 3A. Potential releases to the aquifer under Waste Management Alternative 2, Disposal Group 1, Subgroup 1-B, are indicated in Figures N–89 and N–90.

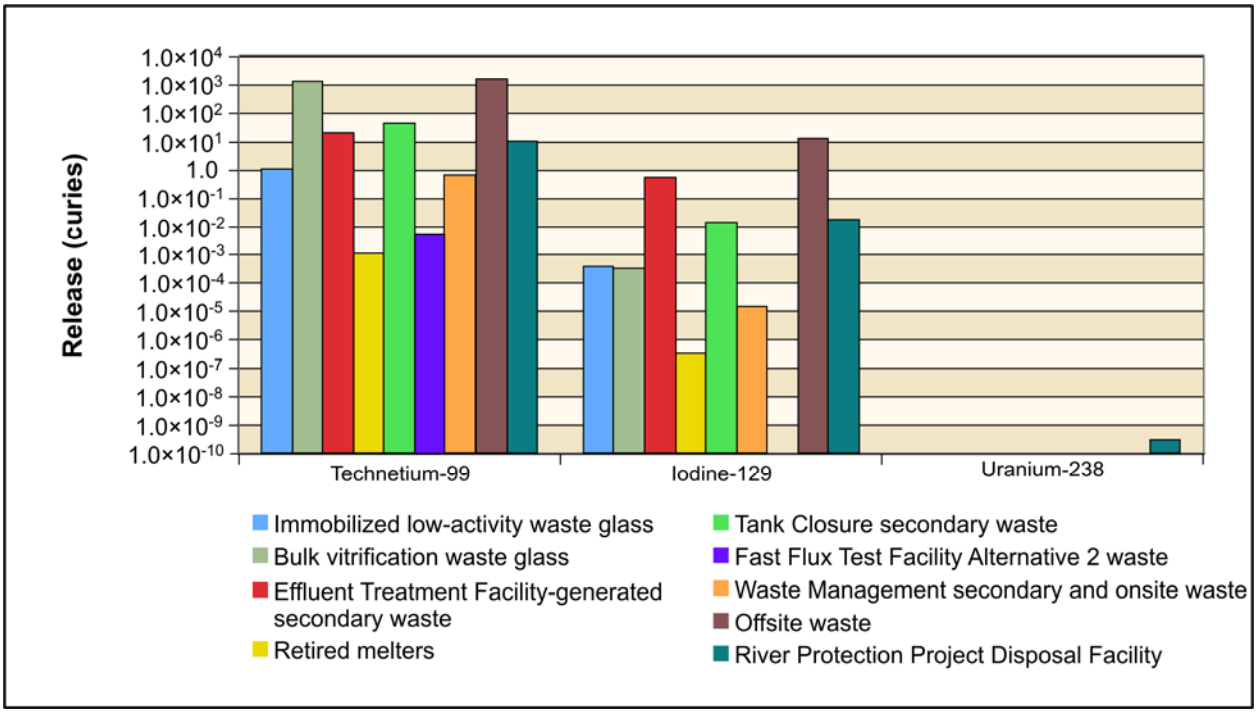


Figure N–89. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-B, Radiological Release to Aquifer

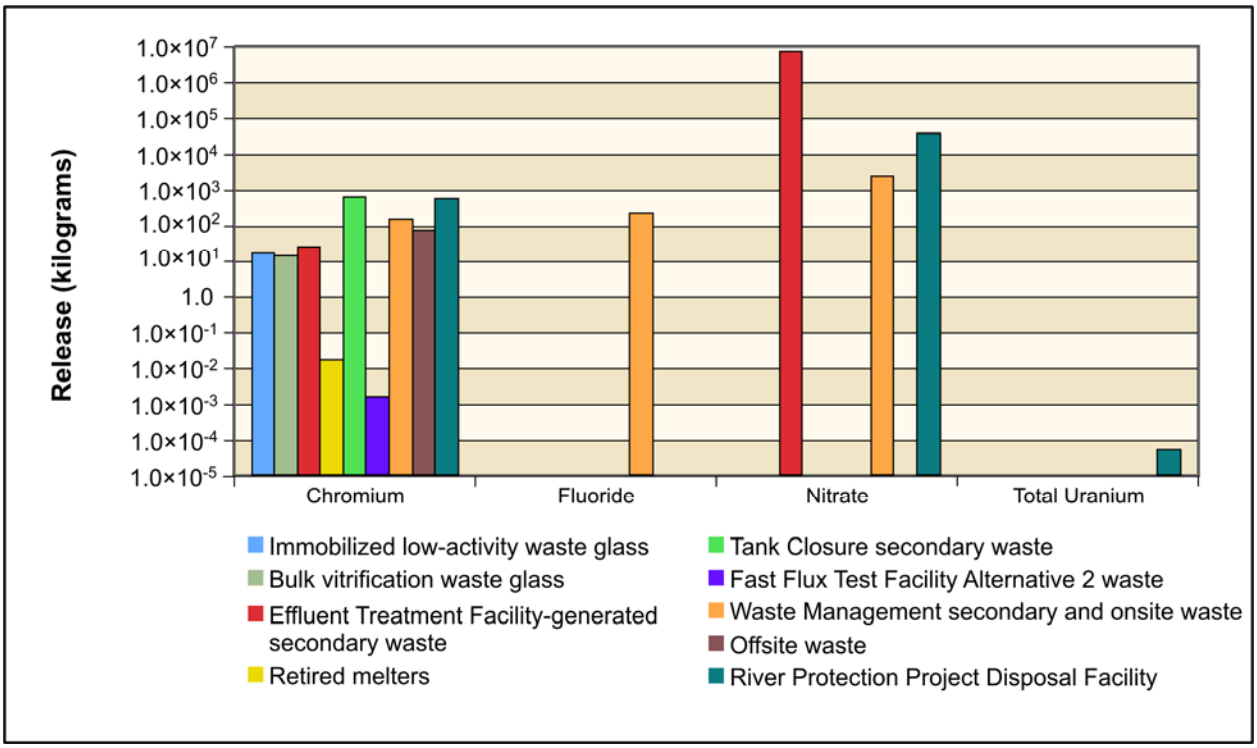


Figure N–90. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-B, Chemical Release to Aquifer

N.2.3.2.3 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only, Disposal Group 1, Subgroup 1-C

Disposal Group 1, Subgroup 1-C, addresses the waste from Tank Closure Alternative 3B, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Cast stone
- Tank closure secondary waste
- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 3B. Potential releases to the aquifer under Waste Management Alternative 2, Disposal Group 1, Subgroup 1-C, are indicated in Figures N–91 and N–92.

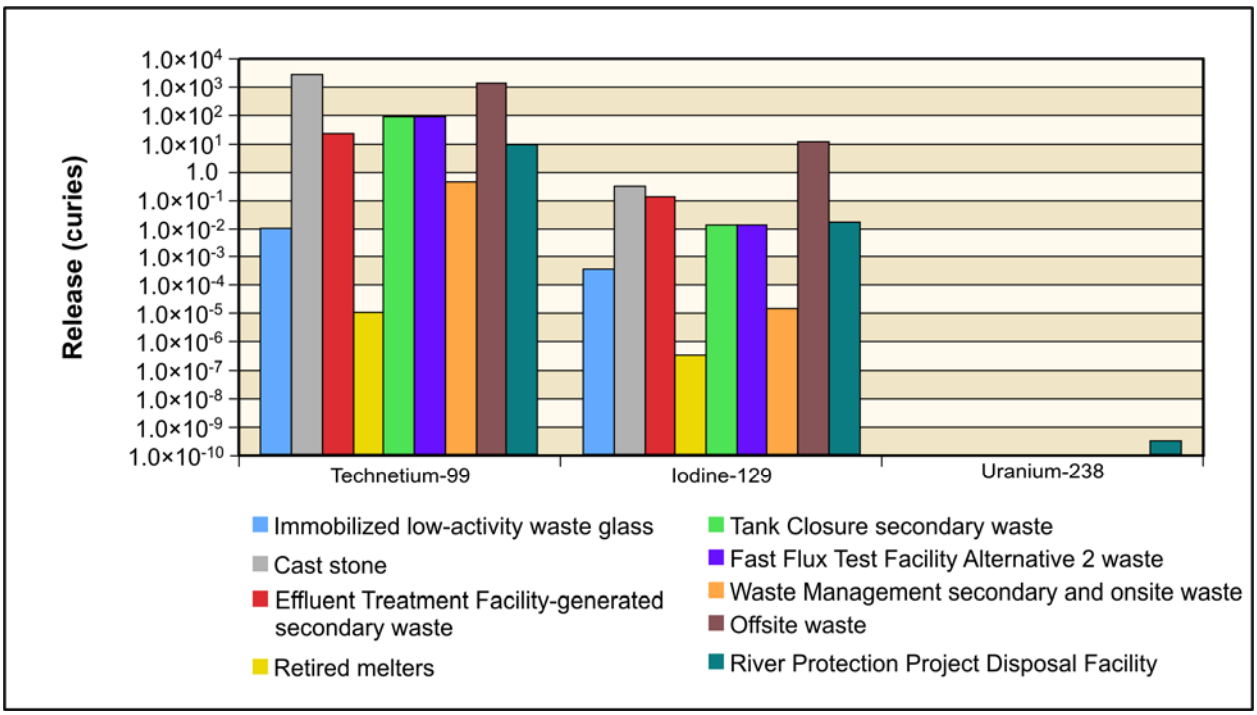


Figure N–91. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-C, Radiological Release to Aquifer

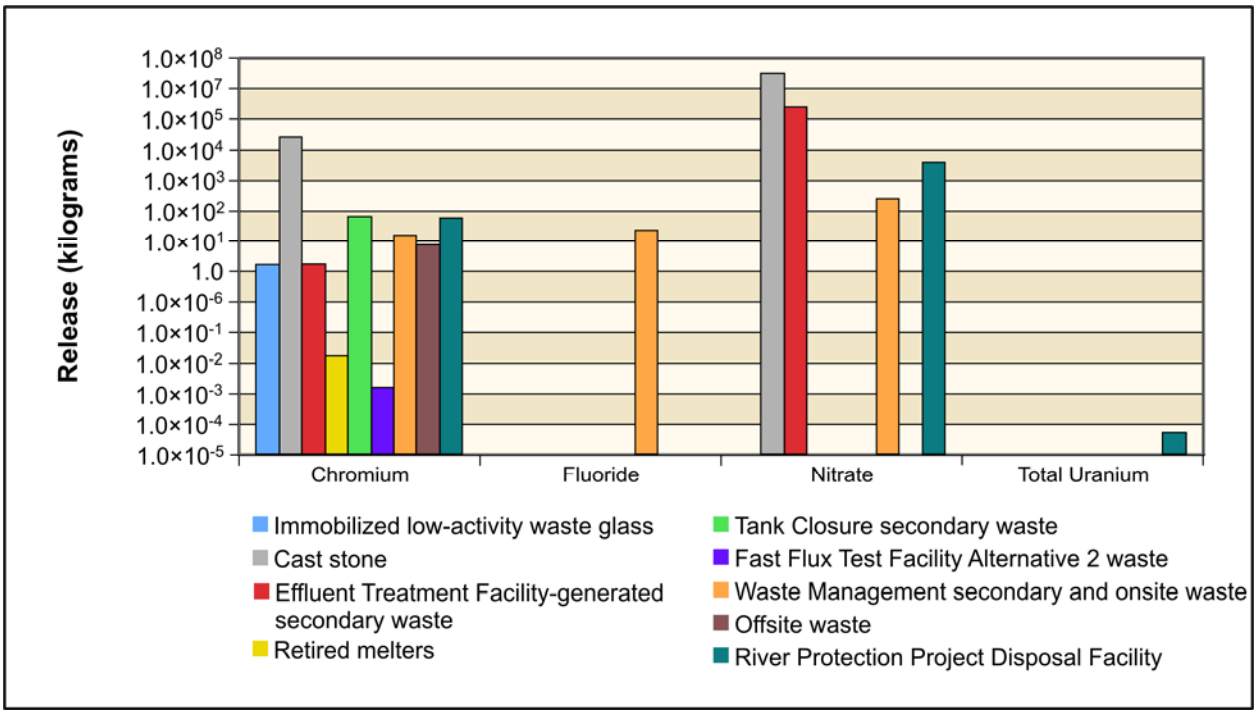


Figure N–92. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-C, Chemical Release to Aquifer

N.2.3.2.4 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only, Disposal Group 1, Subgroup 1-D

Disposal Group 1, Subgroup 1-D, addresses the waste from Tank Closure Alternative 3C, onsite non-CERCLA sources, FFTF decommissioning, waste management and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Steam reforming waste
- Tank closure secondary waste
- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 3C. Potential releases to the aquifer under Waste Management Alternative 2, Disposal Group 1, Subgroup 1-D, are indicated in Figures N–93 and N–94.

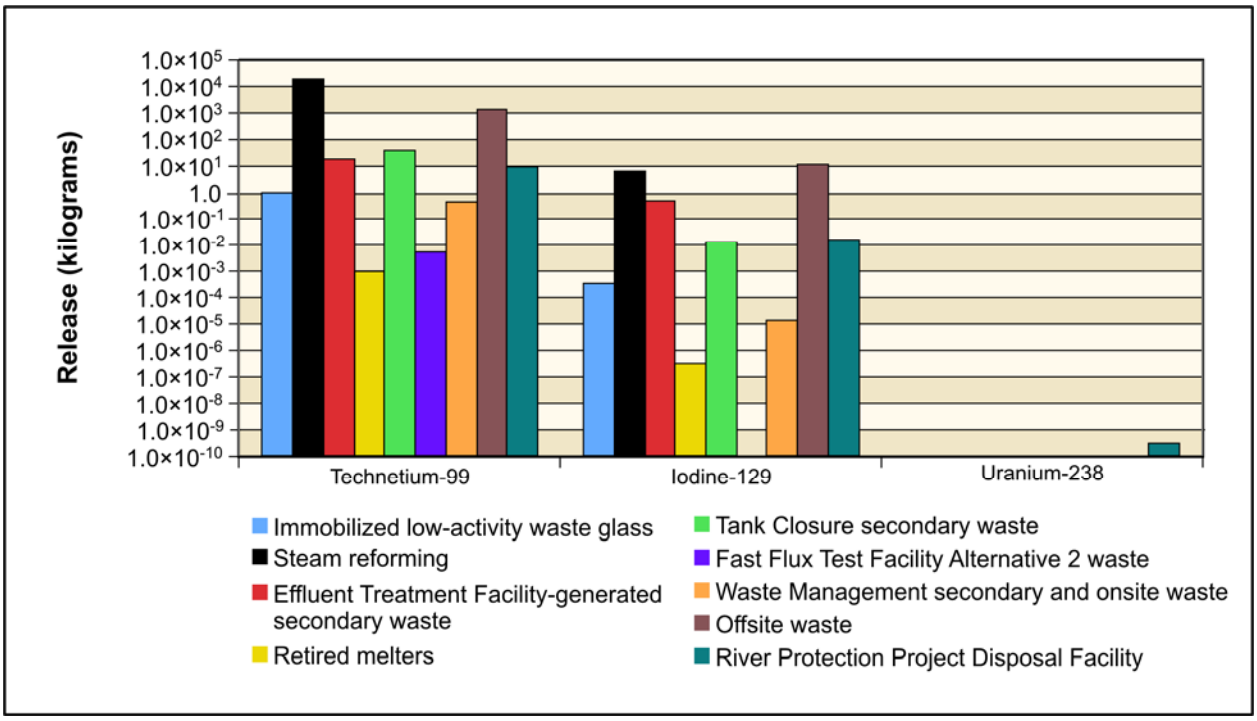


Figure N–93. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-D, Radiological Release to Aquifer

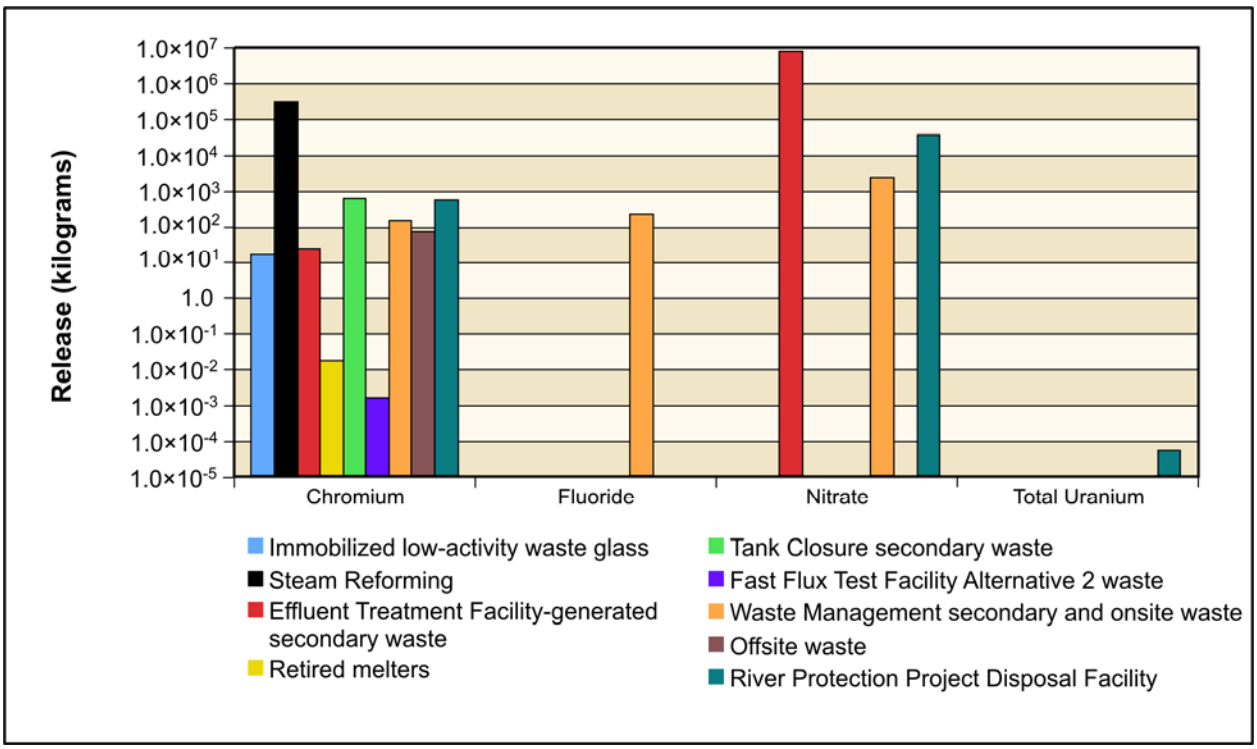


Figure N–94. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-D, Chemical Release to Aquifer

N.2.3.2.5 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only, Disposal Group 1, Subgroup 1-E

Disposal Group 1, Subgroup 1-E, addresses the waste from Tank Closure Alternative 4, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Bulk vitrification glass
- Cast stone
- Tank closure secondary waste
- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 4. Potential releases to the aquifer under Waste Management Alternative 2, Disposal Group 1, Subgroup 1-E, are indicated in Figures N–95 and N–96.

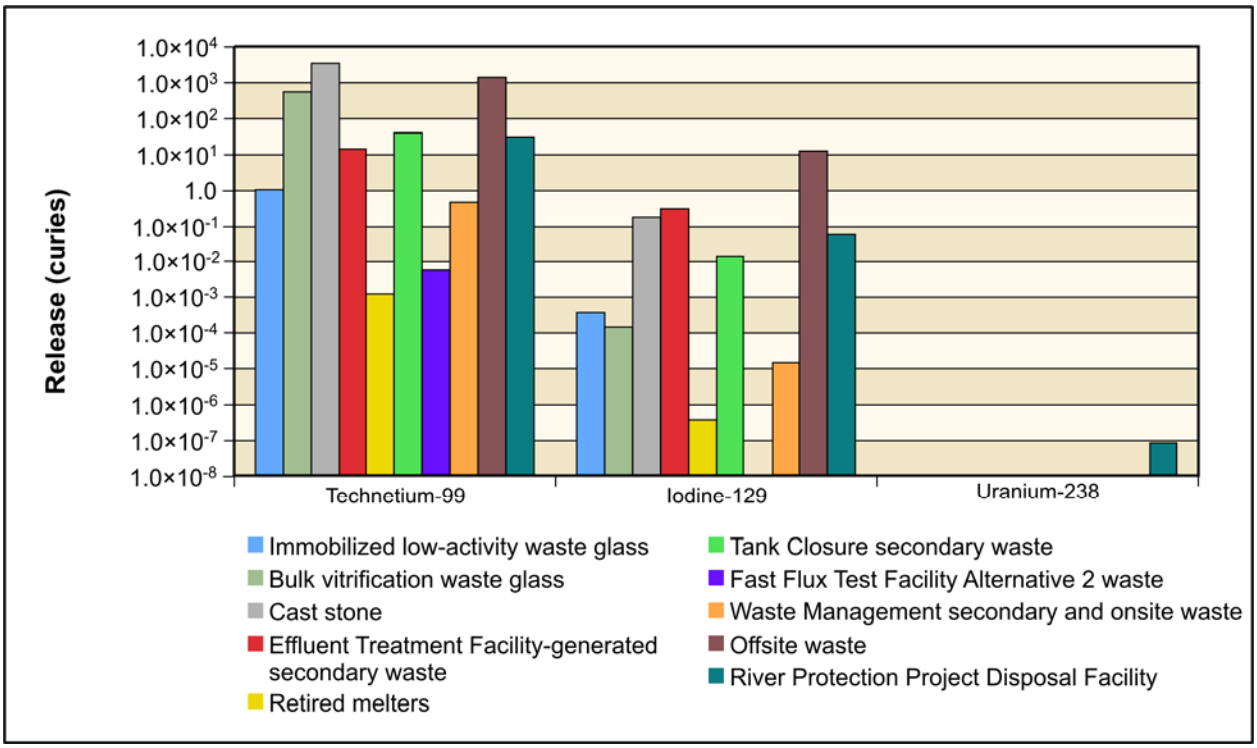


Figure N–95. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-E, Radiological Release to Vadose Zone

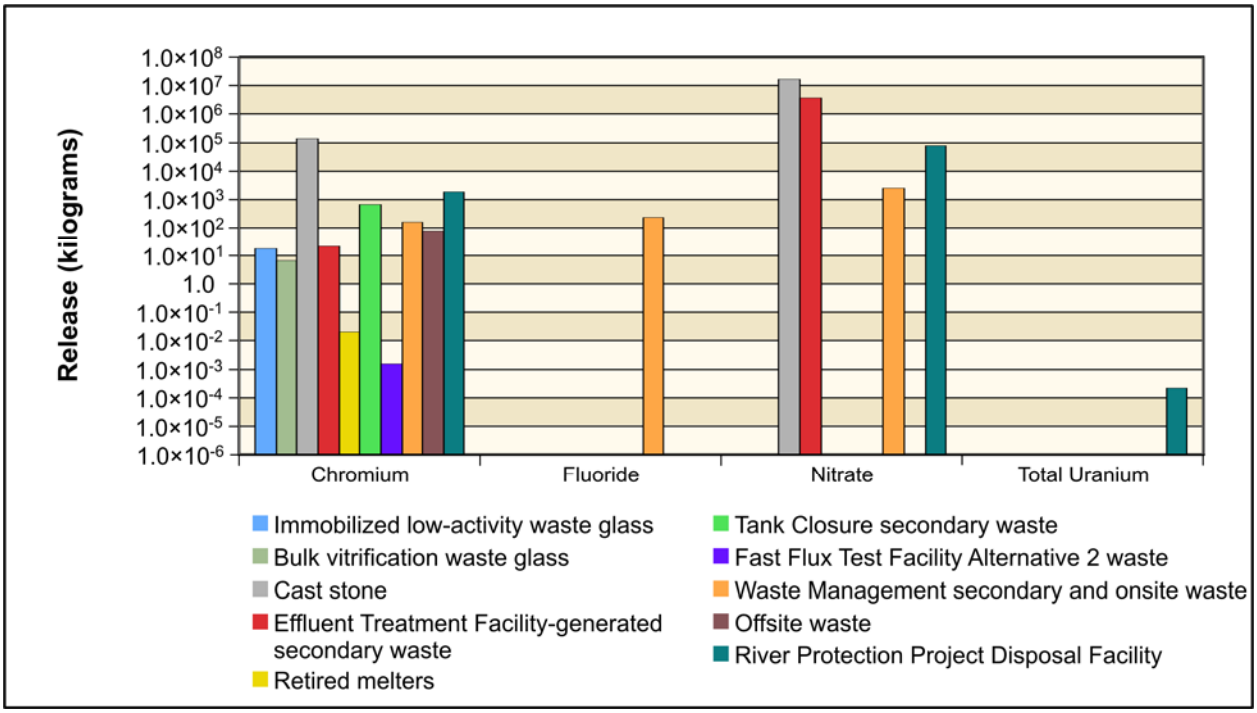


Figure N–96. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-E, Chemical Release to Aquifer

N.2.3.2.6 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only, Disposal Group 1, Subgroup 1-F

Disposal Group 1, Subgroup 1-F, addresses the waste from Tank Closure Alternative 5, onsite non-CERCLA sources, FFTF decommissioning, waste management and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Bulk vitrification glass
- Cast stone
- Sulfate grout
- Tank closure secondary waste
- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

The RPPDF would not be constructed or operated for Tank Closure Alternative 5 because tank closure cleanup activities would not be conducted. Potential releases to the aquifer under Waste Management Alternative 2, Disposal Group 1, Subgroup 1-F, are indicated in Figures N–97 and N–98.

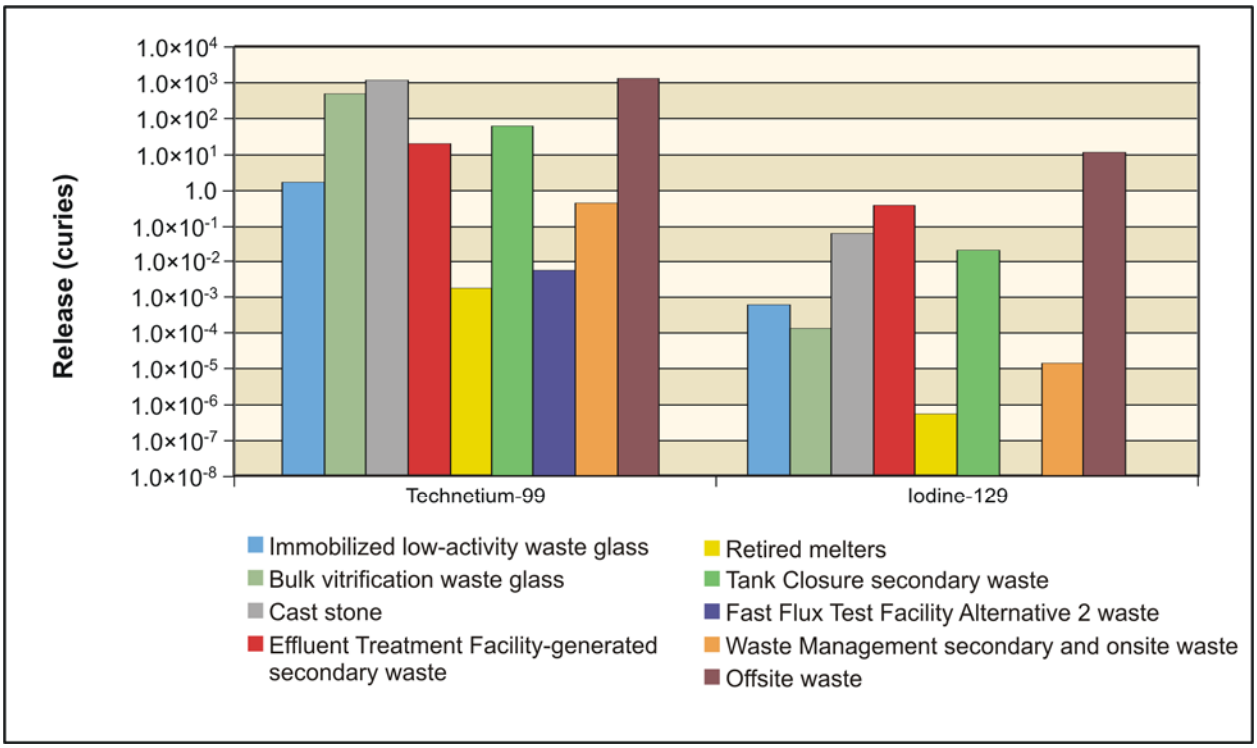


Figure N–97. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-F, Radiological Release to Aquifer

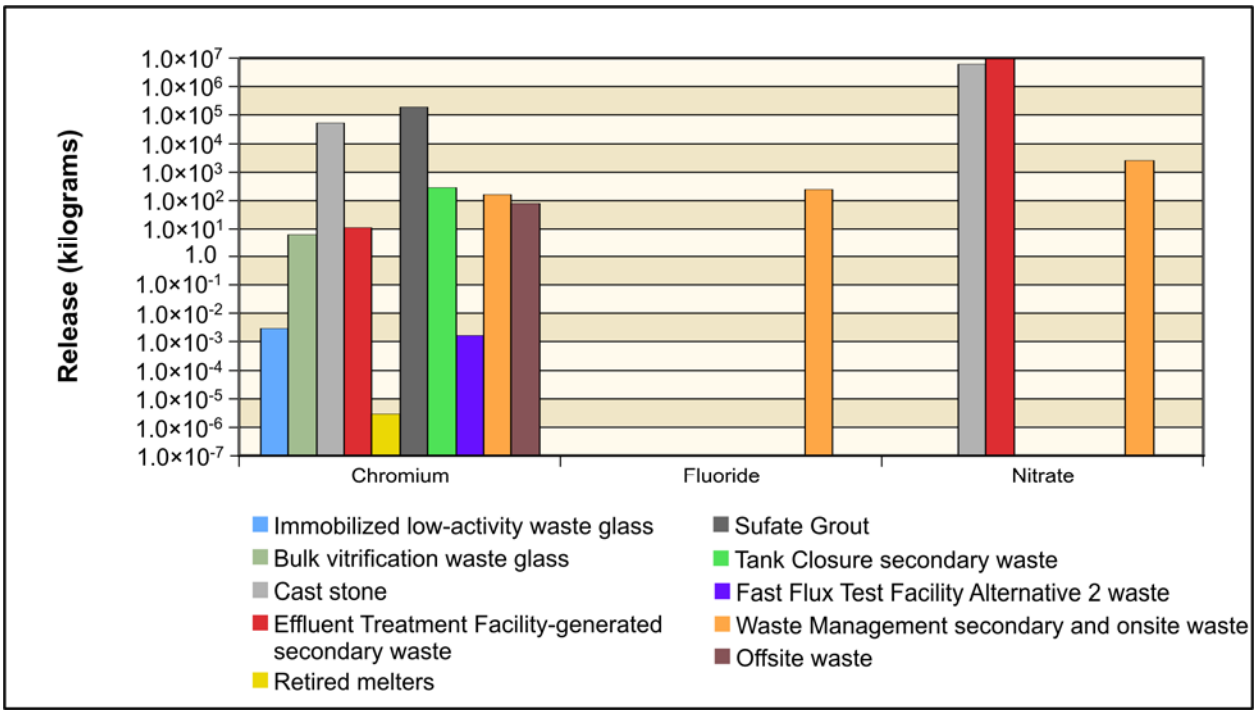


Figure N–98. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-F, Chemical Release to Aquifer

N.2.3.2.7 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only, Disposal Group 1, Subgroup 1-G

Disposal Group 1, Subgroup 1-G, addresses the waste from Tank Closure Alternative 6C, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- Tank closure secondary waste
- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 6C. Potential releases to the aquifer under Waste Management Alternative 2, Disposal Group 1, Subgroup 1-G, are indicated in Figures N–99 and N–100.

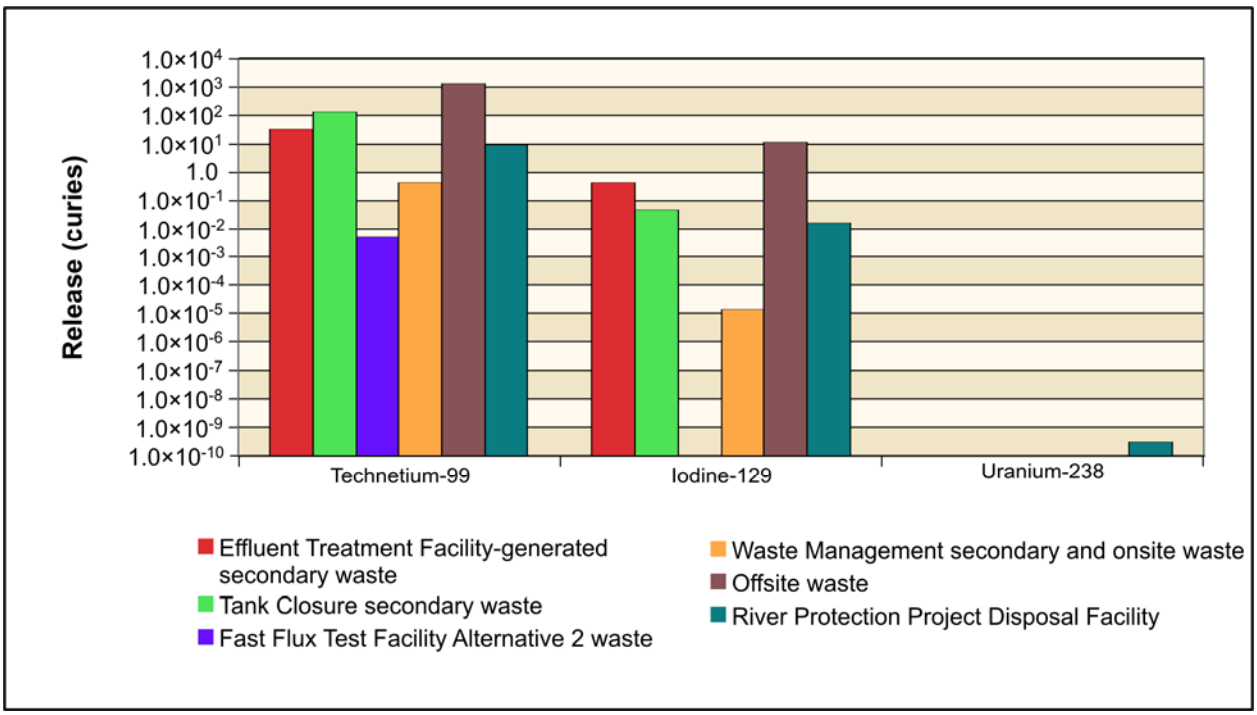


Figure N–99. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-G, Radiological Release to Aquifer

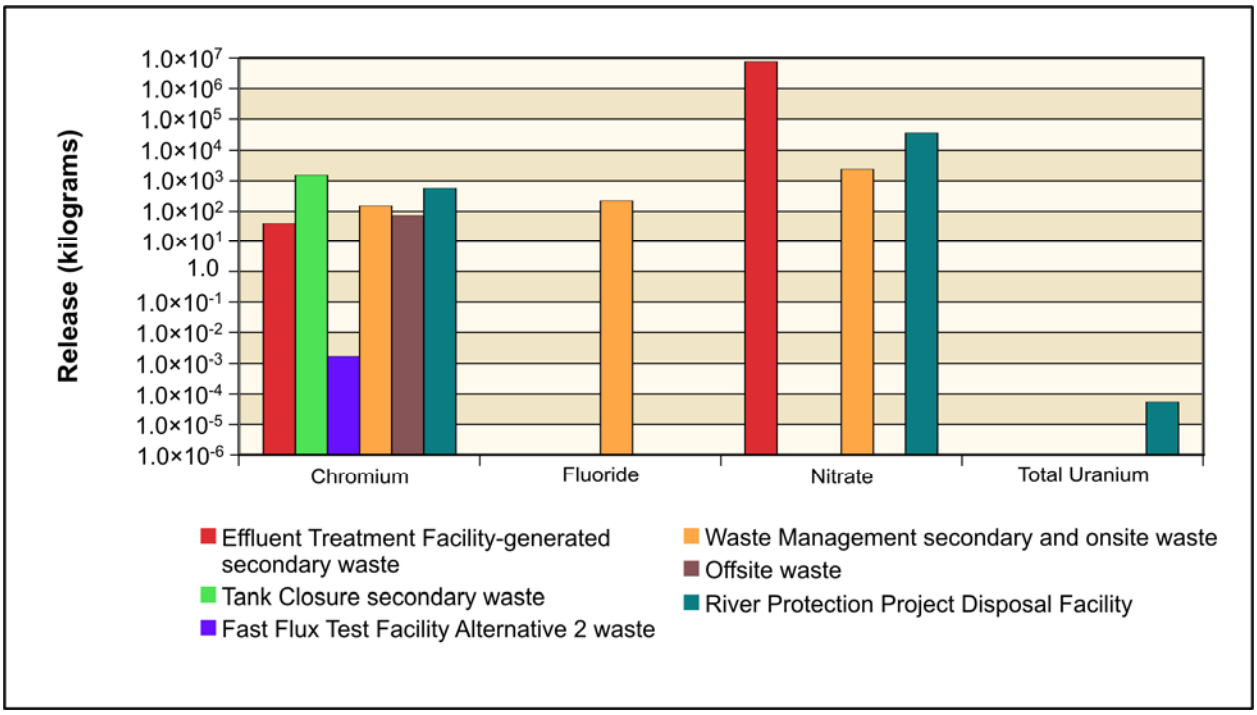


Figure N–100. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-G, Chemical Release to Aquifer

N.2.3.2.8 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only, Disposal Group 2, Subgroup 2-A

Disposal Group 2, Subgroup 2-A, addresses the waste from Tank Closure Alternative 2A, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Tank closure secondary waste
- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

The RPPDF would not be constructed or operated for Tank Closure Alternative 2A because tank closure cleanup activities would not be conducted. Potential releases to the aquifer under Waste Management Alternative 2, Disposal Group 2, Subgroup 2-A, are indicated in Figures N–101 and N–102.

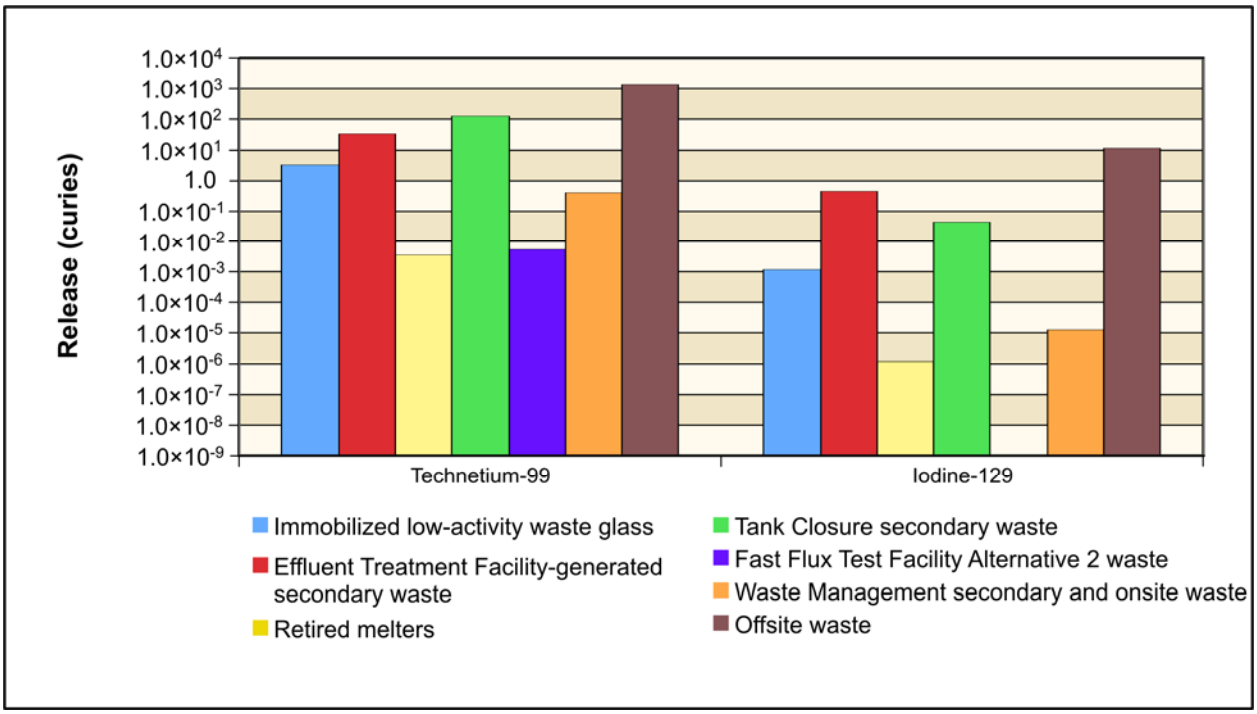


Figure N–101. Waste Management Alternative 2, Disposal Group 2, Subgroup 2-A, Radiological Release to Aquifer

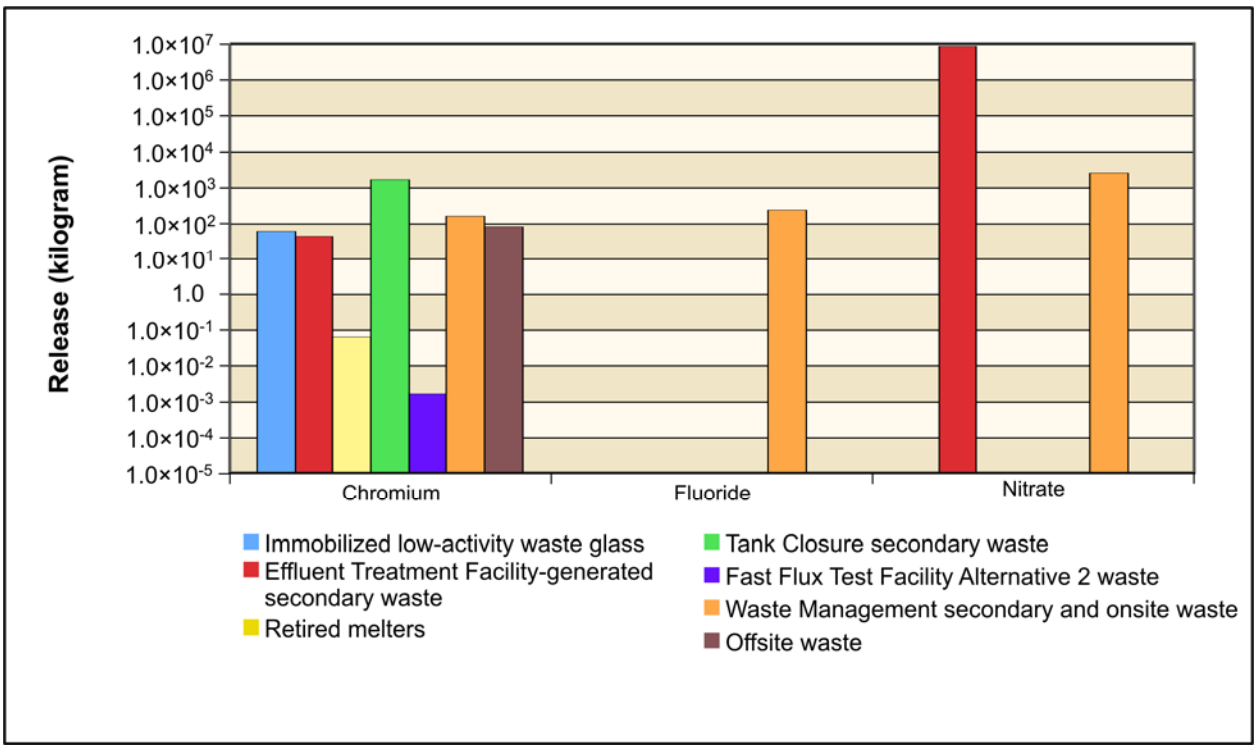


Figure N–102. Waste Management Alternative 2, Disposal Group 2, Subgroup 2-A, Chemical Release to Aquifer

N.2.3.2.9 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only, Disposal Group 2, Subgroup 2-B

Disposal Group 2, Subgroup 2-B, addresses the waste from Tank Closure Alternative 6B (Base and Option Cases), onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- Preprocessing Facility (PPF) glass
- PPF melters
- Tank closure secondary waste
- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 6B, Base and Option Cases. Potential releases to the aquifer under Waste Management Alternative 2, Disposal Group 2, Subgroup 2-B, Base and Option Cases, are indicated in Figures N–103 through N–106.

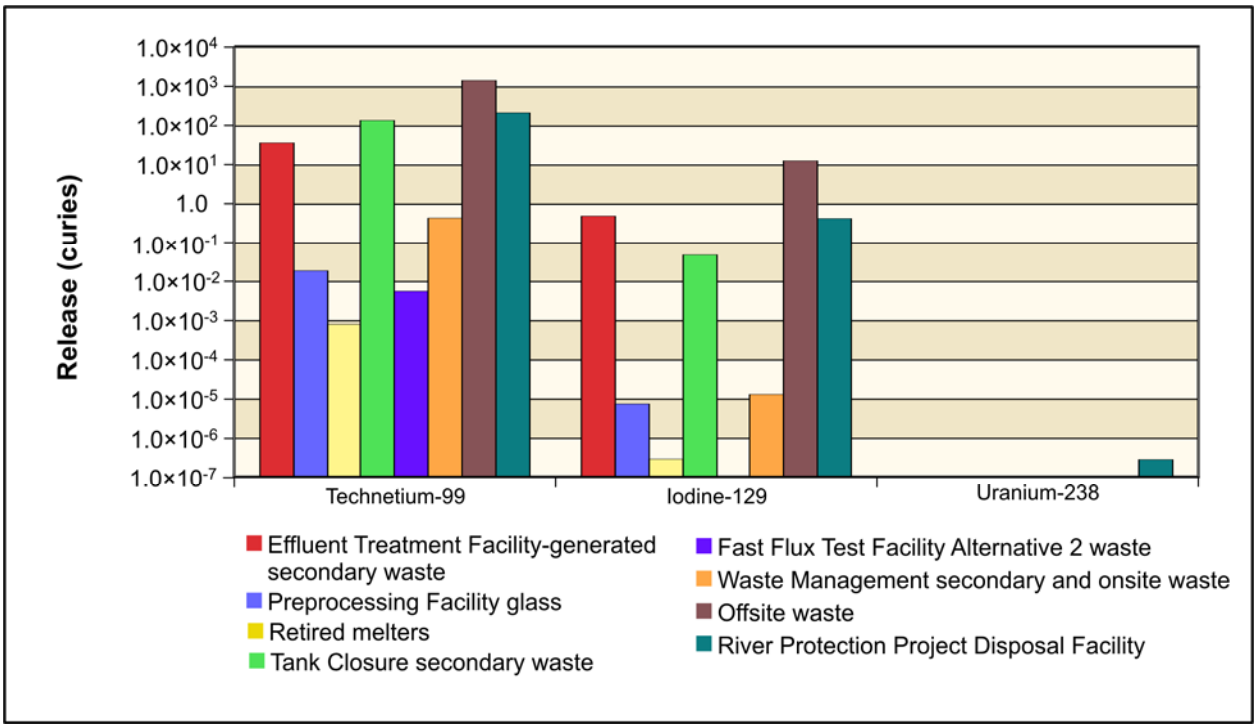


Figure N–103. Waste Management Alternative 2, Disposal Group 2, Subgroup 2-B, Base Case, Radiological Release to Aquifer

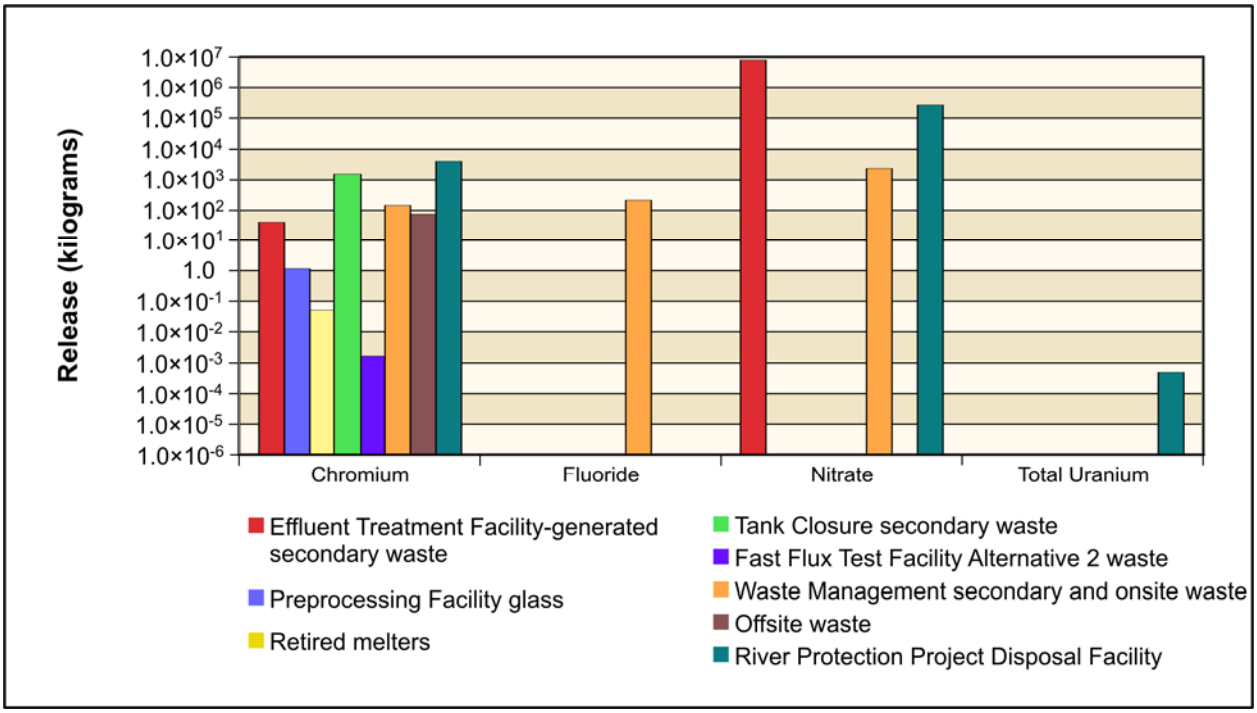


Figure N–104. Waste Management Alternative 2, Disposal Group 2, Subgroup 2-B, Base Case, Chemical Release to Aquifer

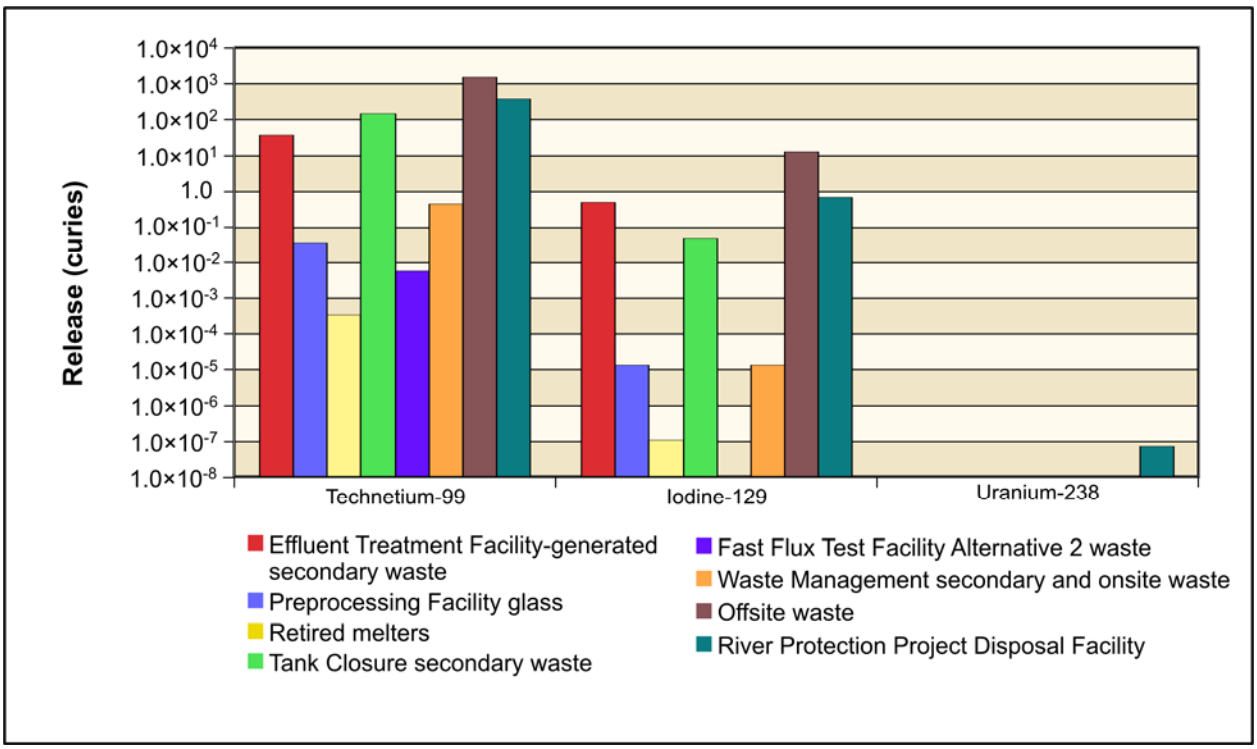


Figure N–105. Waste Management Alternative 2, Disposal Group 2, Subgroup 2-B, Option Case, Radiological Release to Aquifer

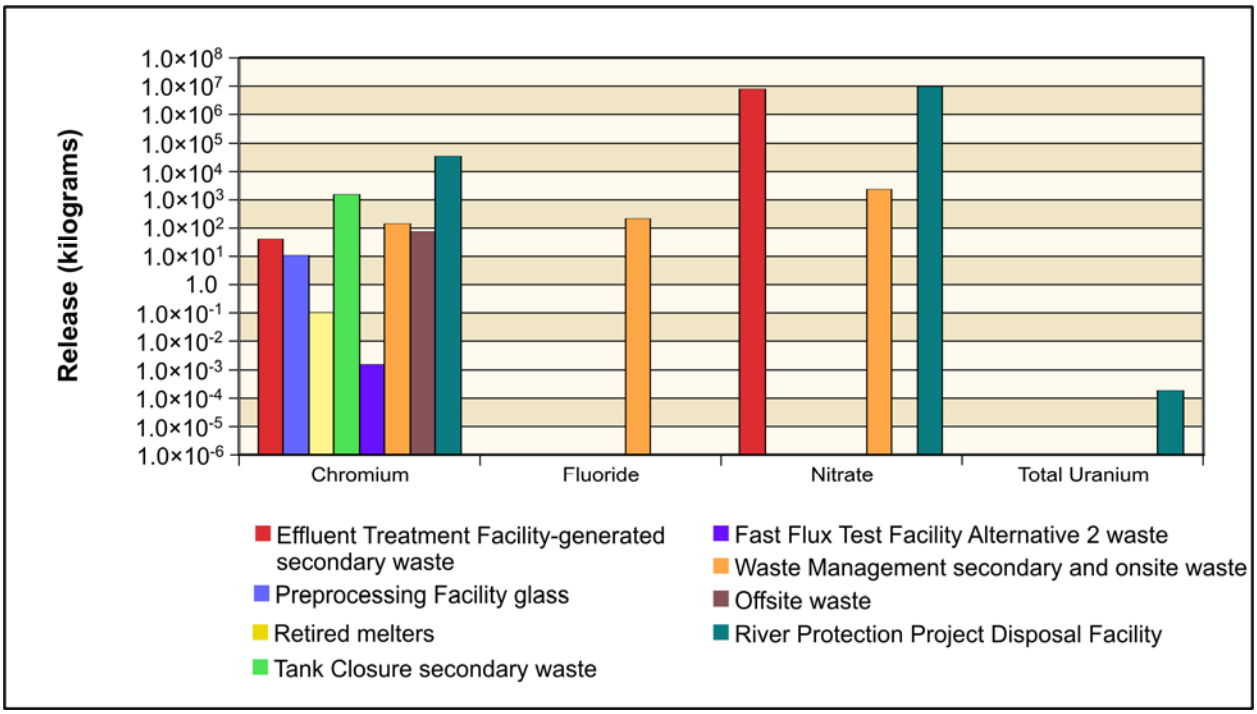


Figure N–106. Waste Management Alternative 2, Disposal Group 2, Subgroup 2-B, Option Case, Chemical Release to Aquifer

N.2.3.2.10 Waste Management Alternative 2: Disposal in IDF, 200-East Area Only, Disposal Group 3

Disposal Group 3 addresses the waste from Tank Closure Alternative 6A (Base and Option Cases), onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- PPF glass
- PPF melters
- Tank closure secondary waste
- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 6A, Base and Option Cases. Potential releases to the aquifer under Waste Management Alternative 2, Disposal Group 3, Base and Option Cases, are indicated in Figures N–107 through N–110.

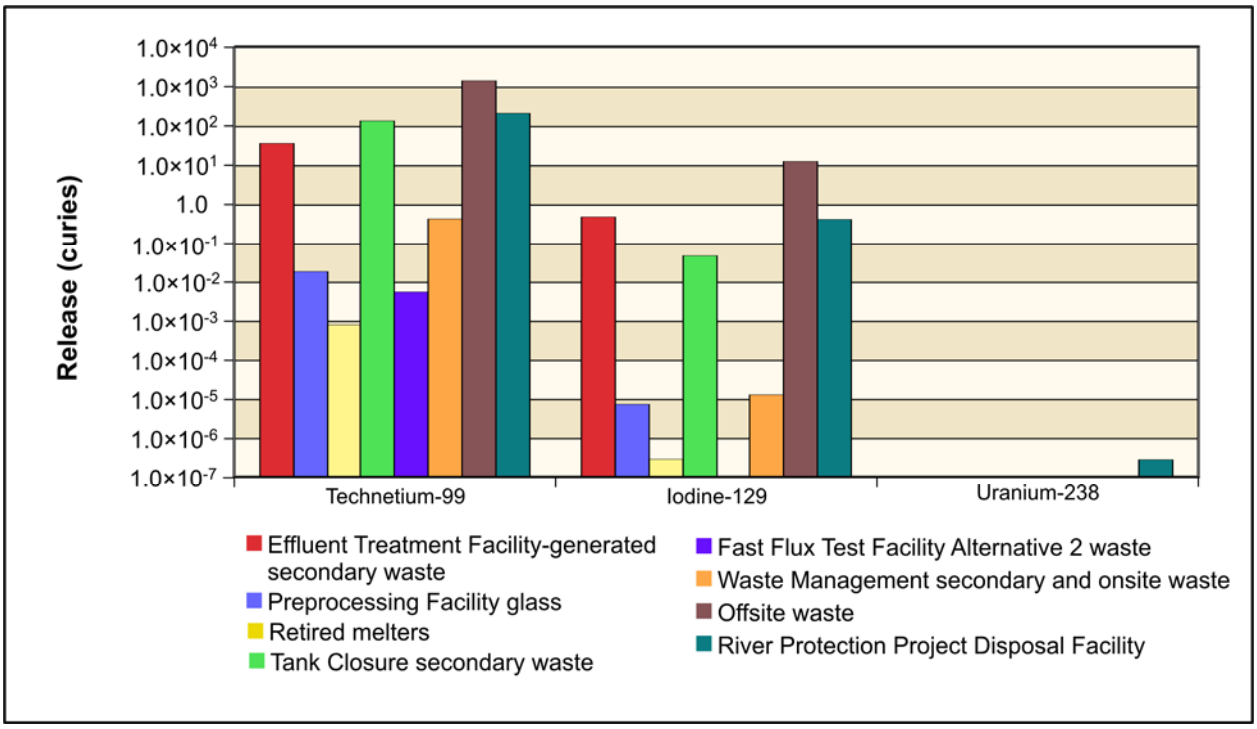


Figure N–107. Waste Management Alternative 2, Disposal Group 3, Base Case, Radiological Release to Aquifer

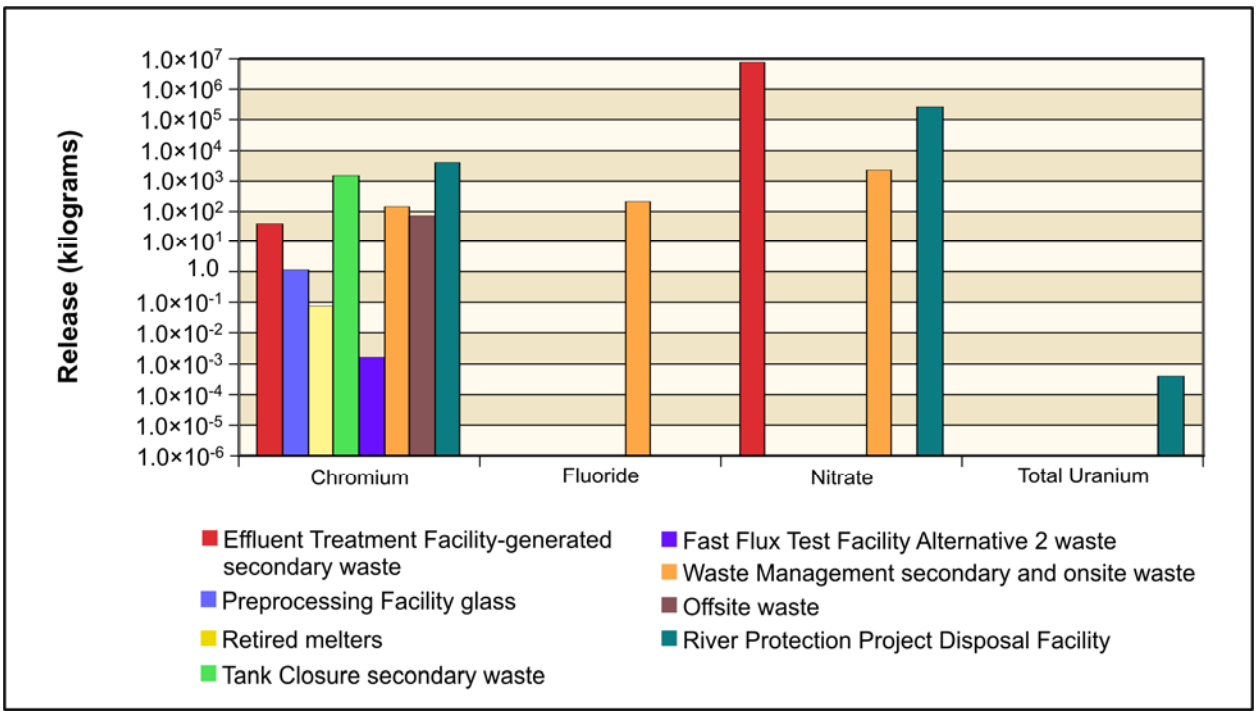


Figure N–108. Waste Management Alternative 2, Disposal Group 3, Base Case, Chemical Release to Aquifer

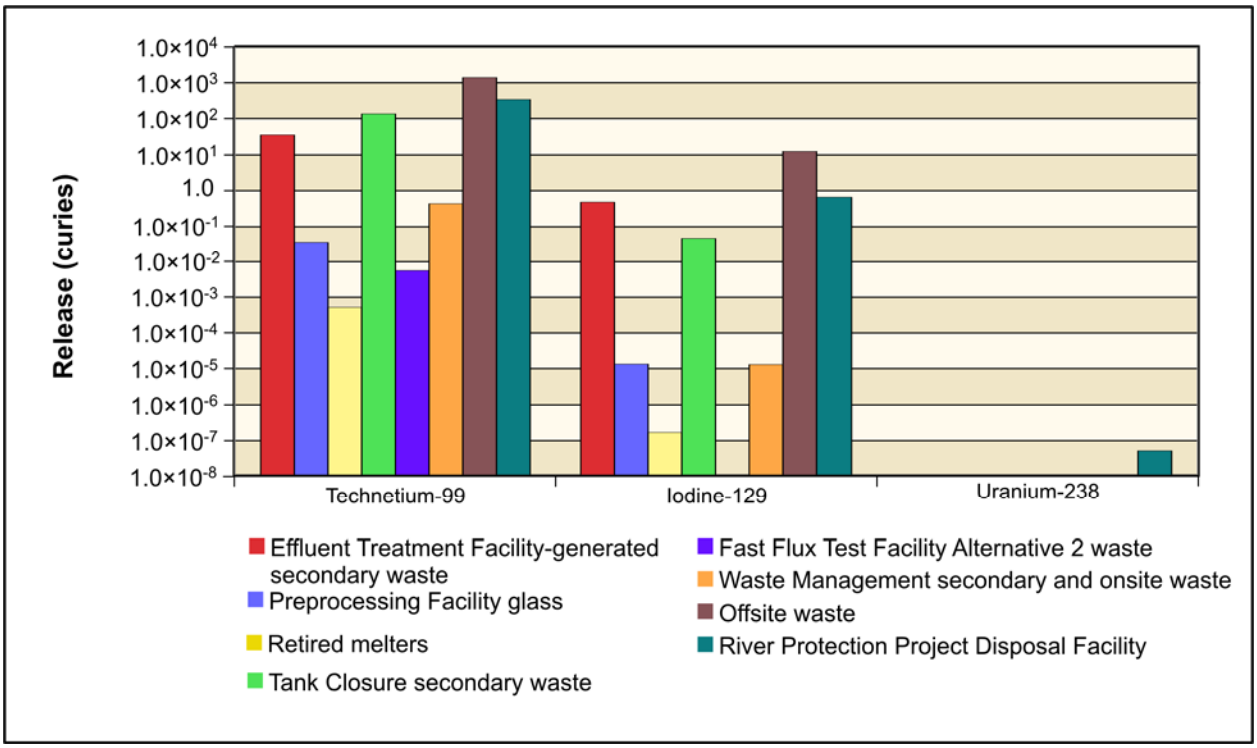


Figure N–109. Waste Management Alternative 2, Disposal Group 3, Option Case, Radiological Release to Aquifer

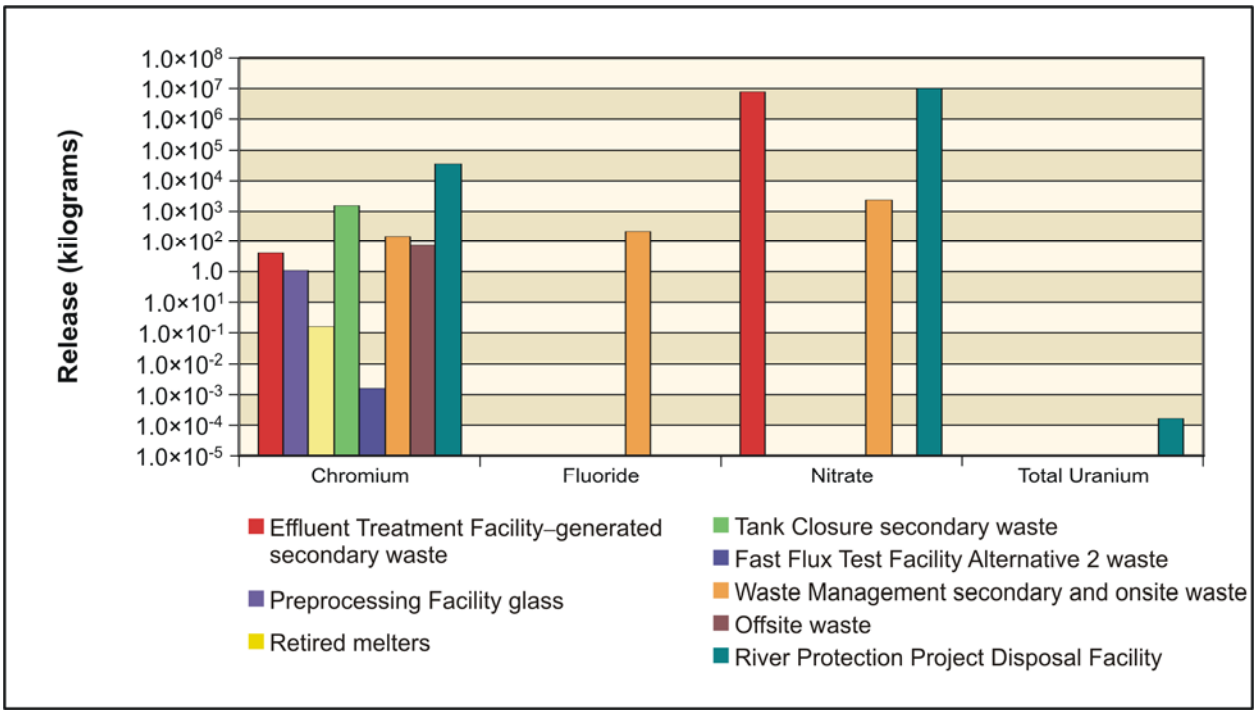


Figure N–110. Waste Management Alternative 2, Disposal Group 3, Option Case, Chemical Release to Aquifer

N.2.3.3 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas

Under Waste Management Alternative 3, the waste from tank treatment operations would be disposed of in IDF-East, and that from onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites would be disposed of in the 200-West Area IDF (IDF-West). Waste from tank farm cleanup operations would be disposed of in the RPPDF. As a result, the waste disposed of in these three facilities would become available for release to the environment. Because of the different waste types that result from the Tank Closure action alternatives, three disposal groups were considered to account for the different IDF-East sizes and operational time periods. In addition, within these three disposal groups, subgroups were identified to allow consideration of the different waste types resulting from the Tank Closure alternatives.

The amount of waste disposed of at IDF-West under each subgroup is identical. Potential releases to the aquifer from IDF-West under Waste Management Alternative 3 are indicated in Figures N–111 and N–112 and are displayed only once for all disposal groups for Waste Management Alternative 3.

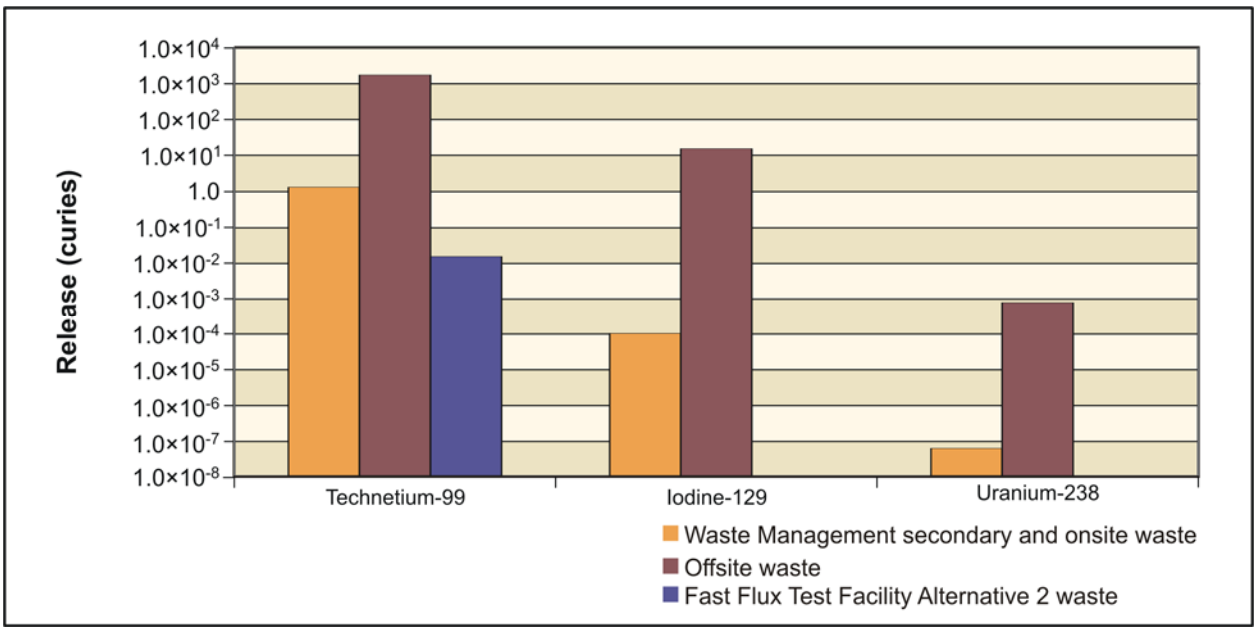


Figure N–111. Waste Management Alternative 3, 200-West Area Integrated Disposal Facility Radiological Release to Aquifer

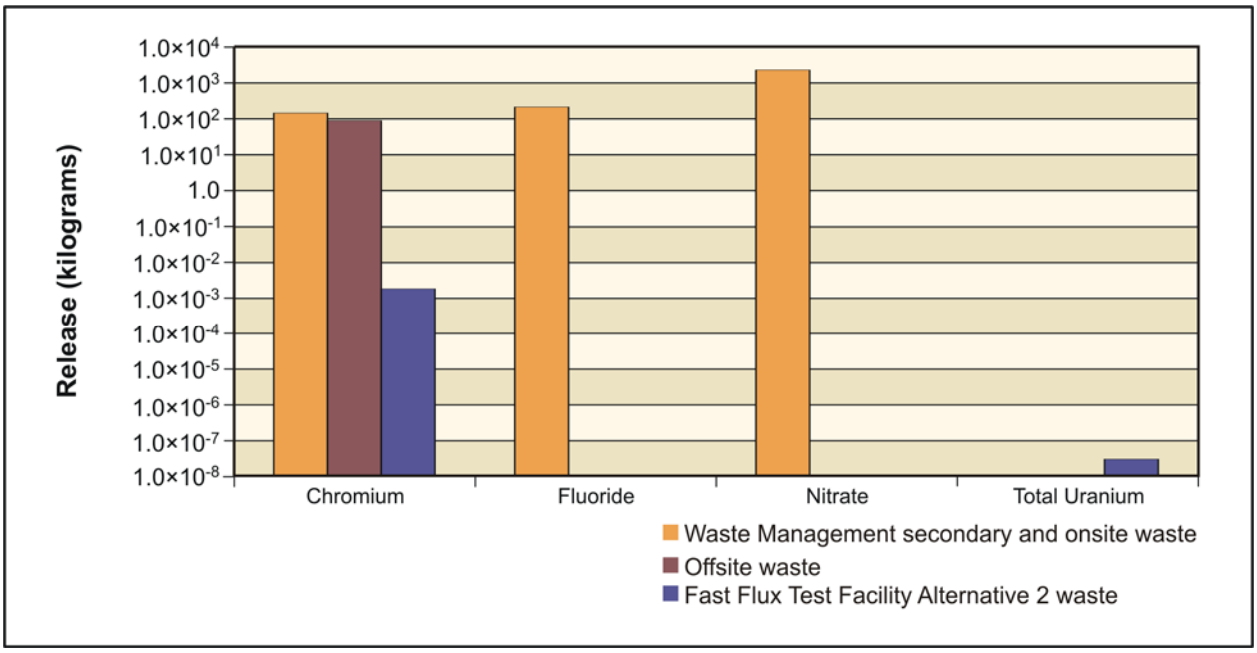


Figure N–112. Waste Management Alternative 3, 200-West Area Integrated Disposal Facility Chemical Release to Aquifer

N.2.3.3.1 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas, Disposal Group 1, Subgroup 1-A

Disposal Group 1, Subgroup 1-A, addresses the waste from Tank Closure Alternative 2B, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Tank closure secondary waste

Waste forms for IDF-West include the following:

- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 2B. Potential releases to the aquifer under Waste Management Alternative 3, Disposal Group 1, Subgroup 1-A, are indicated in Figures N–113 and N–114.

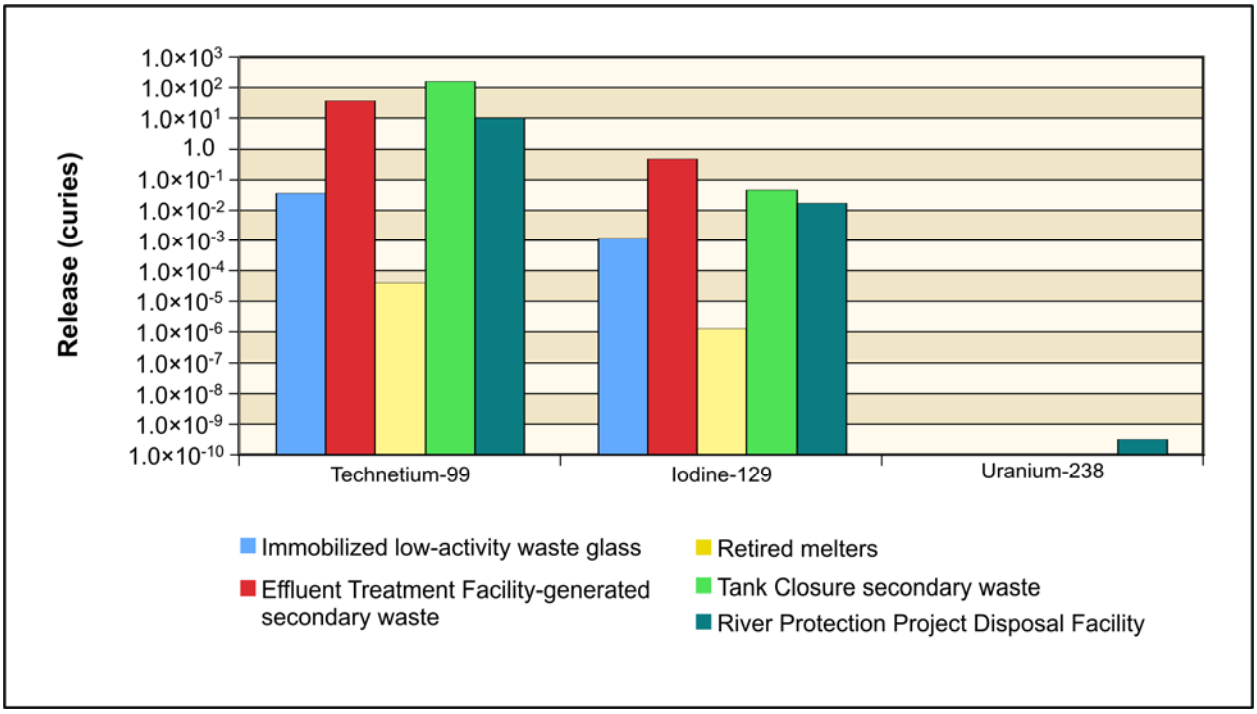


Figure N–113. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-A, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

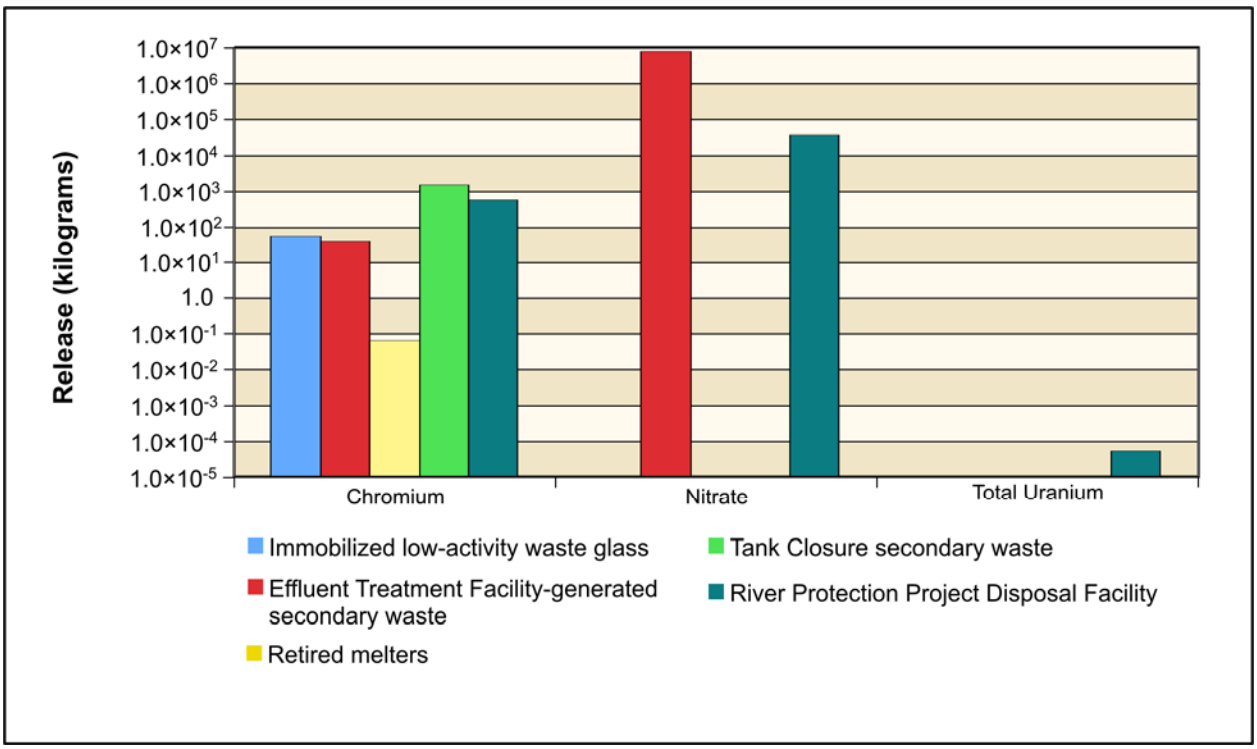


Figure N–114. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-A, 200-East Area Integrated Disposal Facility Chemical Release to Vadose Zone

N.2.3.3.2 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas, Disposal Group 1, Subgroup 1-B

Disposal Group 1, Subgroup 1-B, addresses the waste from Tank Closure Alternative 3A, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Bulk vitrification glass
- Tank closure secondary waste

Waste forms for IDF-West include the following:

- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 3A. Potential releases to the aquifer under Waste Management Alternative 3, Disposal Group 1, Subgroup 1-B, are indicated in Figures N–115 and N–116.

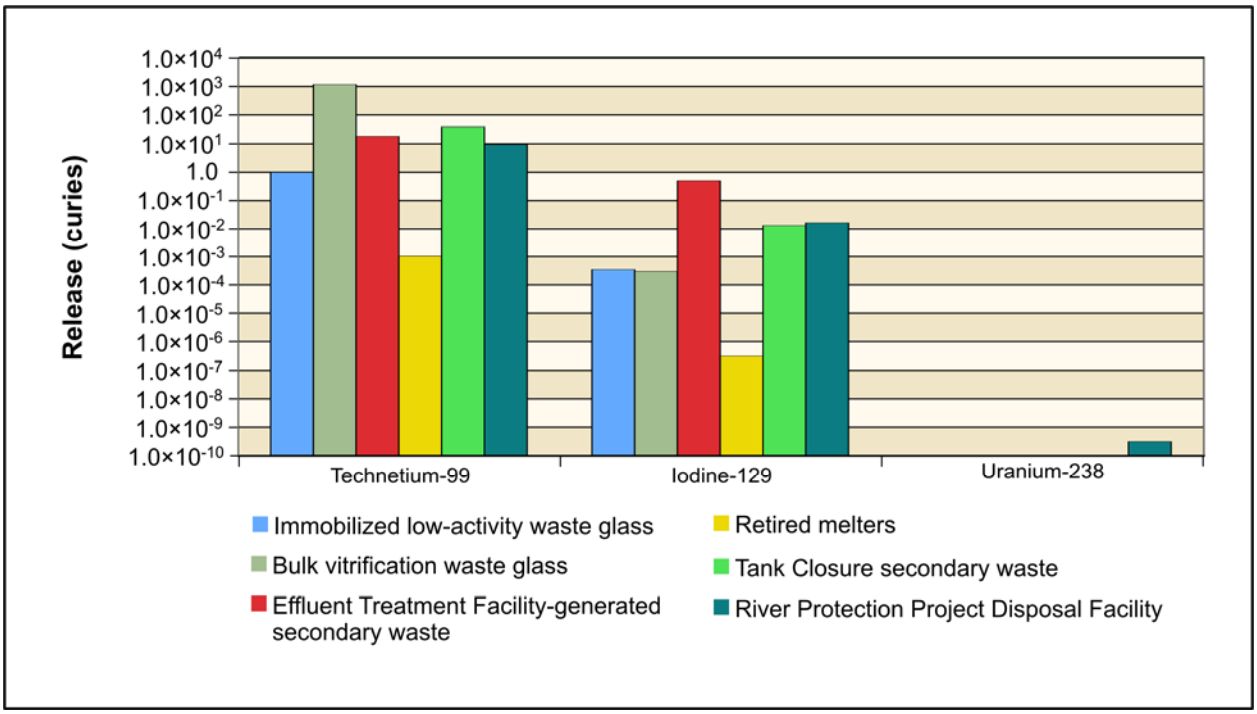


Figure N–115. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-B, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

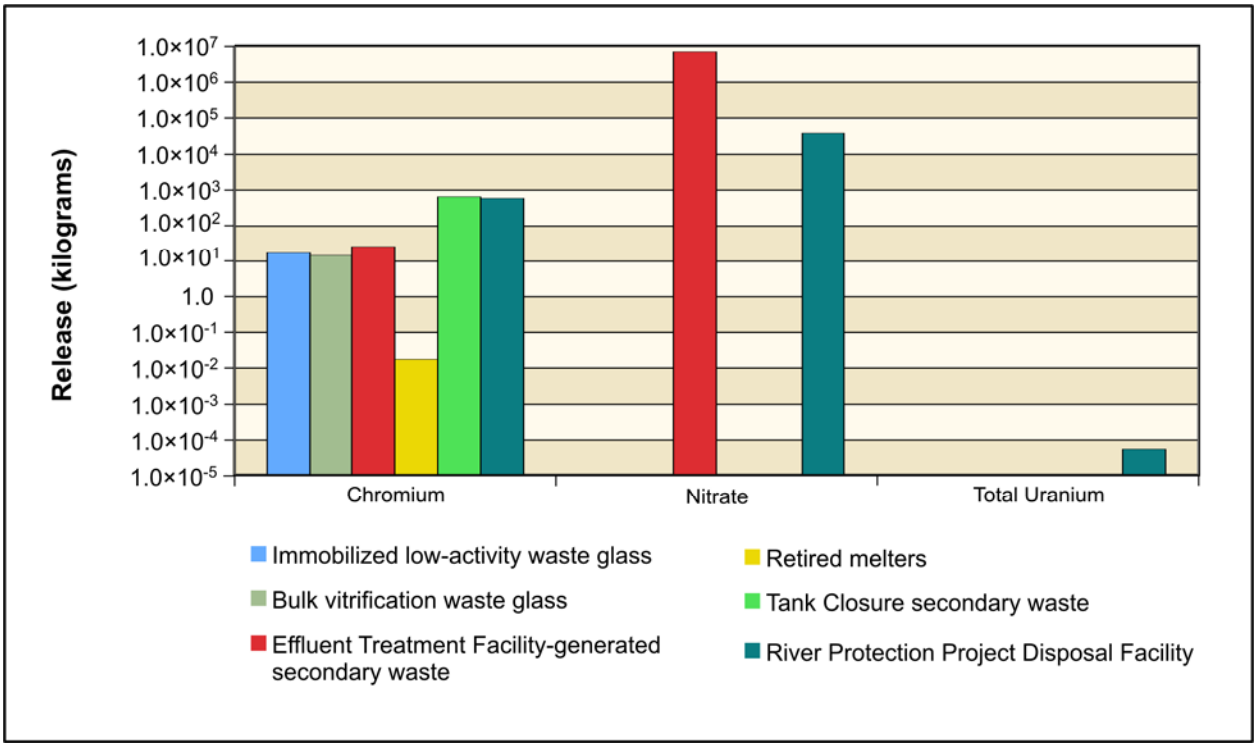


Figure N–116. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-B, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

N.2.3.3.3 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas, Disposal Group 1, Subgroup 1-C

Disposal Group 1, Subgroup 1-C, addresses the waste from Tank Closure Alternative 3B, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Cast stone
- Tank closure secondary waste

Waste forms for IDF-West include the following:

- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 3B. Potential releases to the aquifer under Waste Management Alternative 3, Disposal Group 1, Subgroup 1-C, are indicated in Figures N–117 and N–118.

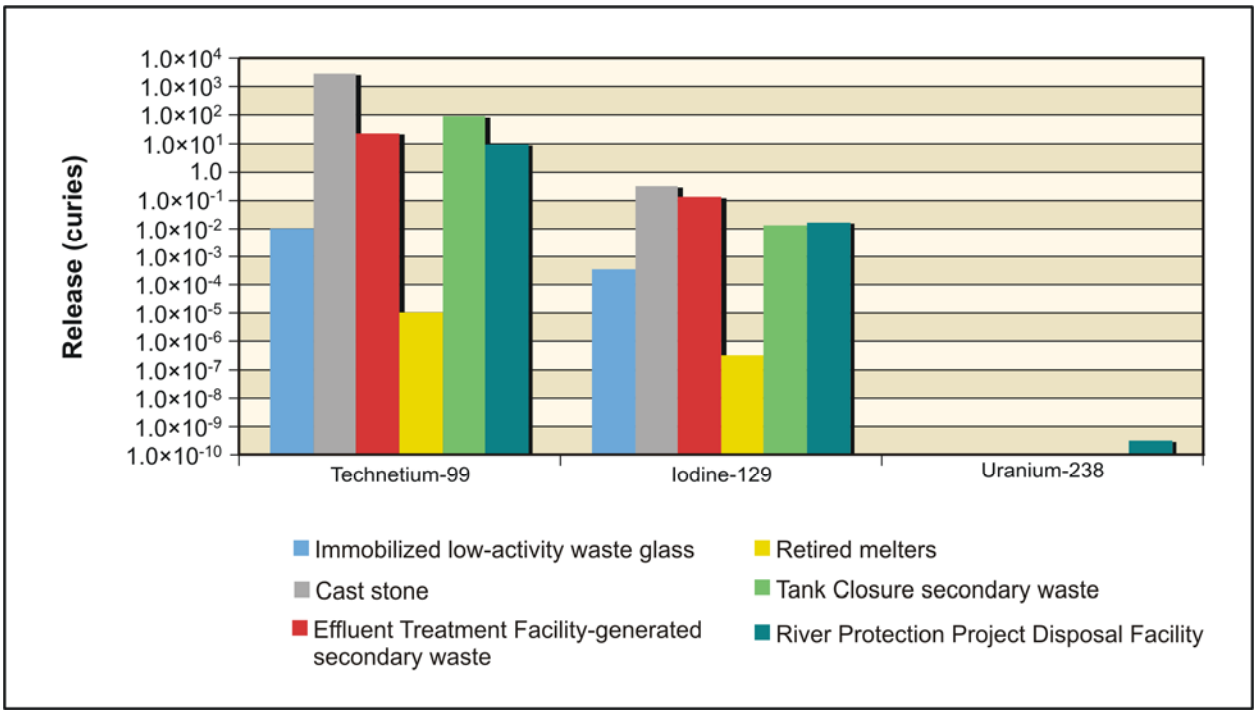


Figure N–117. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-C, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

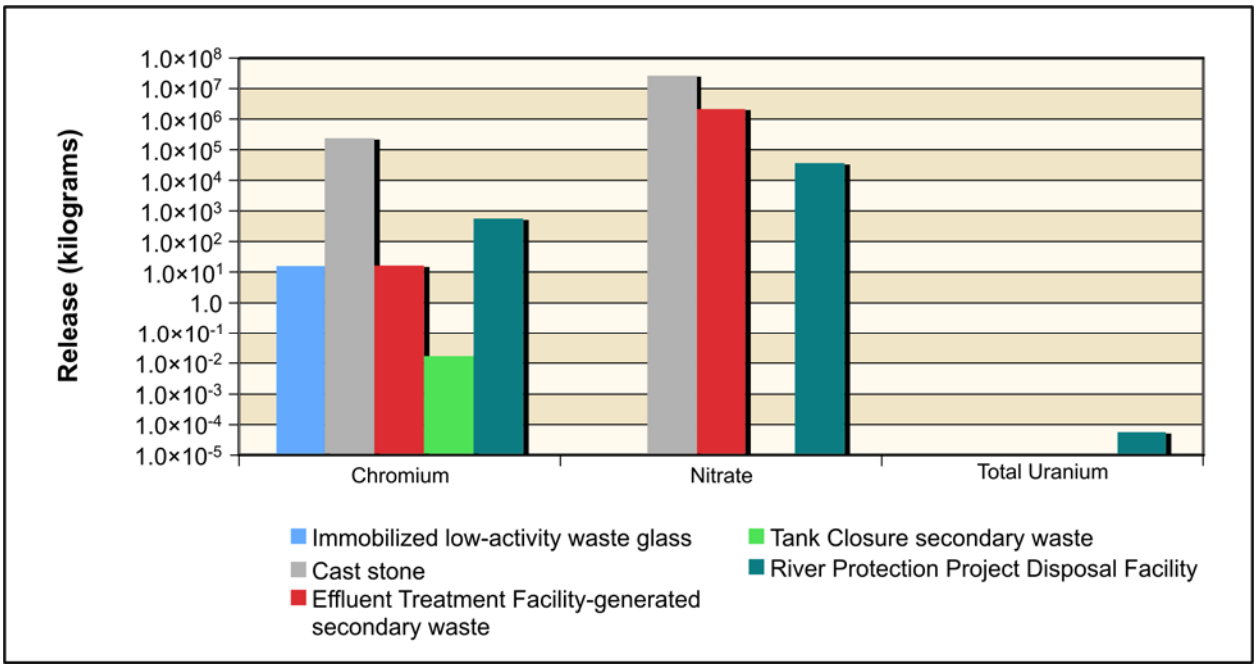


Figure N–118. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-C, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

N.2.3.3.4 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas, Disposal Group 1, Subgroup 1-D

Disposal Group 1, Subgroup 1-D, addresses the waste from Tank Closure Alternative 3C, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Steam reforming waste
- Tank closure secondary waste

Waste forms for IDF-West include the following:

- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 3C. Potential releases to the aquifer under Waste Management Alternative 3, Disposal Group 1, Subgroup 1-D, are indicated in Figures N–119 and N–120.

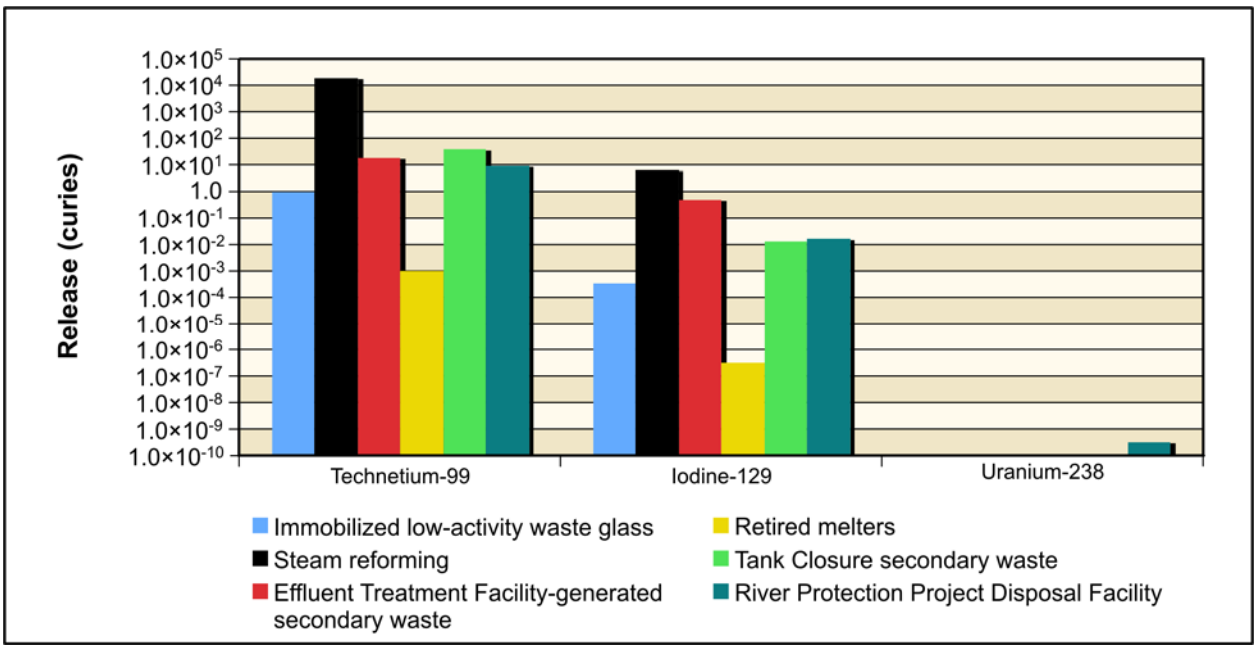


Figure N–119. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-D, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

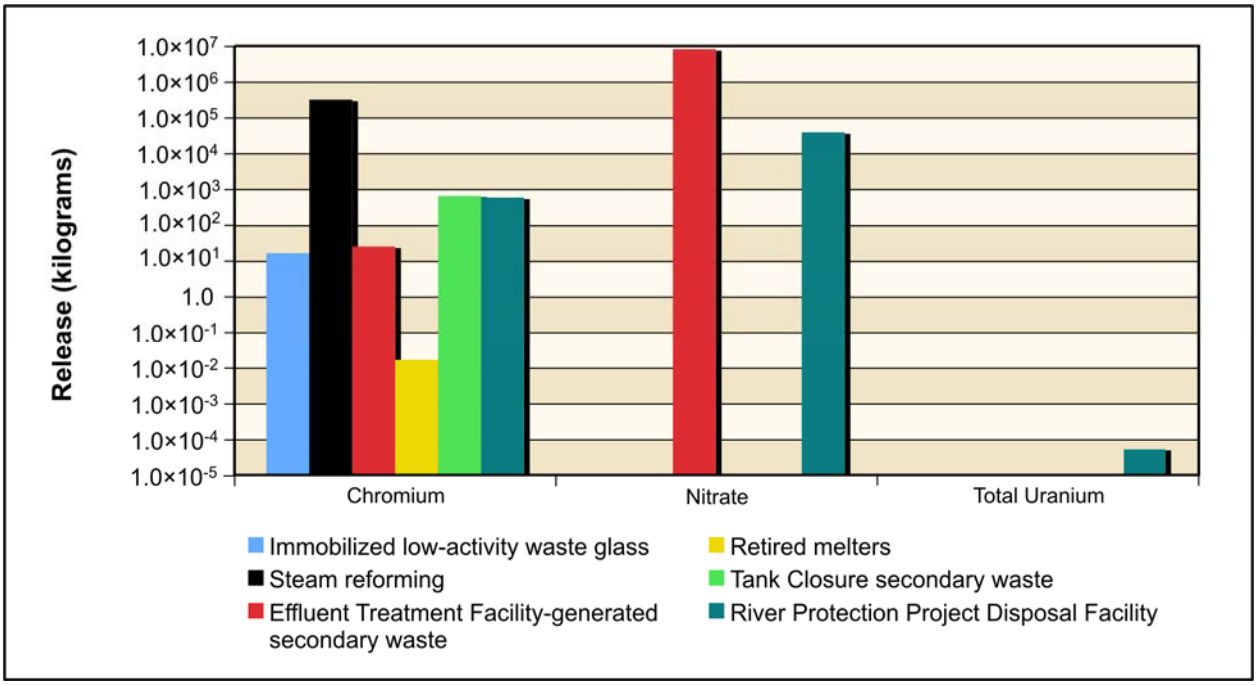


Figure N–120. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-D, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

N.2.3.3.5 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas, Disposal Group 1, Subgroup 1-E

Disposal Group 1, Subgroup 1-E, addresses the waste from Tank Closure Alternative 4, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Bulk vitrification glass
- Cast stone
- Effluent Treatment Facility (ETF) secondary solid waste
- Tank closure secondary waste

Waste forms for IDF-West include the following:

- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

The RPPDF would not be constructed or operated for Tank Closure Alternative 4 because tank closure cleanup activities would not be conducted. Potential releases to the aquifer under Waste Management Alternative 3, Disposal Group 1, Subgroup 1-E, are indicated in Figures N–121 and N–122.

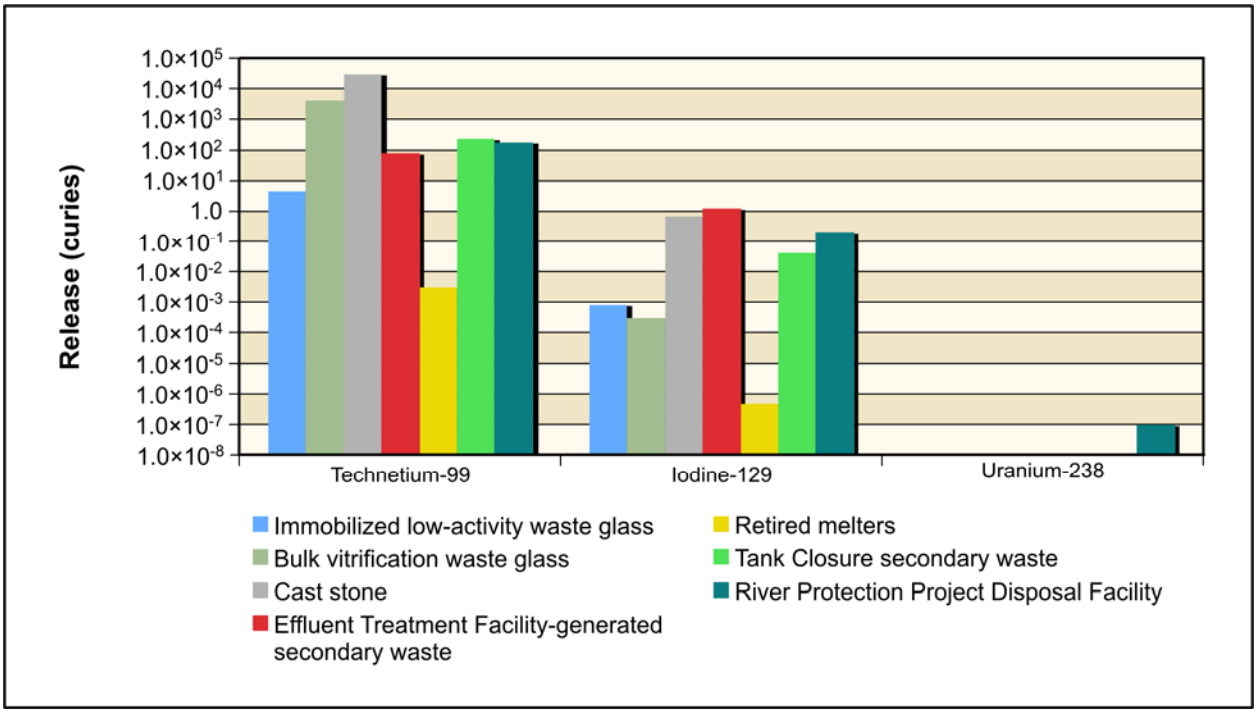


Figure N–121. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-E, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

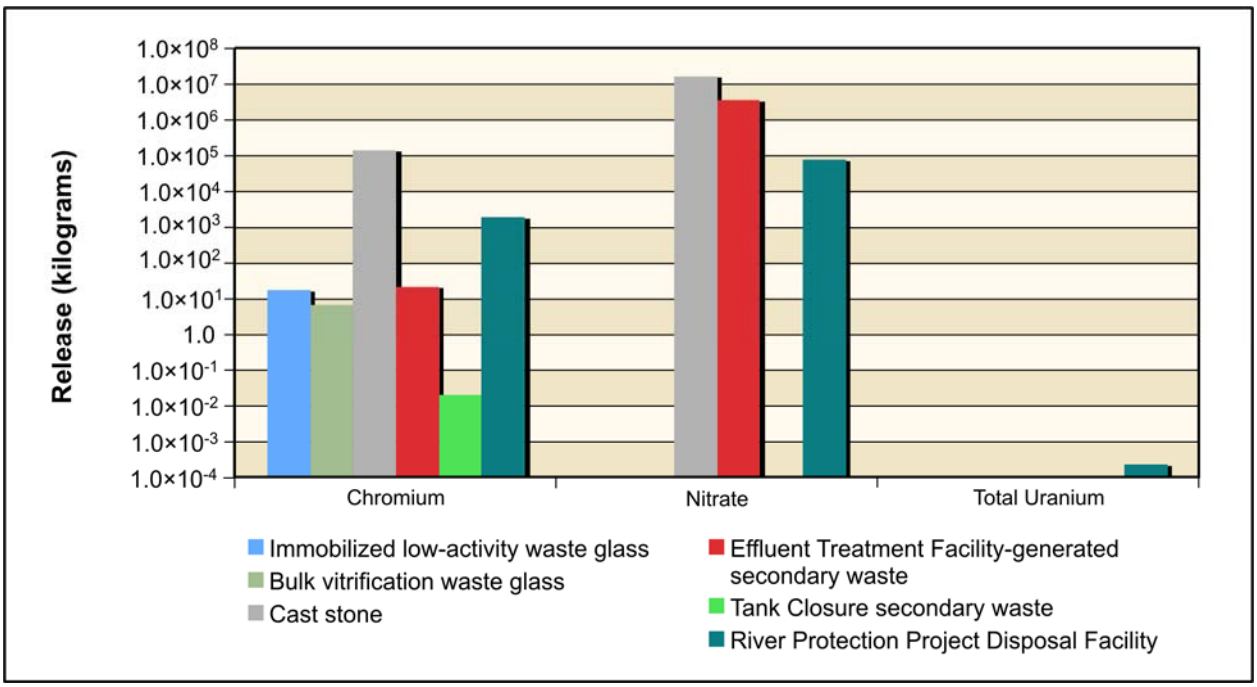


Figure N–122. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-E, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

N.2.3.3.6 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas, Disposal Group 1, Subgroup 1-F

Disposal Group 1, Subgroup 1-F, addresses the waste from Tank Closure Alternative 5, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Bulk vitrification glass
- Cast stone
- Sulfate grout
- Tank closure secondary waste

Waste forms for IDF-West include the following:

- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 5. Potential releases to the aquifer under Waste Management Alternative 3, Disposal Group 1, Subgroup 1-F, are indicated in Figures N–123 and N–124.

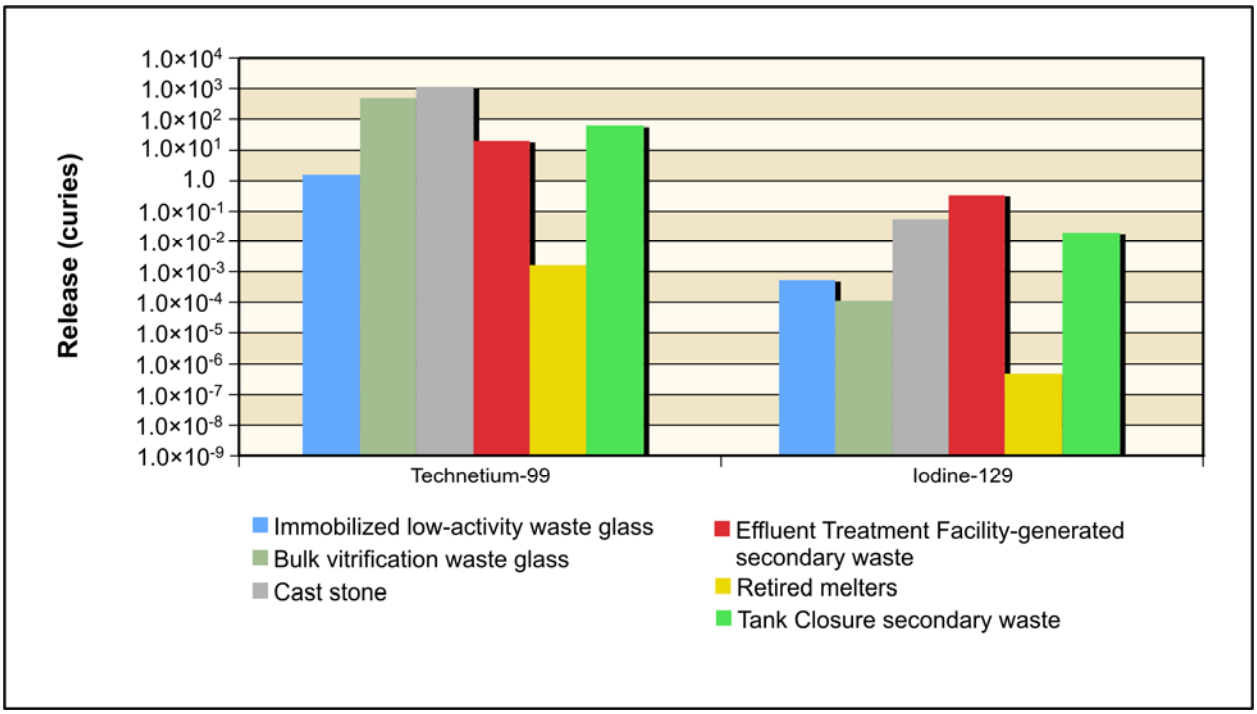


Figure N–123. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-F, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

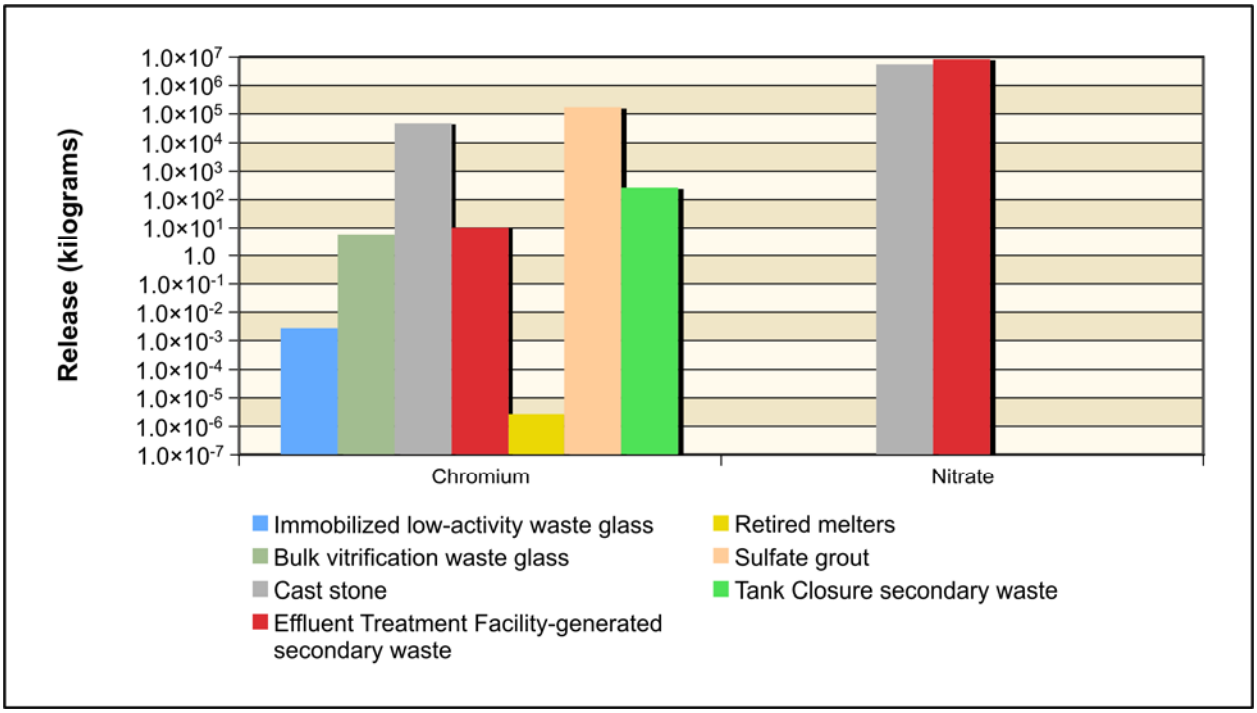


Figure N–124. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-F, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

N.2.3.3.7 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas, Disposal Group 1, Subgroup 1-G

Disposal Group 1, Subgroup 1-G, addresses the waste from Tank Closure Alternative 6C, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- Tank closure secondary waste

The waste forms for IDF-West include the following:

- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 6C. Potential releases to the aquifer under Waste Management Alternative 3, Disposal Group 1, Subgroup 1-G, are indicated in Figures N–125 and N–126.

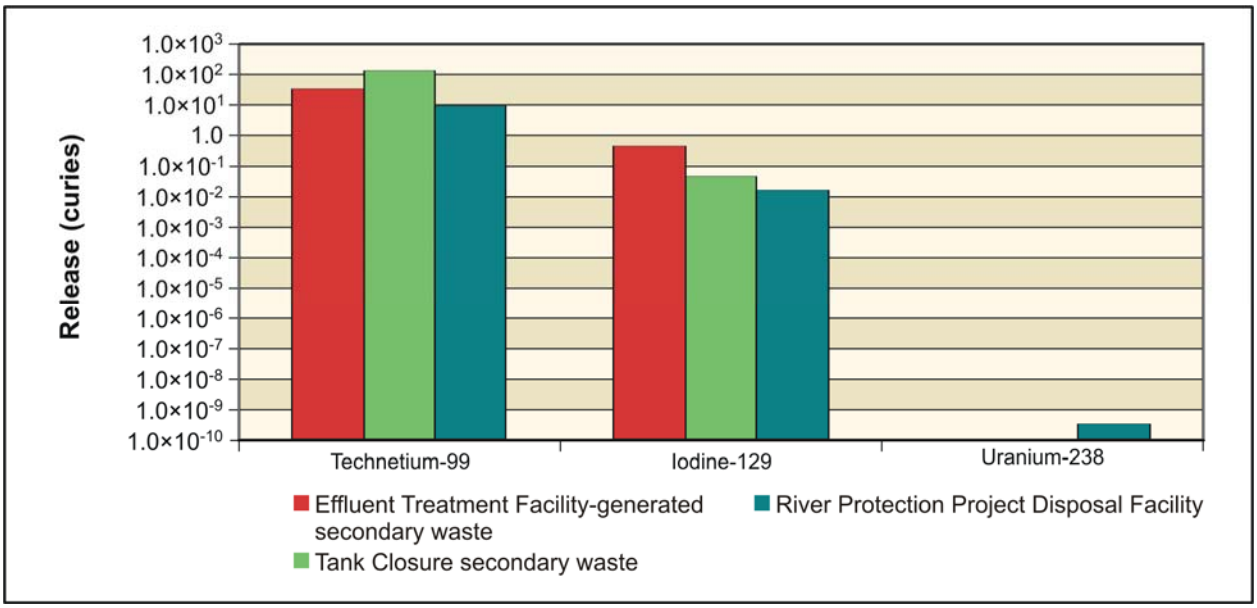


Figure N–125. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-G, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

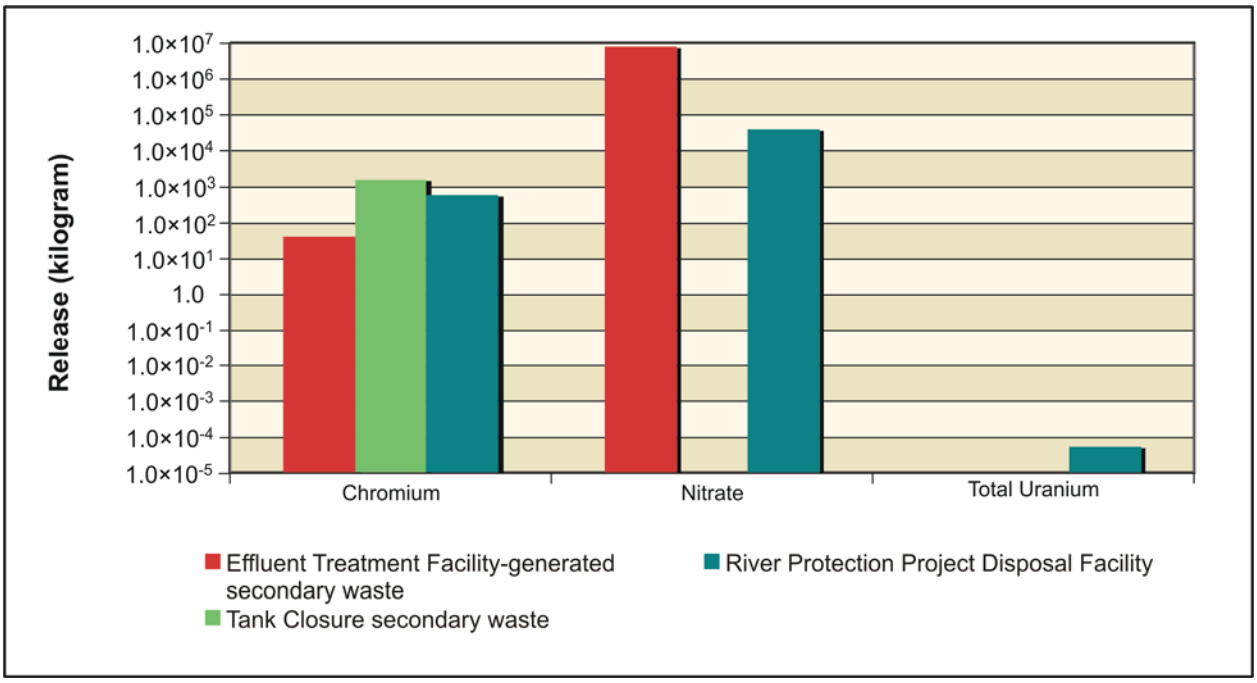


Figure N–126. Waste Management Alternative 3, Disposal Group 1, Subgroup 1-G, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

N.2.3.3.8 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas, Disposal Group 2, Subgroup 2-A

Disposal Group 2, Subgroup 2-A, addresses the waste from Tank Closure Alternative 2A, onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- ILAW glass
- LAW melters
- Tank closure secondary waste

The waste forms for IDF-West include the following:

- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

The RPPDF would not be constructed or operated for Tank Closure Alternative 2A because tank closure cleanup activities would not be conducted. Potential releases to the aquifer under Waste Management Alternative 3, Disposal Group 2, Subgroup 2-A, are indicated in Figures N–127 and N–128.

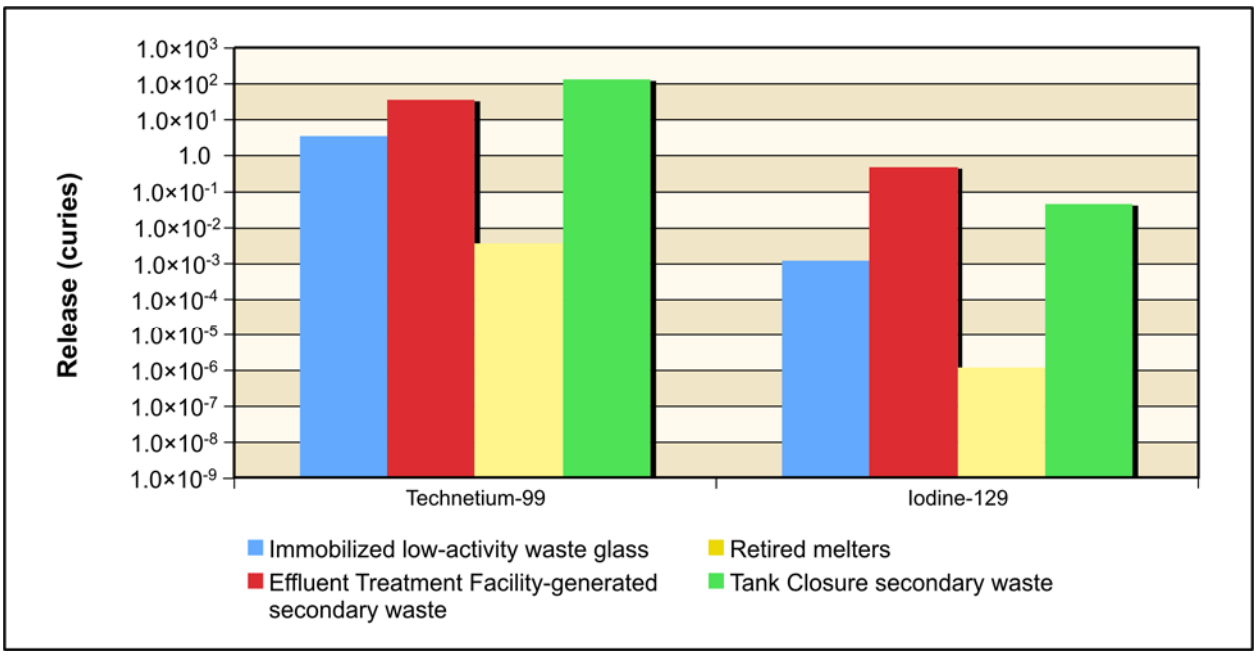


Figure N–127. Waste Management Alternative 3, Disposal Group 2, Subgroup 2-A, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

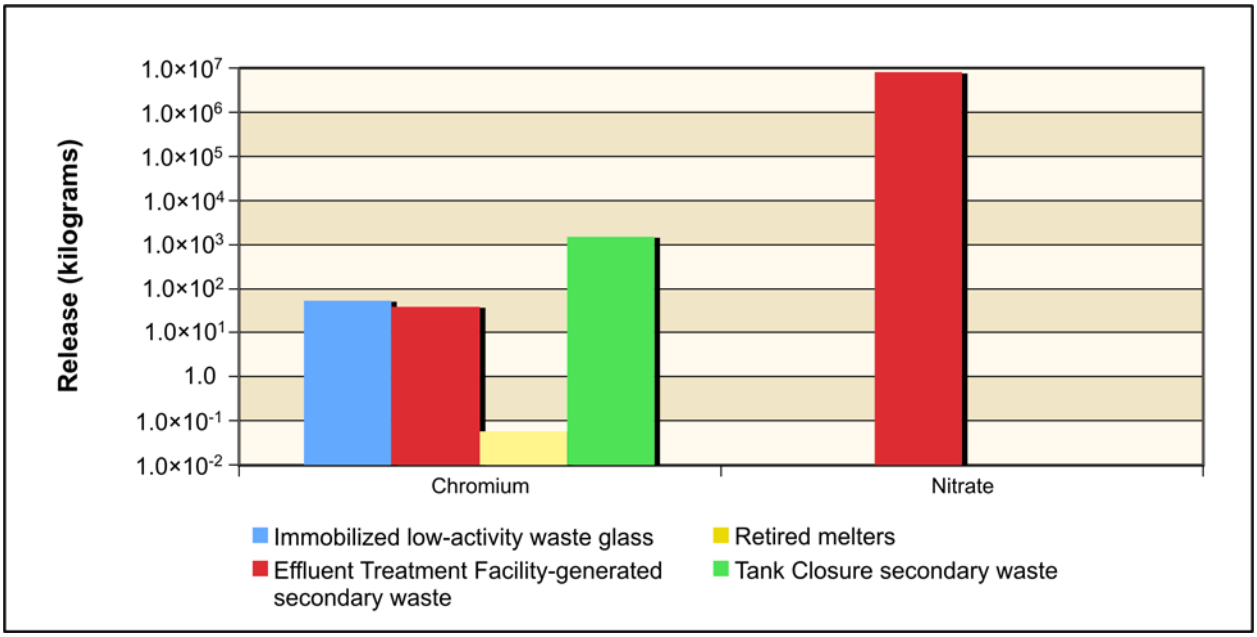


Figure N–128. Waste Management Alternative 3, Disposal Group 2, Subgroup 2-A, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

N.2.3.3.9 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas, Disposal Group 2, Subgroup 2-B

Disposal Group 2, Subgroup 2-B, addresses the waste from Tank Closure Alternative 6B (Base and Option), onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- PPF glass
- PPF melters
- Tank closure secondary waste

The waste forms for IDF-West include the following:

- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 6B, Base and Option Cases. Potential releases to the aquifer under Waste Management Alternative 3, Disposal Group 2, Subgroup 2-B, Base and Option Cases, are indicated in Figures N–129 through N–132.

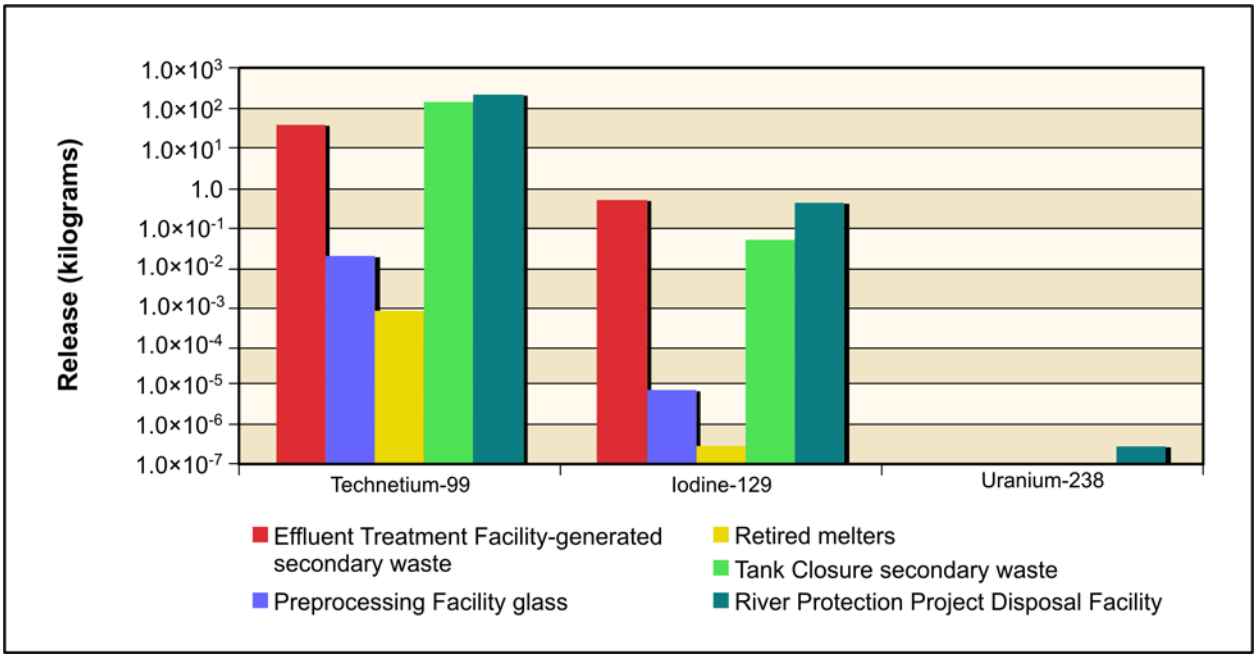


Figure N–129. Waste Management Alternative 3, Disposal Group 2, Subgroup 2-B, Base Case, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

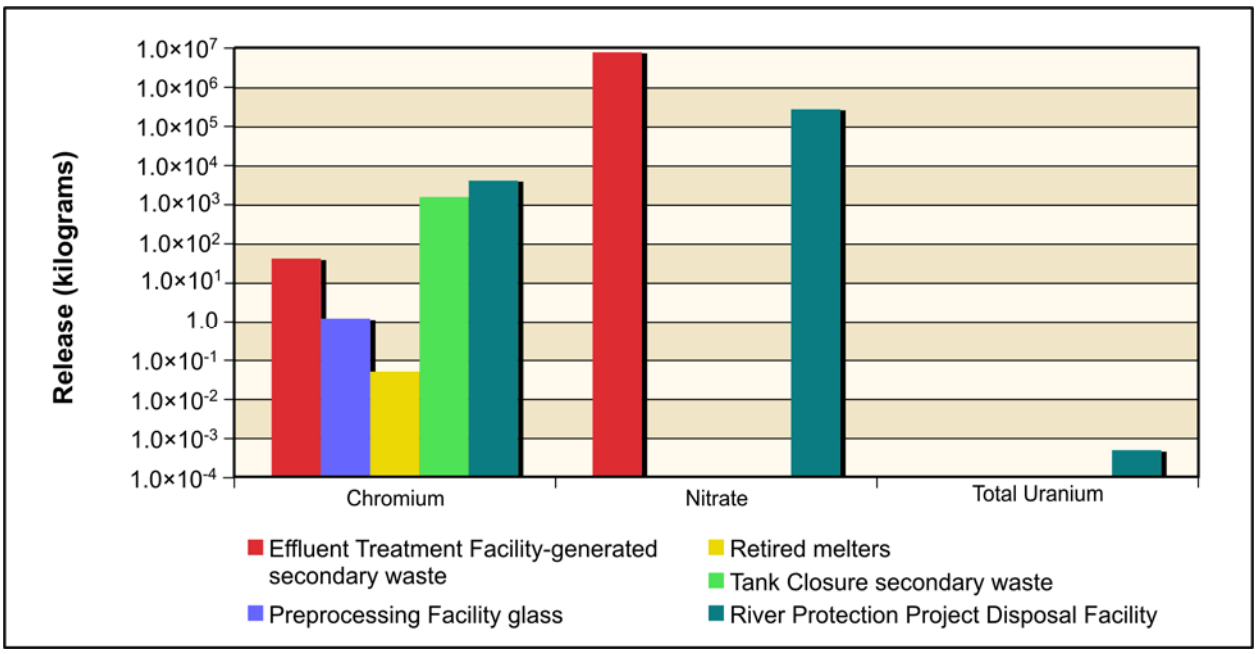


Figure N–130. Waste Management Alternative 3, Disposal Group 2, Subgroup 2-B, Base Case, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

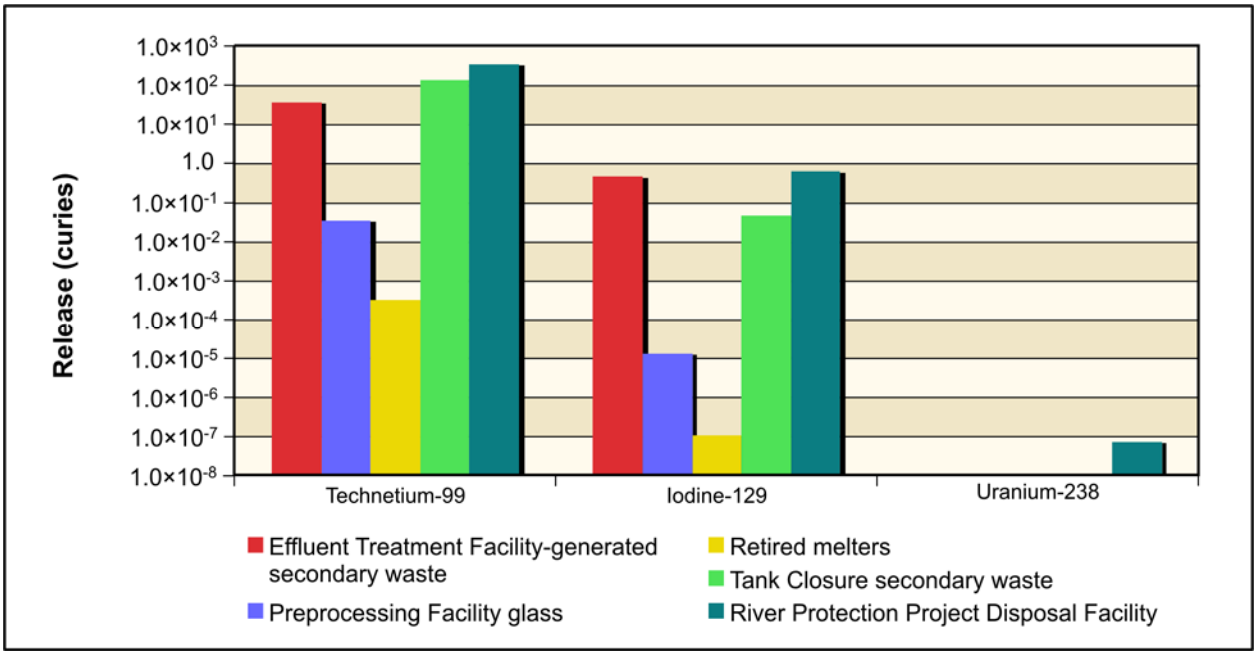


Figure N–131. Waste Management Alternative 3, Disposal Group 2, Subgroup 2-B, Base Case, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

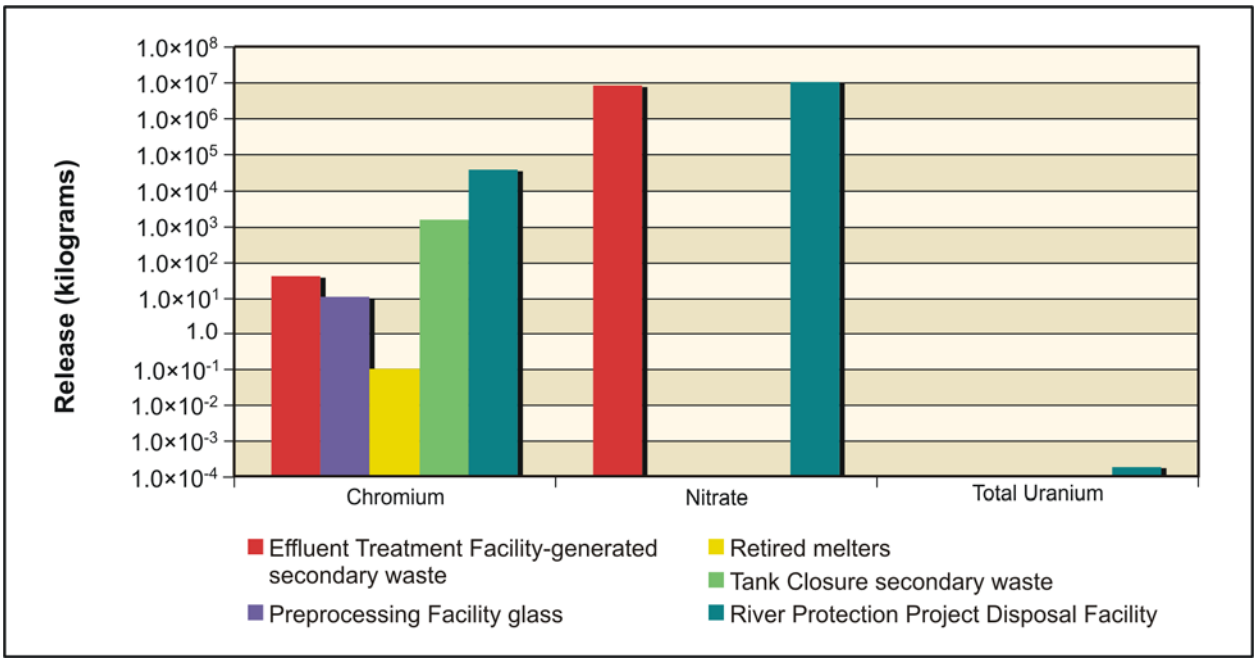


Figure N–132. Waste Management Alternative 3, Disposal Group 2, Subgroup 2-B, Option Case, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

N.2.3.3.10 Waste Management Alternative 3: Disposal in IDF, 200-East and 200-West Areas, Disposal Group 3

Disposal Group 3 addresses the waste resulting from Tank Closure Alternative 6A (Base and Option), onsite non-CERCLA sources, FFTF decommissioning, waste management, and other DOE sites. Waste forms for IDF-East include the following:

- PPF glass
- PPF melters
- Tank closure secondary waste

The waste forms for IDF-West include the following:

- FFTF decommissioning secondary waste
- Waste management secondary waste
- Offsite waste
- Onsite non-CERCLA waste

Waste forms for the RPPDF include those resulting from tank closure cleanup activities for Tank Closure Alternative 6A, Base and Option Cases. Potential releases to the aquifer under Waste Management Alternative 3, Disposal Group 3, Base and Option Cases, are indicated in Figures N–133 through N–136.

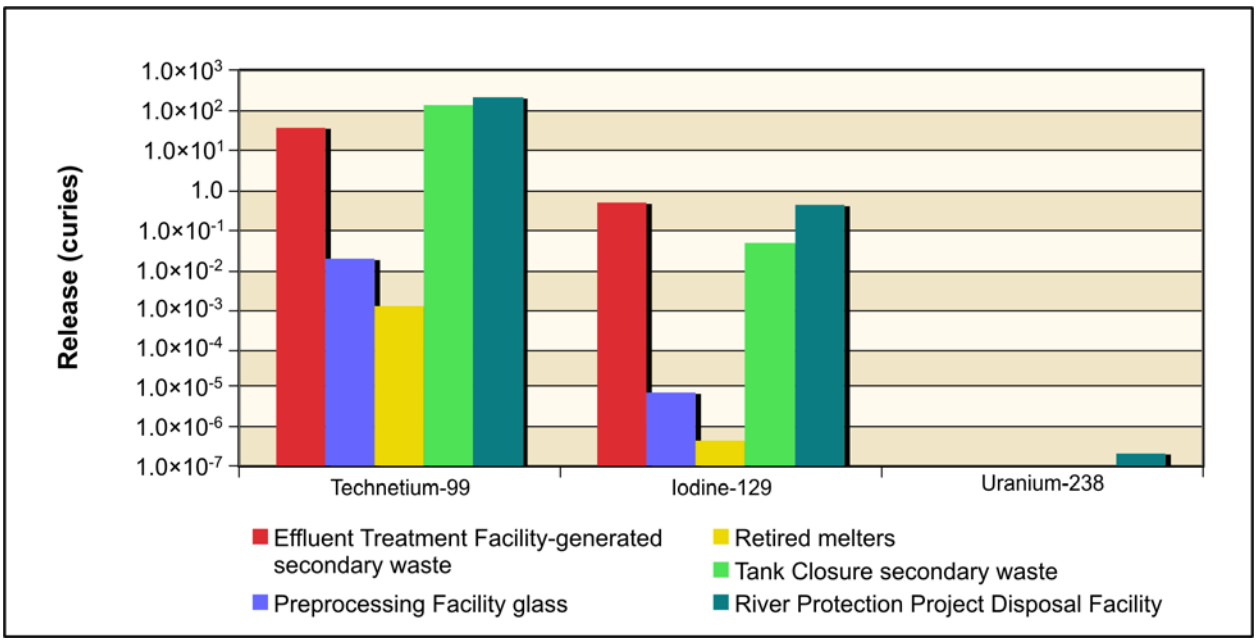


Figure N–133. Waste Management Alternative 3, Disposal Group 3, Base Case, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

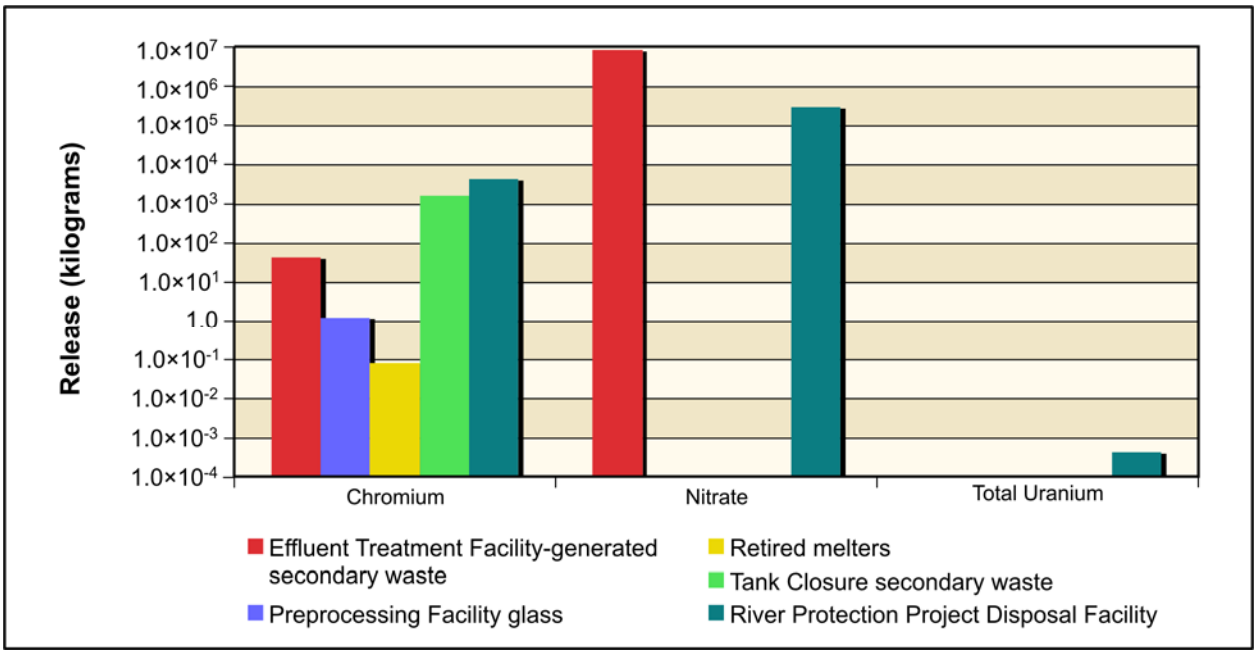


Figure N–134. Waste Management Alternative 3, Disposal Group 3, Base Case, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

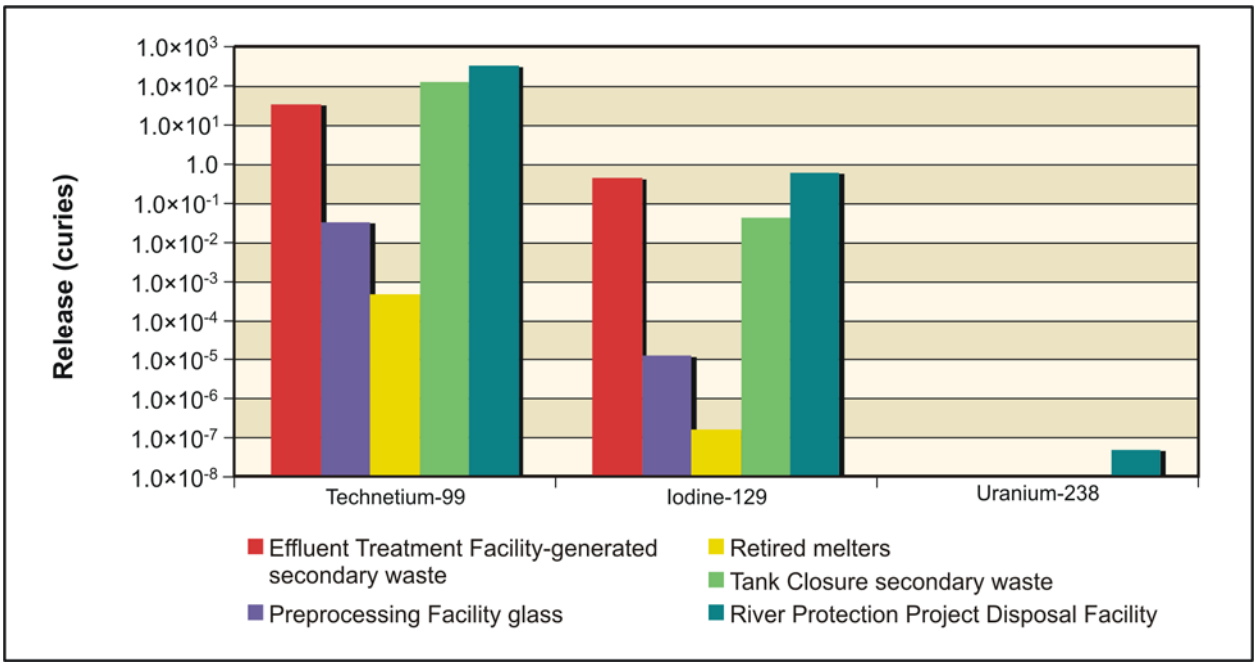


Figure N–135. Waste Management Alternative 3, Disposal Group 3, Option Case, 200-East Area Integrated Disposal Facility Radiological Release to Aquifer

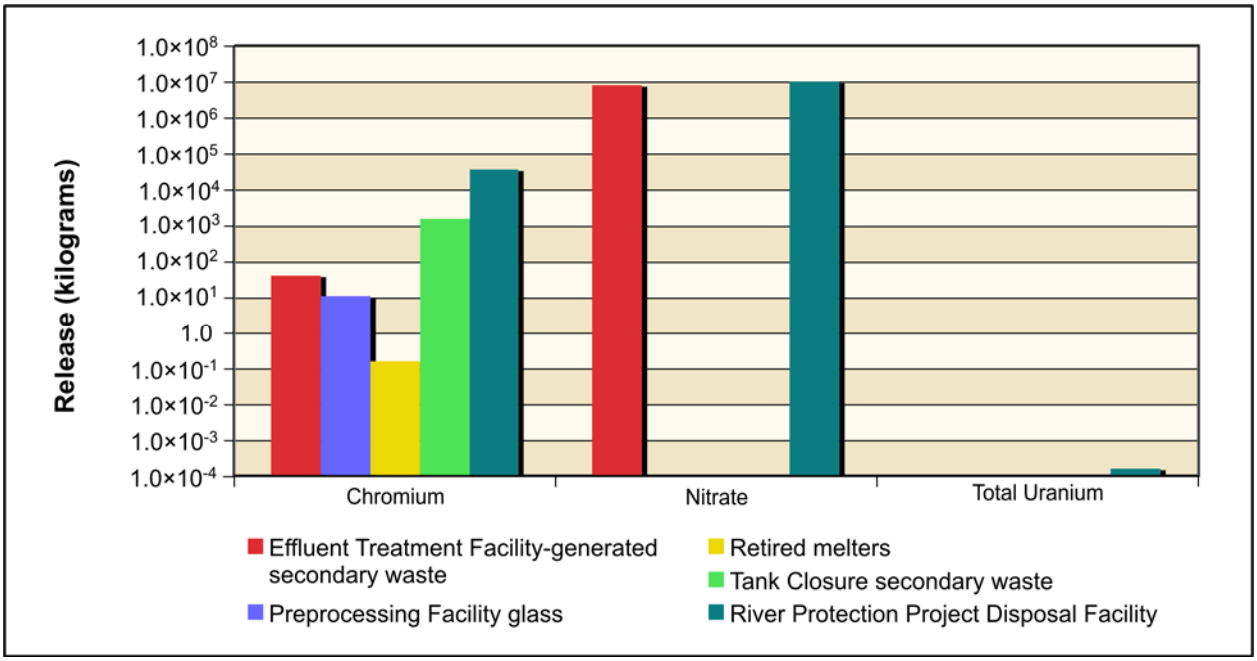


Figure N–136. Waste Management Alternative 3, Disposal Group 3, Option Case, 200-East Area Integrated Disposal Facility Chemical Release to Aquifer

N.3 SENSITIVITY ANALYSIS

The rate of movement of water and solute through the vadose zone varies in space and time, reflecting the influence of infiltration at the ground surface, source conditions, and the geology and properties of the sediments constituting the vadose zone. This section discusses the variation of these conditions and presents estimates of the sensitivity of the flux of water and solute at the water table to changes in conditions. Eight cases were assessed for the following:

- The dependence of travel time on rate of recharge
- The dependence of solute flux at the water table on the magnitude of aqueous discharge at the source
- The dependence of solute flux at the water table on the thickness of silt layers
- The role of the tilting of layers in directing flow
- The role of dikes in directing or focusing flow
- The dependence of estimates of impacts on the recharge rate for sitewide and IDF conditions
- The dependence of impacts on the magnitude of the distribution coefficient of iodine in the vadose zone
- The role of the efficiency of capture of iodine in ILAW glass

N.3.1 Travel Time and Rate of Recharge

The rate of groundwater movement through the vadose zone under steady state conditions varies with the geology and related hydraulic properties of the vadose zone and the rate of recharge initiating the flow. The background rate of recharge varies locally and is a function of geology, the amount of precipitation, and the degree of evapotranspiration mediated by the type of ground cover (Fayer and Walters 1995). This section presents estimates of travel time through the vadose zone for rates of recharge recommended for Hanford (DOE 2005) using the values of hydraulic properties identified in Appendix M. The magnitude of travel time is important because it influences the timing and flux of solutes at the water table with respect to potential remediation actions or placement of caps. A range of recharge conditions is considered to investigate uncertainty related to surface and subsurface soil conditions and variability in evapotranspiration moderated by vegetation. The range of recharge rate considered depends on (1) background conditions at the undisturbed IDF-East site in the southeast portion of the 200-East Area (0.9 millimeters per year), (2) background conditions at undisturbed locations over the balance of the 200-East and 200-West Areas (3.5 millimeters per year), (3) disturbed conditions at cribs and trenches (ditches) (50 millimeters per year), and (4) disturbed conditions at tank farms (100 millimeters per year). Two cases are considered: geology representative of the 200-East Area and geology representative of the 200-West Area. In each case, the recharge rate is constant in time and uniform across the study area, and the soil layers constituting the vadose zone are horizontal and of uniform thickness. Representative geology for the 200-East Area includes an upper layer of Hanford Gravel, a center layer of Hanford Sand, and a lower layer of Ringold Gravel. For the 200-West Area, layers of Hanford Gravel, Hanford Sand, Plio-Pleistocene Silt, and Ringold Gravel extend from the ground surface to the water table. The thicknesses of the vadose zone assumed for these calculations are 78 and 70 meters (256 and 230 feet) for the 200-East and 200-West Areas, respectively.

Plots of the frequency distribution of travel time for the 200-East and 200-West Areas are presented as Figures N–137 and N–138, respectively. Results indicate very long travel times for low recharge rates but travel times as short as 60 years for disturbed conditions at tank farms. Estimates of average travel time, ranging from 63 to 4,270 years, as summarized in Table N–2, are slightly lower for the 200-East Area than for the 200-West Area. The difference in travel time is due primarily to difference in hydraulic properties between soil types in the 200-East and 200-West Areas, and to the presence of the Plio-Pleistocene soil type in the 200-West Area. The short travel times estimated for higher recharge sites indicate that the timing of the release and placement of the cap may play a role in conjunction with the

short travel time in comparison of alternatives. The significance of this effect would be determined through review of the time series of health impacts (see Appendix Q) for the alternatives under comparison.

Table N–2. Estimates of Travel Time in the Vadose Zone for Differing Rates of Recharge

Rate of Recharge (millimeters per year)	Average Travel Time (years)	
	200-East Area	200-West Area
0.9	4,270	Not applicable
3.5	1,240	1,300
50	115	118
100	63	64

Note: Technical basis for recharge rate of 0.9 millimeters per year is available for the 200-East Area Integrated Disposal Facility, but is not available for any portion of the 200-West Area.

N.3.2 Aqueous Discharge near the Ground Surface

Past operations at Hanford have resulted in spills, leaks, and planned discharges that deposited aqueous fluids and solutes into vadose zone sediments at or near the ground surface. The elevated moisture content caused by these discharges could lead to rapid movement of solutes to the water table with degradation of groundwater quality in the unconfined aquifer. The case evaluated in this section, discharge of a volume of liquid to the vadose zone, is comparable to a past leak at a tank farm, with aqueous discharge ranging from 4 cubic meters (1,057 gallons) to 400 cubic meters (105,700 gallons). This range corresponds to current estimates of volumes of past leaks (Hanlon 2003) and reflects the degree of uncertainty in estimates of leak volumes that is related to difficulty in measurement of volume of material in large underground tanks. The geology is that of the 200-East Area with an upper layer of Hanford Gravel, a center layer of Hanford Sand, and a lower layer of Ringold Gravel. The area of the discharge has a horizontal extent of 20 meters (66 feet) in each direction, the approximate cross-sectional area of a single tank, and the overall thickness of the vadose zone for this simulation is 78 meters (256 feet). Recharge conditions are the uniform background rate of 3.5 millimeters per year across the study area prior to discharge, with an increase to 100 millimeters per year at the time of discharge. The discharge of water and solute is assumed to occur over a period of 1 year. Given the above conditions, the recharge rate to the immediate area of the discharge is 40 cubic meters (10,570 gallons) per year for the period of time following the discharge.

Time series of the flux of solute at the water table for three values of aqueous discharge are presented as Figure N–139. Results show almost no dependence of solute flux on the volume of the discharge when that volume is comparable to or smaller than the annual rate of recharge. A small decrease in travel time is predicted when the discharge is larger than the annual rate of recharge. Time to arrival of peak flux is approximately 60 years, indicating that the transition of background recharge from 3.5 to 100 millimeters per year does not delay movement of solute relative to that expected for steady state conditions at the higher rate of recharge. A minor dependence of solute flux at the water table on the duration of release was indicated in the analysis presented in Appendix M. The results indicate that comparison of alternatives would not be significantly biased by uncertainty in estimates of aqueous volume of past leaks.

N.3.3 Influence of a Silt Layer

One difference between geologies of the 200-East and 200-West Areas is the increased frequency of laterally extensive Plio-Pleistocene Silt layers in the 200-West Area. Because silt layers are known to retain water and facilitate spreading of infiltrating water and solute, silt layers may be important in estimation of the magnitude and time of solute flux at the water table and related human health impacts.

The potential influence of silt layers was evaluated in simulations that varied the thickness from 0 (not present) to 8 meters (26 feet). The analysis considered layers of Hanford Gravel, Hanford Sand, Plio-Pleistocene Silt, and Ringold Gravel extending from the ground surface to the water table at a depth of 70 meters (230 feet). Recharge and discharge conditions correspond to that of a crib with a horizontal dimension of 20 meters (66 feet) in each direction. The initial steady state moisture distribution is for background recharge of 3.5 millimeters per year, transitioning to 50 millimeters per year starting at the time of discharge. An aqueous discharge of 4,000 cubic meters (10,570 gallons) was specified to occur over a period of 1 year.

The time series of solute flux at the water table for a range of silt layer thicknesses are presented as Figure N–140. Results indicate that the absence or presence of the silt layer is more significant than the absolute thickness of the layer. Each of the time series shows two peaks, the first corresponding to an early arrival of solute associated with the large aqueous discharge, and the second associated with the moisture front due to the increase of recharge rate from 3.5 to 50 millimeters per year. The separation of the peaks is most pronounced when the silt layer is absent and muted when the silt layer is present. The results support inclusion of silt layers in the vadose zone models.

N.3.4 Tilt of Geologic Layers

Interspersed layers of sediment with differing hydraulic properties is one of the features of the large-scale structure of the vadose zone at Hanford. The downward movement of water to the unconfined aquifer will be influenced by the difference in the magnitude of values (offset) in hydraulic properties that occurs at the interface between adjacent layers. The accumulation of water above the interface, spreading of water at the interface, and preferential movement of water along the interface are possible consequences of the offset in hydraulic properties at the interface. This effect could be important on its own or in combination with dikes in forming a preferential path for potential flow of water and solute. This section investigates the effect of interface tilting between two layers on the redistribution of solute flux originating at a local source near the ground surface. A plan view of the large-scale structure of the vadose zone for the study area is presented as Figure N–141. The figure shows an interface between an upper layer of Hanford Gravel and an underlying Hanford Sand that is tilted with respect to a horizontal plane. For the purpose of analysis, two cases were considered: (1) the interface is level (not tilted), and (2) the interface is tilted. The assumed slope of the interface is 0.1 with a related angle of tilt of7 approximately 6 degrees from the horizontal plane. The geology of the study area is that of the 200-East Area with an upper layer of Hanford Gravel, a center layer of Hanford Sand, and a lower layer of Hanford Gravel. The area of the discharge has a horizontal extent of 5 meters (16 feet) in each direction (the area of a small crib), and the overall thickness of the vadose zone for this simulation is 80 meters (262 feet). Recharge conditions are uniform background across the study area of 3.5 millimeters per year for both the initial steady state condition and the transient portion of the analysis. For the transient simulation, a single 250-cubic-meter (66,052 gallons) discharge of water with 100 curies of technetium-99 is assumed to occur over a 1-year period.

For the purpose of reporting results, the horizontal or tilted plane at the water table is divided into release areas. The first area has the same dimension as the source and is immediately below the source. An additional four release areas are defined as concentric rectangles surrounding the first release area, as shown in Figure N–142. The size of each release area and the cumulative solute flux reaching the water table through that release area are presented as Table N–3. The time series of solute flux for release area 1 immediately below the source and for the total study area are presented as Figures N–143 and N–144, respectively. Results show that tilting of the interface directs solute away from the immediate location of the source, but that the effect is minor; nearly the entire release reaches the water table within 50 meters (165 feet) (of the source, tilting of the interface notwithstanding. The arrival of no solute at the water table through release areas 4 and 5 indicates that the study area was large enough so that effects due to boundary conditions for the sides of the study volume did not influence results. Lateral spreading due

to capillary forces plays a greater role than the tilt of the interface in moving water and solute away from the immediate area of the release.

Table N–3. Spatial Distribution of Solute Flux at the Water Table with Upper Geologic Layer Tilted

Release Area	Area (square meters)	Cumulative Flux of Technetium-99 at the Water Table (curies)	
		Level Interface	Tilted Interface
1	25	9.36	6.16
2	3,000	56.93	58.41
3	8,000	0.01	0.04
4	13,000	0	0
5	41,000	0	0

Note: To convert square meters to square feet, multiply by 10.7639.

N.3.5 Influence of a Dike

Examples of complex geology that could affect the movement of water and solutes through the vadose zone have been identified at Hanford. Included are vertically oriented sand and silt bands (clastic dikes) that cut across the primary, horizontally oriented sedimentary layers. Generally, the dikes have the same mineral content as the host sediments but a smaller grain size that may contribute to a faster advance of wetting fronts (Murray, Ward, and Wilson 2003). Average width as great as 1 to 3 meters (3 to 10 feet) and average length of 60 meters (197 feet) are reported for dikes at Hanford (Murray, Ward, and Wilson 2003). The presence of dikes could be important either as isolated features or in combination with local structure such as tilting of interfaces in forming preferred flow paths for water and solutes.

This section investigates the effect of a dike intersecting a source area near the ground surface on the distribution of water and solute flux reaching the water table. An elevation view of the large-scale structure of the vadose zone for the study area is presented as Figure N–145. The figure shows three horizontal layers—i.e., Hanford Gravel, Hanford Sand, and Hanford Gravel—and a vertically oriented dike in the center of the study volume. The study volume extends 430 meters (1,410 feet) in both horizontal directions and to a depth of 80 meters (262 feet). For the purpose of analysis, two cases were considered: (1) the dike is not present, and (2) the dike is present. The dike has a width of 2 meters (7 feet) and extends the full width and depth of the study volume. The simulations were run in two steps: an initial calculation with constant recharge and no source to establish background moisture and water flow conditions, and a second step to investigate transient behavior attributable to constant recharge from a specific source. The source of the discharge has a horizontal extent of 6 meters (20 feet) in each direction (the area of a small crib), and the dike passes through the center of the source area. Calculation of the background moisture and water flow was completed for uniform recharge rates of 3.5 and 100 millimeters per year. Recharge was applied at the ground surface at the same rate horizontally across the study area. For the transient simulation, the recharge rate of 100 millimeters per year was applied, and a single 54-cubic-meter (1,907-cubic-foot) discharge of water with 150 curies of technetium-99 was assumed to occur over a 1-year period. The hydraulic properties of the Hanford Gravel and Hanford Sand are those reported in Appendix M. For these horizontally oriented layers, the magnitude of the vertical component of hydraulic conductivity is one-tenth the magnitude of the horizontal component. The dike is assumed to have the same hydraulic properties as the Hanford Sand, with the exception that the magnitude of the vertical component of hydraulic conductivity is a factor of 10 greater than the magnitude of the horizontal component.

For the purpose of reporting results, two sets of release areas located in the horizontal plane at the water table are constructed. For the background moisture and water flow calculation, the study area is divided into five release areas, as shown in Figure N–146. The third release area has the same dimension as the

dike and is immediately below the dike. The additional four release areas are defined as rectangular strips on each side of the central area and below the dike. Results for the spatial distribution of recharge at the water table are presented as Table N–4 for the cases of spatially uniform recharge at the ground surface of 3.5 and 100 millimeters per year. Absent the dike, recharge at the water table is spatially uniform. In the case of the dike, flow to the water table is not spatially uniform; it is highest under the dike and slightly reduced outside the dike.

Table N–4. Spatial Distribution of Background Recharge for Study Area Intersected by a Dike

Recharge Area	Area (square meters)	Recharge at the Ground Surface (millimeters per year)	
		Aqueous Flux at the Water Table: 3.5 millimeters per year	Aqueous Flux at the Water Table: 100 millimeters per year
1	86,000	3.49	99.92
2	6,020	3.51	95.91
3	860	5.71	174.17
4	6,020	3.51	95.91
5	86,000	3.49	99.92

Note: To convert square meters to square feet, multiply by 10.7639.

The distribution of release areas for the transient simulation with the source present is presented as Figure N–142. The first release area has the same horizontal dimensions as the source and is immediately below the source, and the remaining areas are concentric rectangular areas around the first. Presented as Table N–5 are the size of each release area and the cumulative solute flux reaching the water table through that release area. The time series of solute flux for release area 1 immediately below the source and for the total study area are presented as Figures N–147 and N–148, respectively. Results show that the dike focuses flow toward the area of the dike. Peak annual flux of solute below the source increases by approximately 30 percent. Cumulative flux for the area outside the dike is reduced by approximately 10 percent. The arrival of no solute at the water table through release areas 4 and 5 indicates that the study area was large enough so that effects due to boundary conditions for the sides of the study volume did not influence results.

Table N–5. Spatial Distribution of Solute Flux at the Water Table for Study Area Intersected by a Dike

Release Area	Area (square meters)	Cumulative Flux of Technetium-99 at the Water Table (curies)	
		Without Dike	With Dike
1	36	32.32	43.42
2	864	116.49	101.46
3	16,000	1.03	0.69
4	36,000	0	0
5	148,900	0	0

Note: To convert square meters to square feet, multiply by 10.7639.

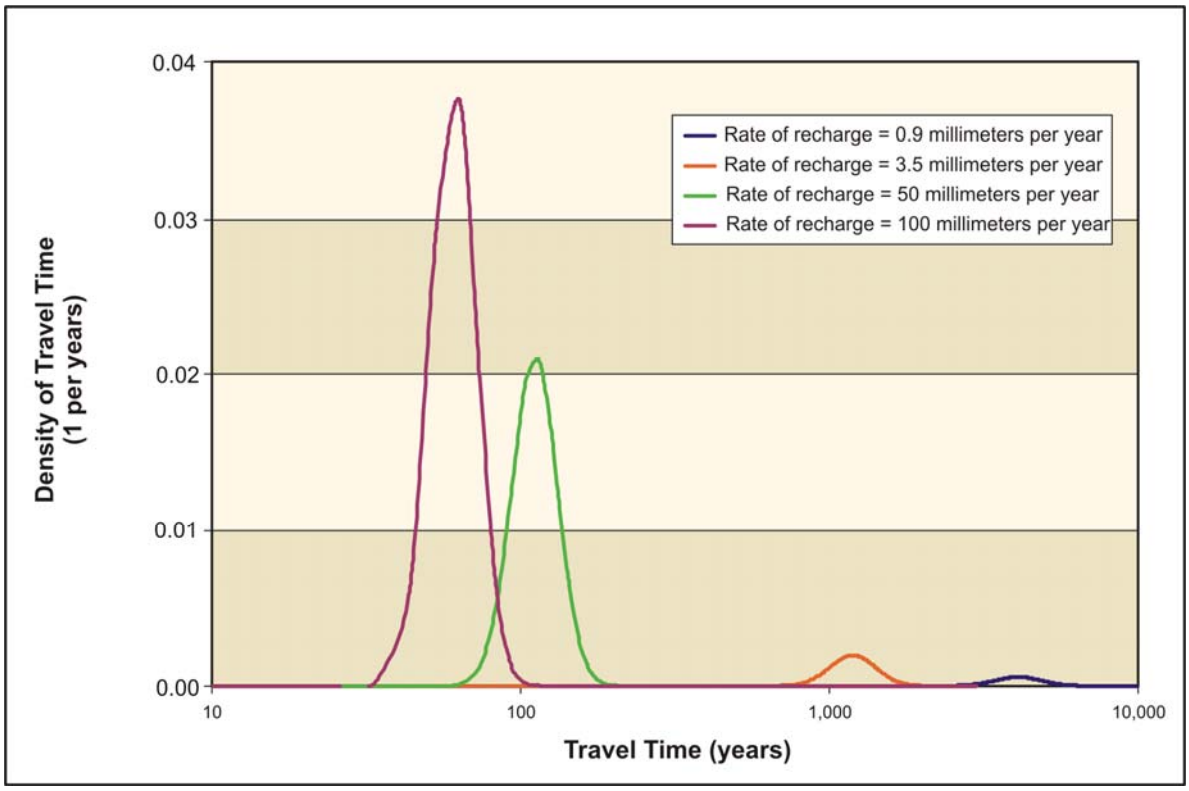


Figure N–137. Distribution of Travel Time in the Vadose Zone for the 200-East Area

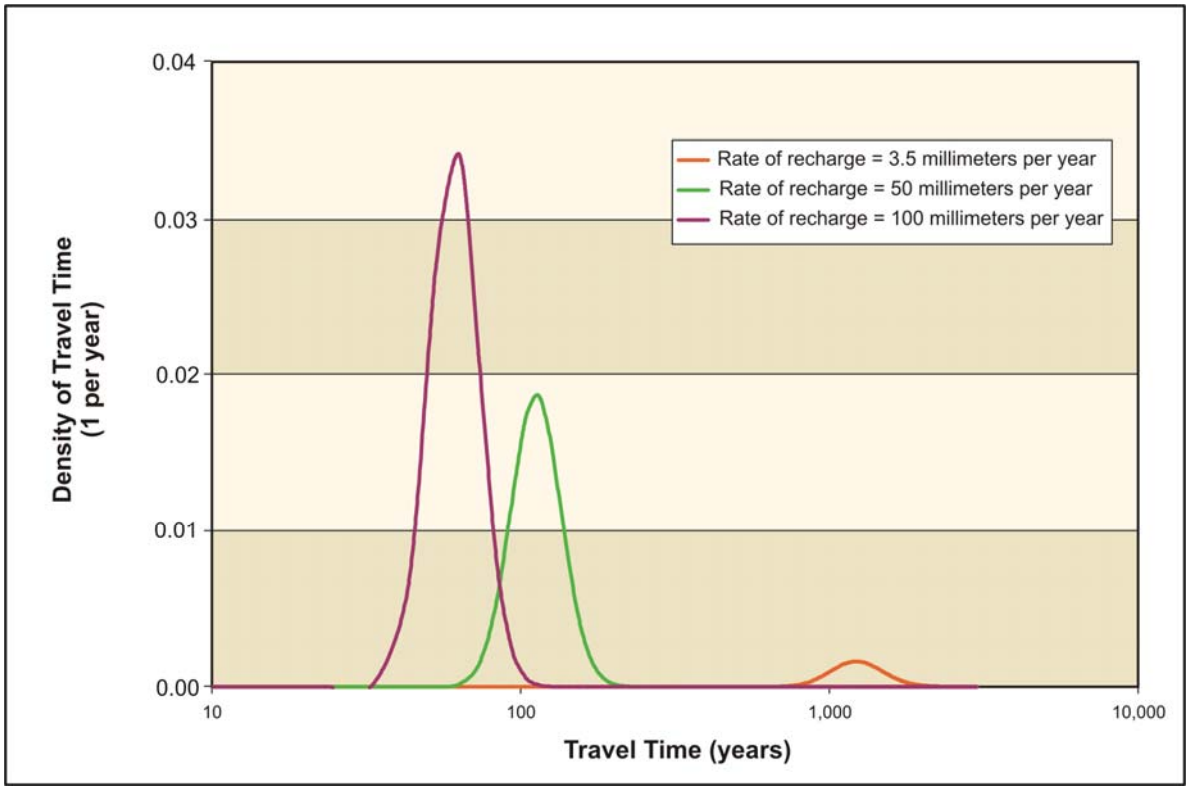


Figure N–138. Distribution of Travel Time in the Vadose Zone for the 200-West Area

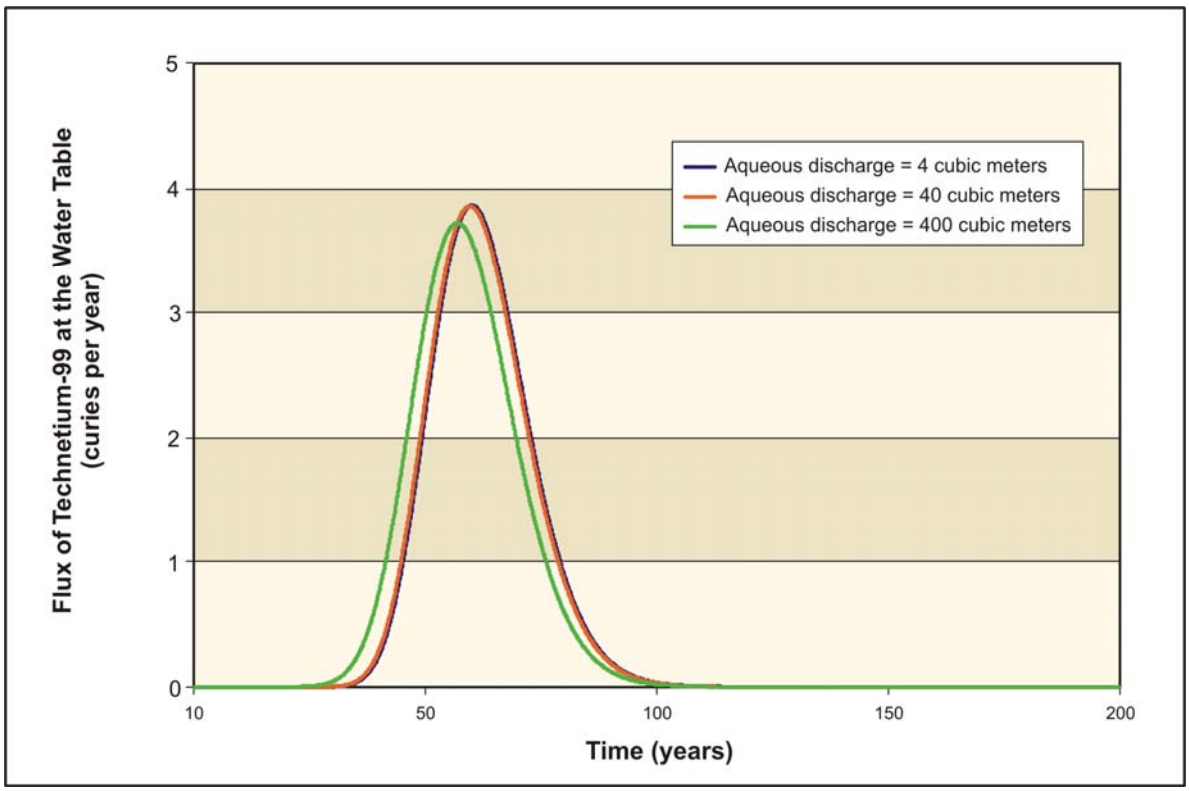


Figure N–139. Dependence of Flux of Solute at the Water Table on Magnitude of Aqueous Discharge

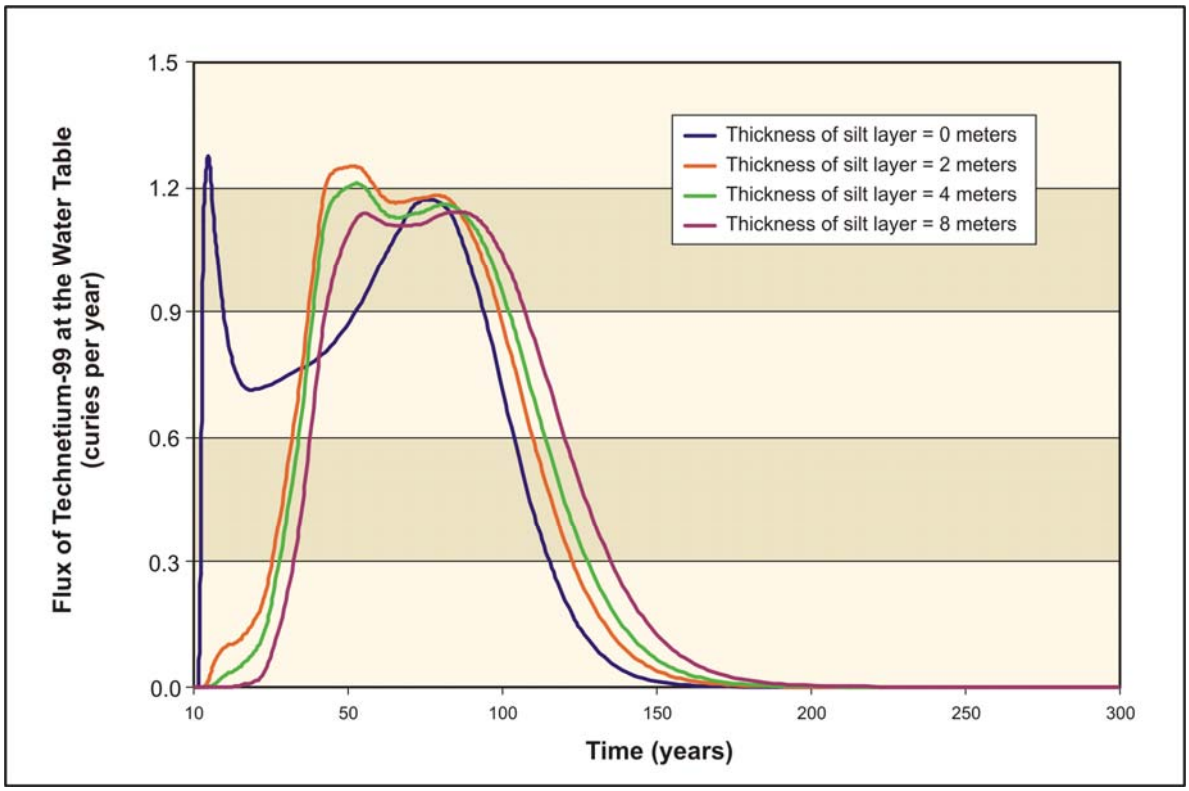


Figure N–140. Dependence of Solute Flux on Thickness of a Silt Layer

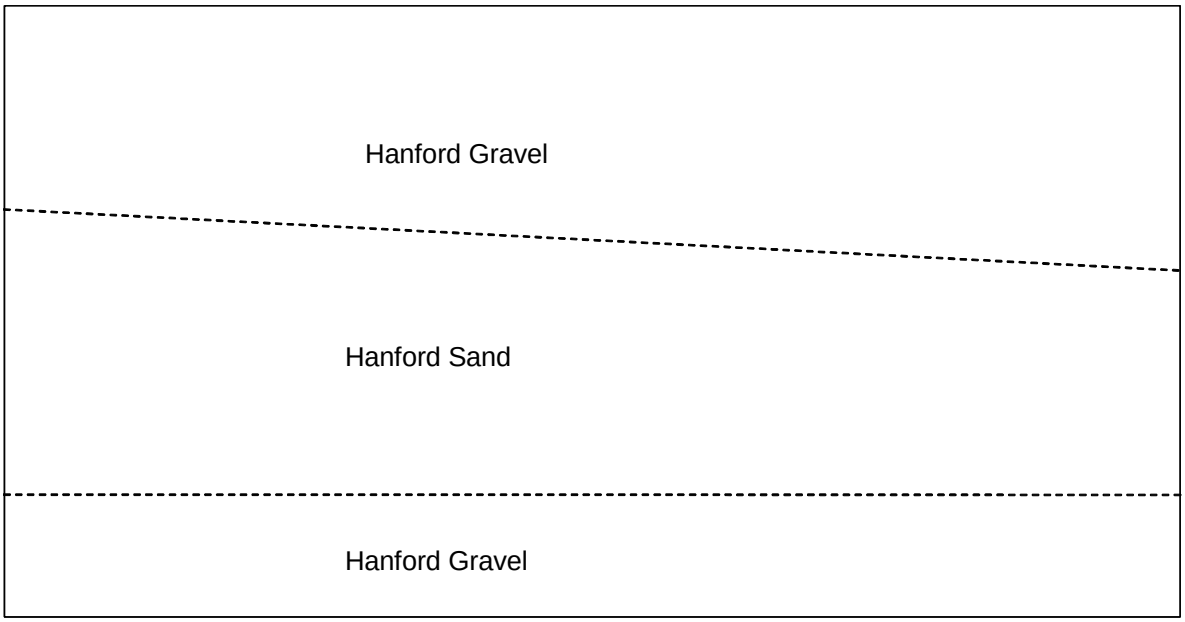


Figure N–141. Schematic of a Tilted Geologic Layer

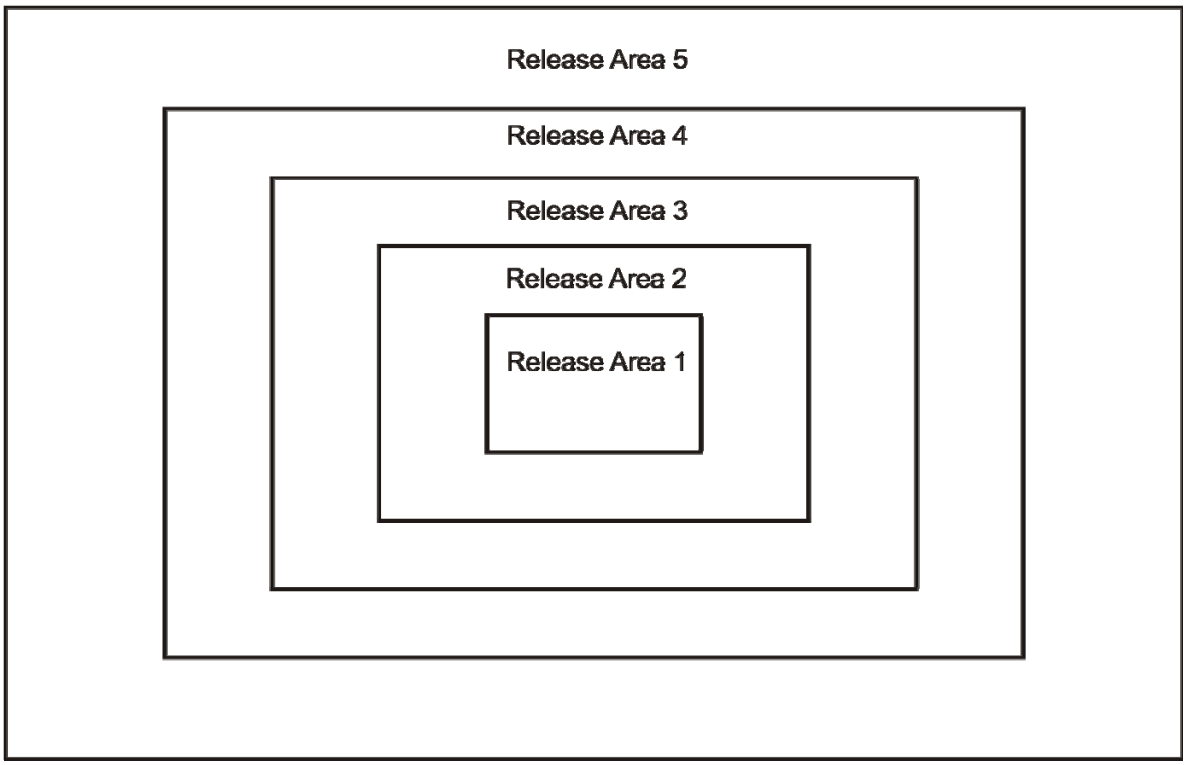


Figure N–142. Schematic of Configuration of Vadose Zone Release Areas at the Water Table, Upper Geologic Layer Tilted

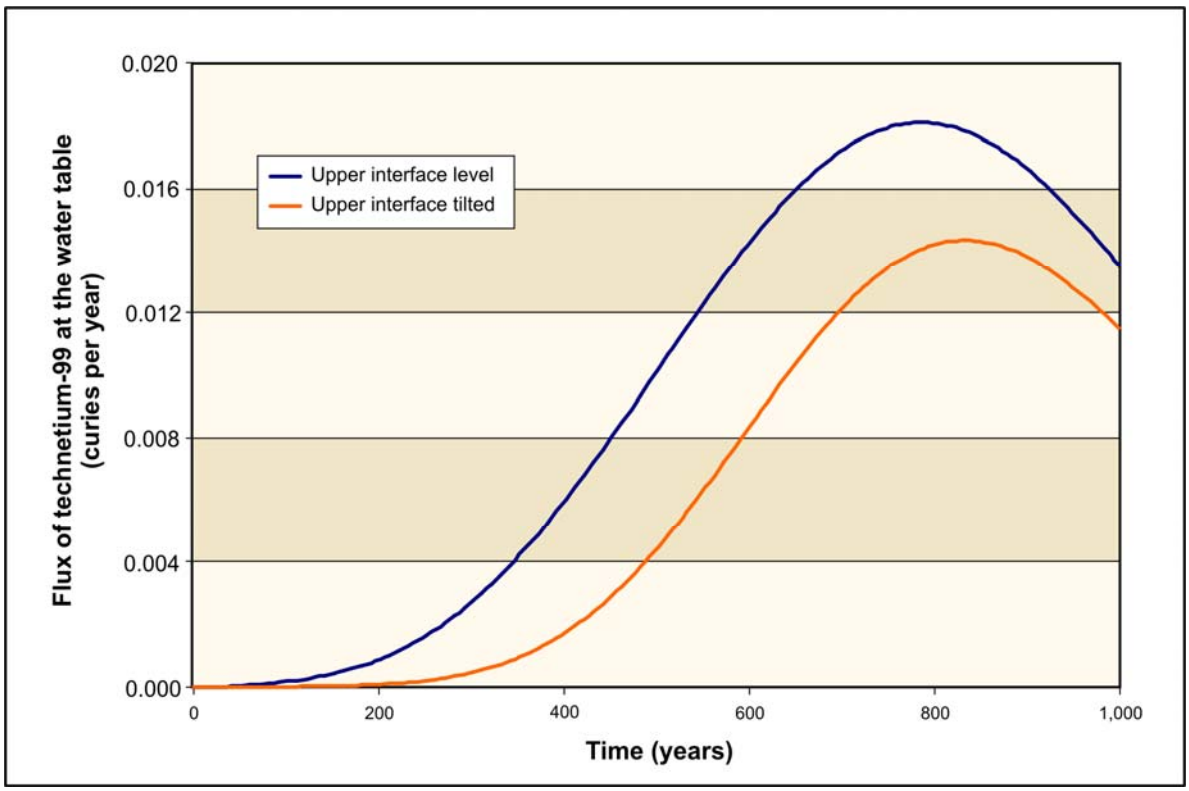


Figure N–143. Time Series of Solute Flux Immediately Below the Source, Upper Geologic Layer Tilted

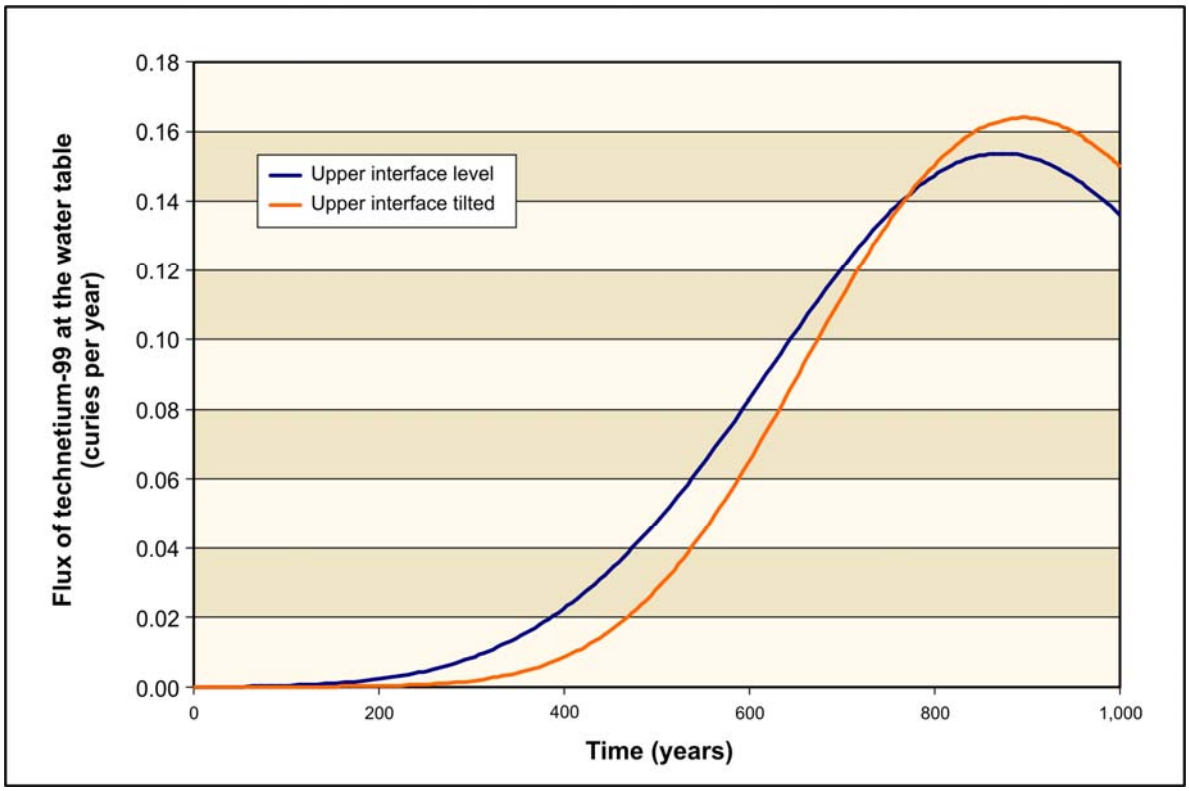


Figure N–144. Time Series of Solute Flux Below the Entire Study Area, Upper Geologic Layer Tilted

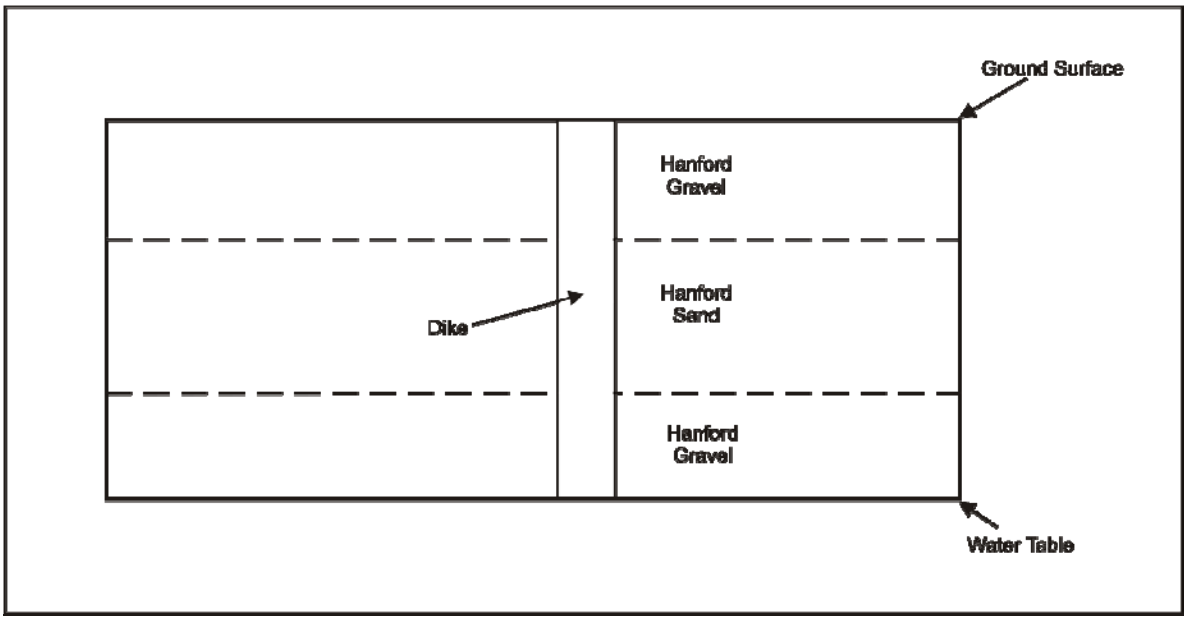


Figure N–145. Schematic of an Elevation View of the Vadose Zone with the Study Volume Intersected by a Dike

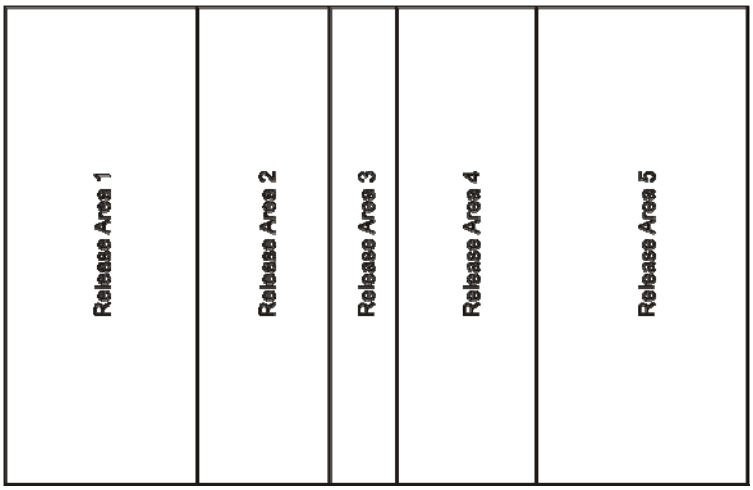


Figure N–146. Schematic of Plan View of Recharge Areas with Study Area Intersected by a Dike

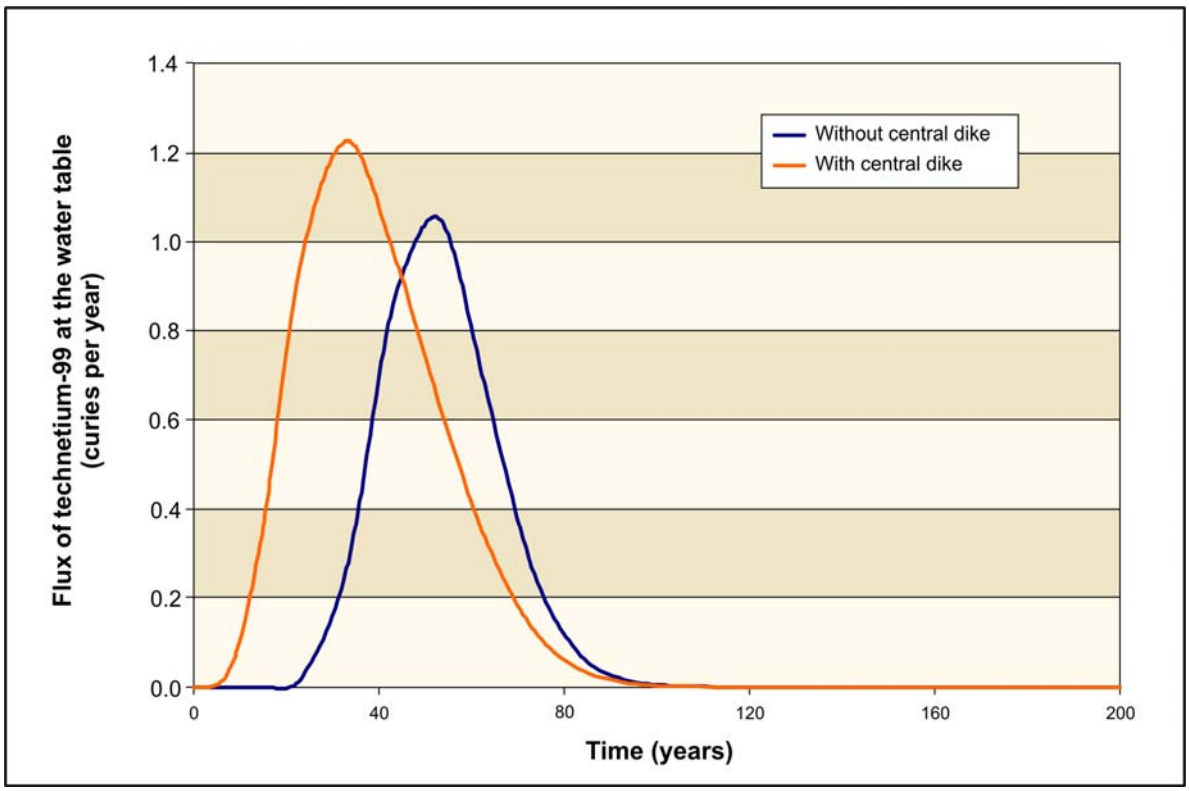


Figure N–147. Time Series of Solute Flux Immediately Below a Source Intersected by a Dike

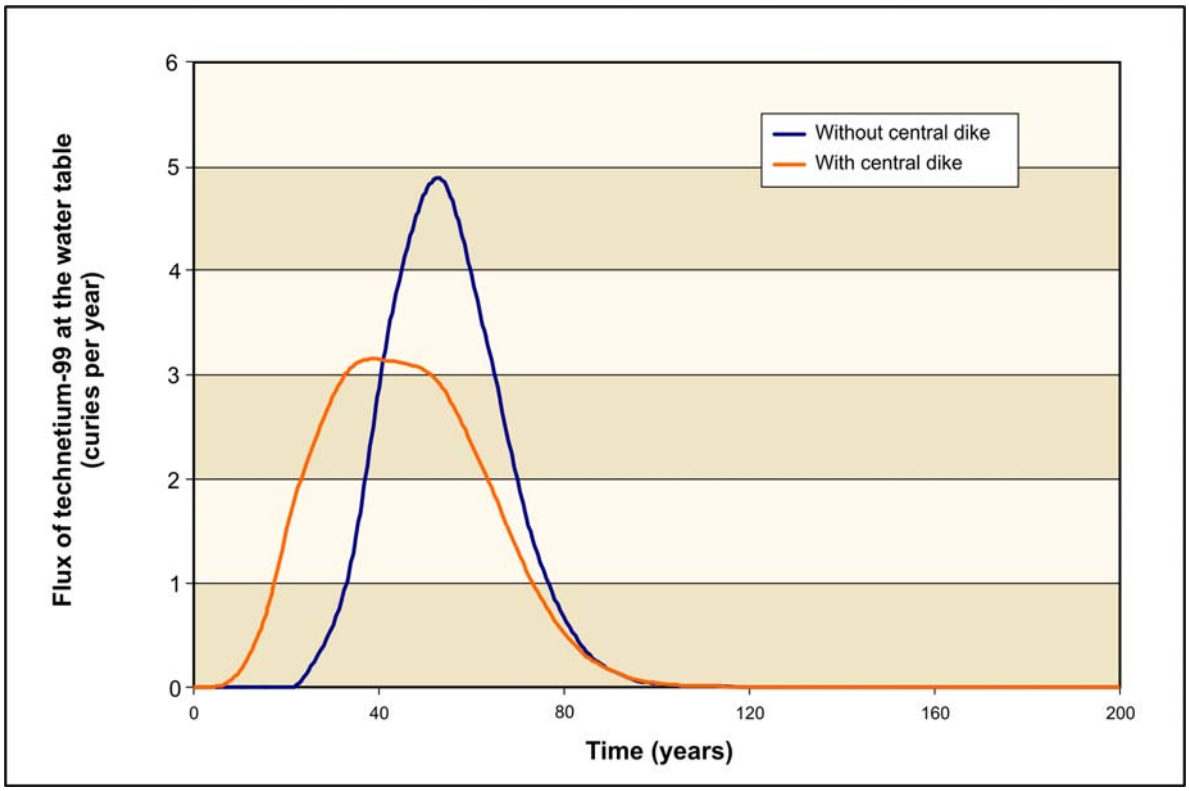


Figure N–148. Time Series of Solute Flux Below Entire Study Area with Source Intersected by a Dike

N.3.6 Rate of Release for a Sitewide Barrier

For engineered disposal facilities, the release rate of solutes from solid waste forms to the vadose zone and the subsequent movement of water and solutes through the vadose zone depend on the time series of the recharge rate through the barriers. As discussed above, the background recharge rate varies locally and is a function of several variables. This variability introduces uncertainty into estimates of impacts on groundwater quality. As recommended in guidance developed for this *TC & WM EIS* (DOE 2005), this section investigates the dependence of estimates of release rate on the magnitude of recharge. The rates of release of solute to the vadose zone and of solute fluxes to the unconfined aquifer were selected as measures of the sensitivity. Two sets of recharge conditions are considered, the first representative of sitewide conditions and the second representative of conditions at IDF-East in the southeast portion of the 200-East Area. Time series of rates of recharge for the sitewide and IDF-East barriers are presented as Table N–6. The following analysis investigates the dependence of rates of release at a location with a sitewide barrier and at a location with an IDF-East barrier on variation of the recharge through the barrier at each location.

Table N–6. Time Series of Rate of Recharge for Sitewide and Integrated Disposal Facility Conditions (millimeters per year)

Condition	*TC & WM EIS* Analysis Case	Sensitivity Case 1	Sensitivity Case 2
Sitewide Barrier			
Background	3.5	3.5	5.0
Design life	0.5	0.5	1.0
Post–design life	3.5	1.0	5.0
200-East Area Integrated Disposal Facility Barrier			
Background	0.9	3.5	5.0
Design life	0.5	0.5	0.9
Post–design life	0.9	0.9	5.0

Key: *TC & WM EIS=Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington.*

Waste volumes and inventories selected for the analysis are those of Tank Closure Alternative 3C. For this case, soil and rubble disposed of at the RPPDF are a single source of material under a barrier experiencing sitewide background recharge conditions, and ETF secondary waste is a single source under a barrier experiencing IDF-East recharge conditions. For the purpose of analysis, nitrate in the soil and rubble at RPPDF and iodine-129 in the ETF secondary waste at IDF-East were selected as the constituents of interest. The release mechanism for the soil and rubble was partitioning-limited convective flow, while the release mechanism for the ETF secondary waste was waste form diffusion limited release coupled with vadose zone convection limited flows. For each of the cases, the site receives the background recharge rate prior to year 110 in the analysis, the engineered cap–reduced rate for the next 500 years, and the long-term rate after year 610. The geology was that of the 200-East Area, and thicknesses of the vadose zone at the RPPDF and IDF-East sites were 90 and 100 meters (295 and 328 feet), respectively. Values of hydraulic properties for the vadose zone used in this analysis were those identified in Appendix M.

The release rate of nitrate to the vadose zone and the nitrate flux at the water table for the RPPDF site and recharge conditions are presented in Figures N–149 and N–150, respectively. Results for the release to the vadose zone show the highest early release for the highest recharge rate (Sensitivity Case 2, 5 millimeters per year). Results for the *TC & WM EIS* Analysis Case and Sensitivity Case 1 show identical release to the vadose zone and recharge conditions prior to year 610, but they diverge after that time due to difference in recharge rate for the long-term period for these two cases. Results for the flux at the water table show an increase in time to peak dose with a decrease in long-term recharge rate, but nonlinear dependence of peak flux on recharge conditions. In general, for a comparison between alternatives with a partitioning-limited convective flow release mechanism, rates of release and related human health impacts would vary in approximate relation to variation in recharge data.

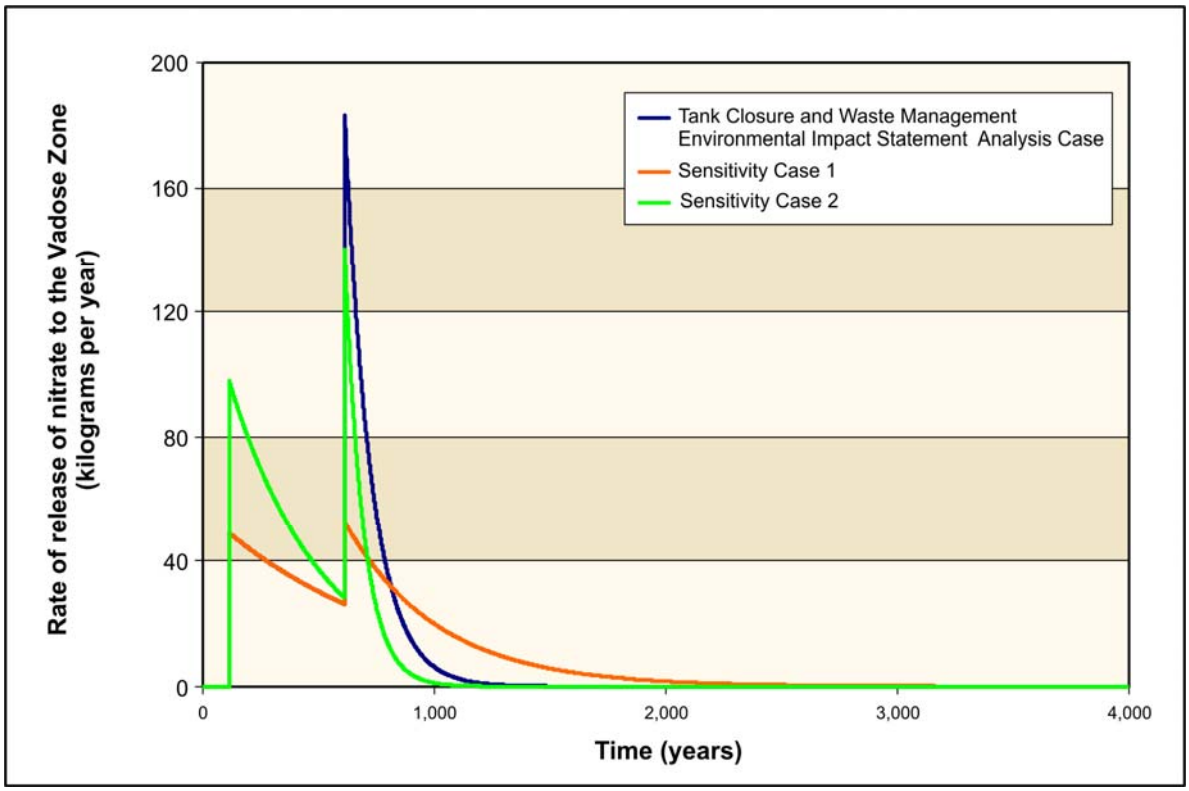


Figure N–149. Rate of Release of Nitrate to the Vadose Zone for River Protection Project Disposal Facility Barrier Conditions

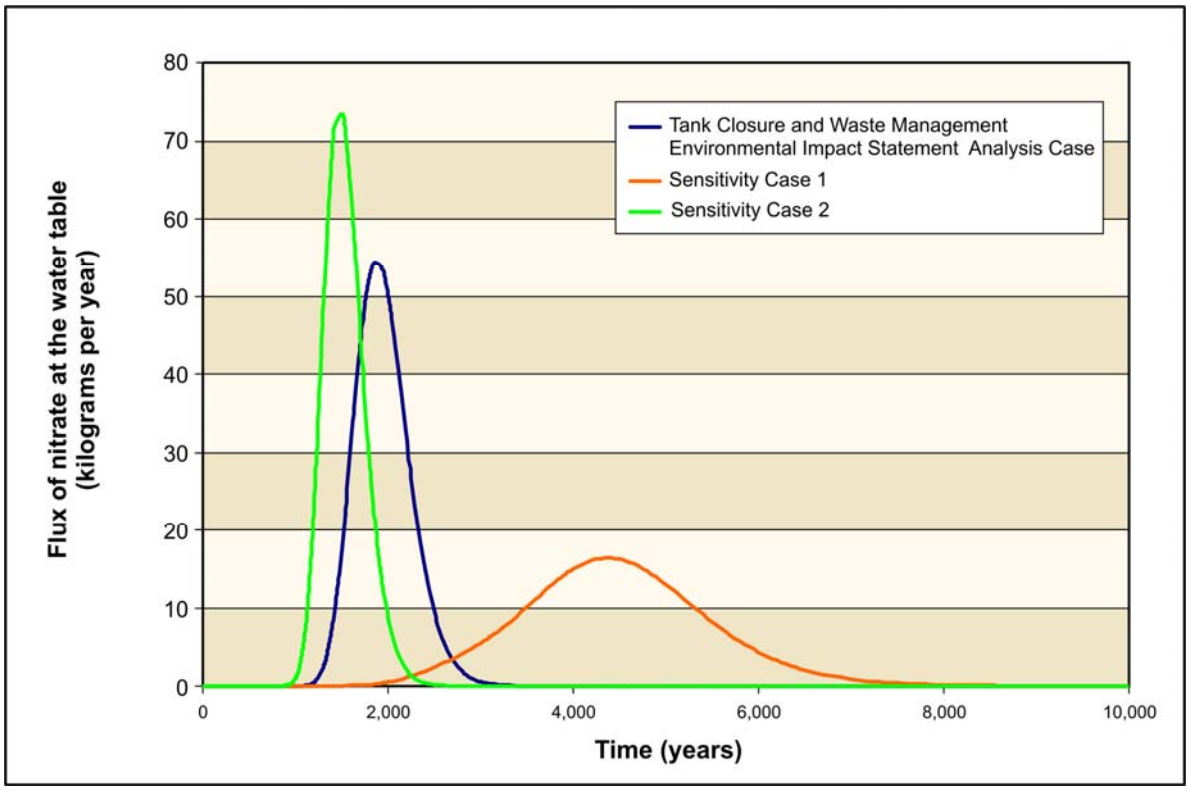


Figure N–150. Flux of Nitrate at the Water Table Zone for River Protection Project Disposal Facility Barrier Conditions

The release rate of iodine-129 to the vadose zone and the iodine-129 flux at the water table for the IDF-East site and recharge conditions are presented in Figures N–151 and N–152, respectively. Results for release to the vadose zone show that the release rate from the waste package by diffusion is rapid relative to the convective flow, proportional to the recharge rate, and nearly constant at a given rate of recharge. Results for the *TC & WM EIS* Analysis Case and Sensitivity Case 1 show identical recharge conditions after initiation of the release and nearly identical results. Results for the flux at the water table also show a flux that is proportional to the recharge rate. Sensitivity Case 2 shows a greater difference between the cap design–limited recharge rate and the long-term recharge rate than the *TC & WM EIS* Analysis Case, a circumstance reflected in the transient behavior of the flux at the water table.

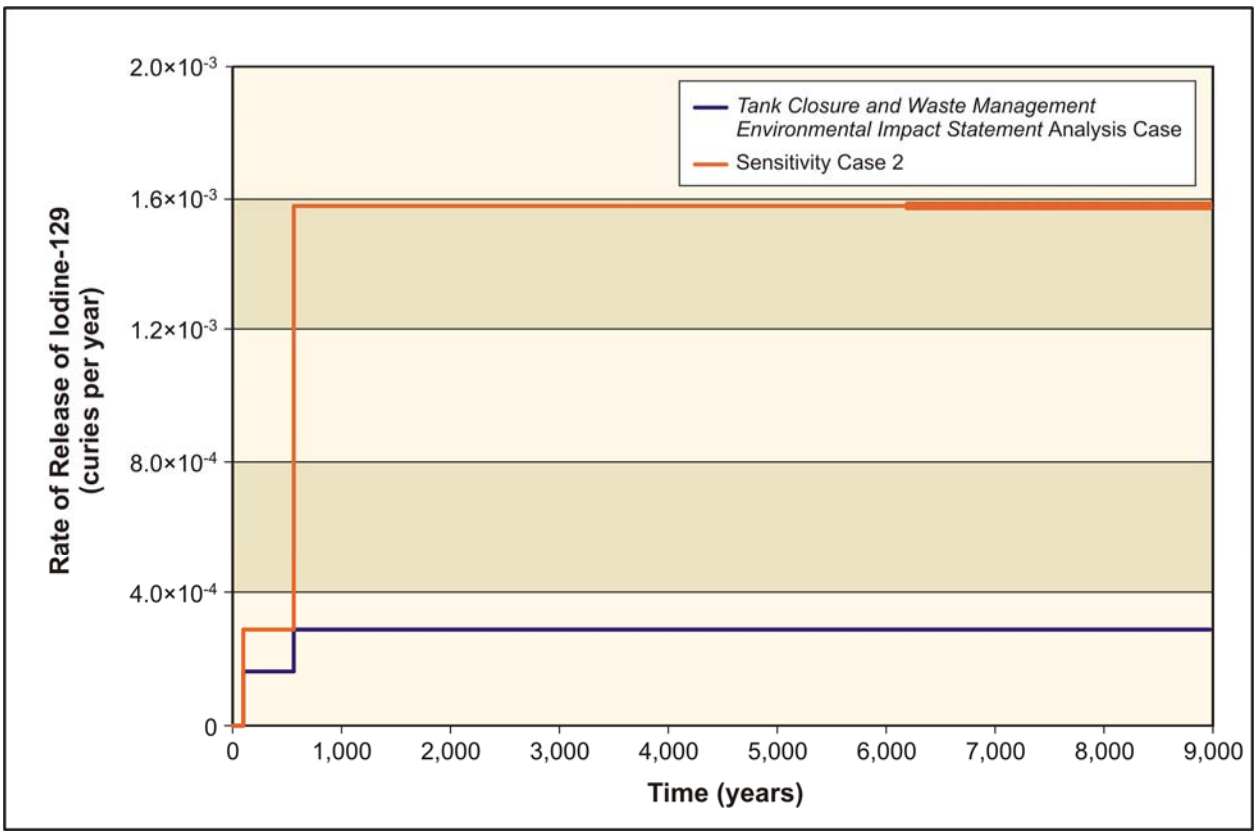


Figure N–151. Rate of Release of Iodine-129 to the Vadose Zone for 200-East Area Integrated Disposal Facility Conditions

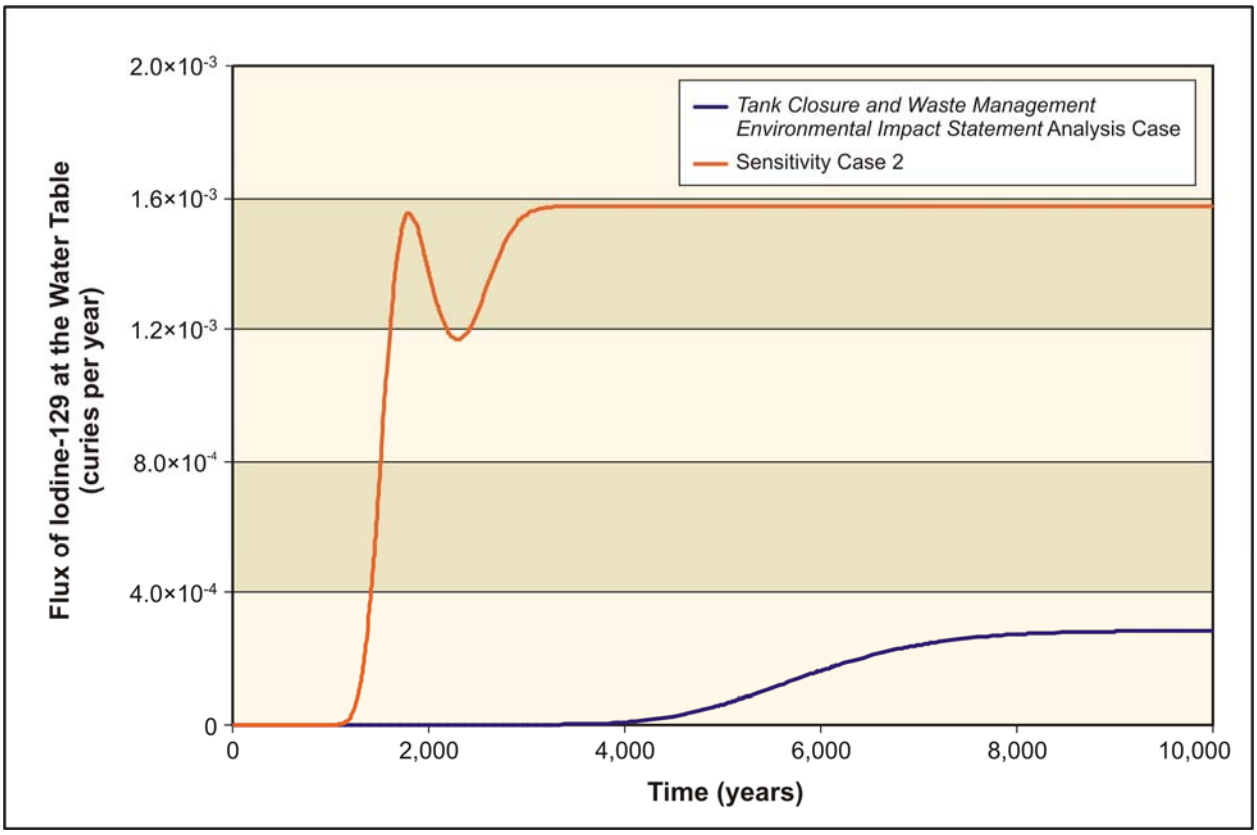


Figure N–152. Flux of Iodine-129 at the Water Table for Integrated Disposal Facility Conditions

N.3.7 Distribution Coefficient and Flux at the Water Table

The rate of movement of solutes through the vadose zone depends on the degree of interaction between the species of the solute in the groundwater and adsorption sites on the surfaces of sediments in the vadose zone. In analysis performed for this *TC & WM EIS*, this interaction is represented as having a linear relation between solute concentration in the groundwater and solute concentration in the solid phase. The constant that expresses the strength of the interaction is termed the distribution coefficient of the solute. As recommended in guidance for this *TC & WM EIS* (DOE 2005), this section evaluates the dependence of estimates of the flux of iodine-129 at the water table on the magnitude of the distribution coefficient of iodine. Two recommended values of the distribution coefficient, 0 and 0.2 milliliters per gram, were adopted for this analysis (DOE 2005) consistent with the variability in this parameter observed in site-specific measurements (Cantrell, Serne, and Last 2003). This variation is selected to reflect the uncertainty in transport rate that derives from spatial variability in soil type and degree of solute-soil interaction as well as lack of knowledge of the mechanism of interaction. Other conditions adopted for this analysis are the same as those described in Section N.3.6 for release from ETF secondary waste at the IDF-East. Results of the analysis, the flux of iodine-129 at the water table for two values of the distribution coefficient of iodine, are presented in Figure N–153. These results show that interaction with the solid delays the arrival of iodine-129 at the water table but does not reduce the peak flux predicted to reach the water table.

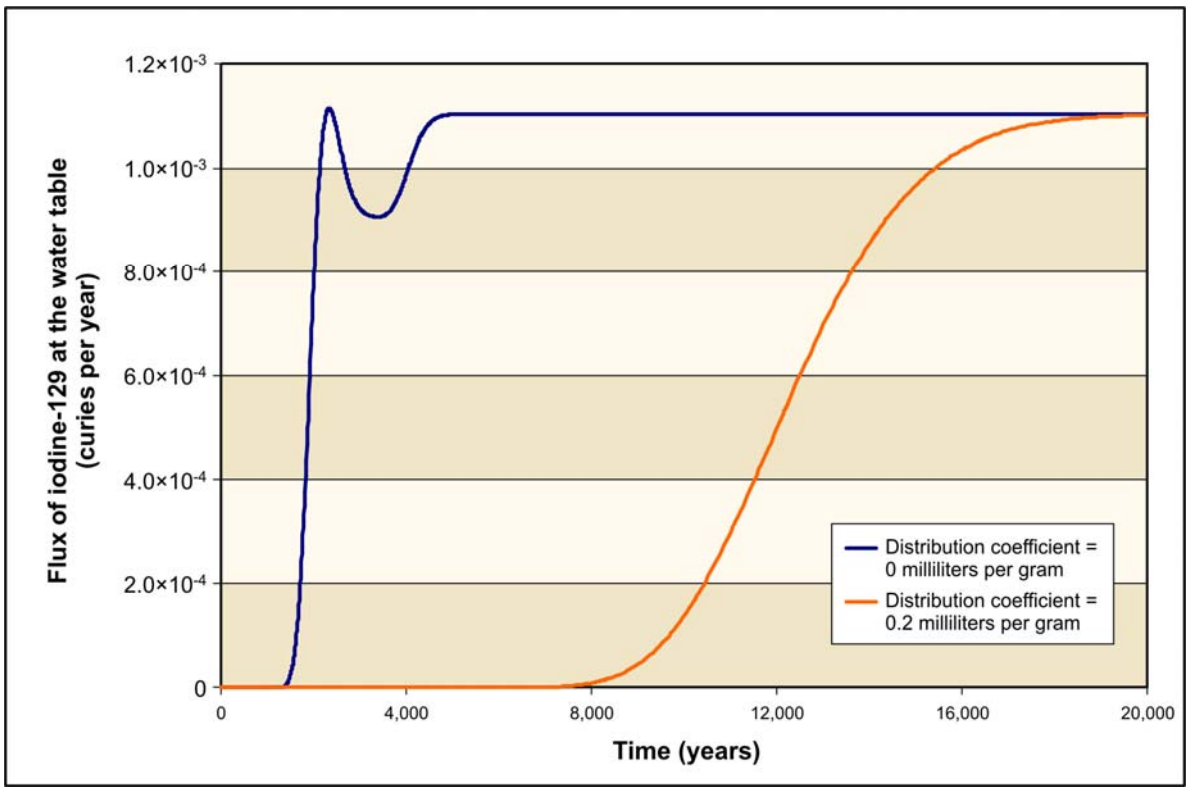


Figure N–153. Dependence of Flux of Iodine-129 at the Water Table on Magnitude of Distribution Coefficient

N.3.8 Retention of Iodine in Immobilized Low-Activity Waste Glass

Waste retrieved from the tank farms would be processed through the Waste Treatment Plant (WTP) for incorporation into a set of candidate waste forms. Among this retrieved waste is approximately 48 curies of iodine-129 that could be distributed across glass, grout, or steam reforming solid waste forms. The distribution among the waste forms varies with tank closure alternative and potentially with the operational design of the WTP. The sensitivity analysis presented in this section investigates an option for operation of the WTP that distributes the iodine inventory between the ILAW glass and a grout waste form. The conditions of Tank Closure Alternative 2B were adopted for this analysis. In this alternative, the primary waste form is ILAW glass and secondary waste is encapsulated in grout. In particular, iodine-129 volatilized in the production of ILAW glass is processed through the ETF and captured in ETF secondary waste, a grout waste form. In the base case analyzed in this *TC & WM EIS*, 20 percent of the iodine entering the ILAW melter is assumed to be retained in the ILAW glass, and the remaining 80 percent is captured in ETF secondary waste. Under an alternative processing option, process streams around the ILAW melter could be recycled to increase the portion of iodine entering the vitrification process that would be retained in the ILAW glass waste form. For this analysis, it is assumed that WTP operational conditions could be such that 70 percent of the iodine-129 entering the vitrification process would be retained in the ILAW glass and the remaining 30 percent captured in ETF secondary waste. A primary objective of the analysis is determination of the sensitivity of flux of iodine-139 at the water table to the retention rate in the glass with potential application to comparison of alternatives with differing supplemental waste forms.

The measure of effectiveness of the iodine-129 distribution among the waste forms is the flux of iodine-129 reaching the water table. Under Tank Closure Alternative 2B, the ILAW glass and ETF secondary waste would be disposed of in IDF-East. Thus, release models described in Appendix M, that is, fractional release for ILAW glass and diffusion-limited release for ETF secondary waste, would be

used in conjunction with the STOMP vadose zone transport model to estimate the flux at the water table. The vadose zone geology is primarily layered Hanford Gravel, Hanford Sand, and Ringold Gravel, and the background recharge rate is 0.9 millimeters per year.

For the case involving 20 percent partition to ILAW glass, 9.6 curies of iodine-129 would be present in ILAW glass and 33.6 curies in ETF secondary waste. The estimated fluxes of iodine-129 at the water table for the two waste forms for this case are presented as Figure N–154. Cumulative fluxes over the 10,000-year period of analysis are 0.001 and 1.08 for the ILAW glass and ETF secondary waste forms, respectively.

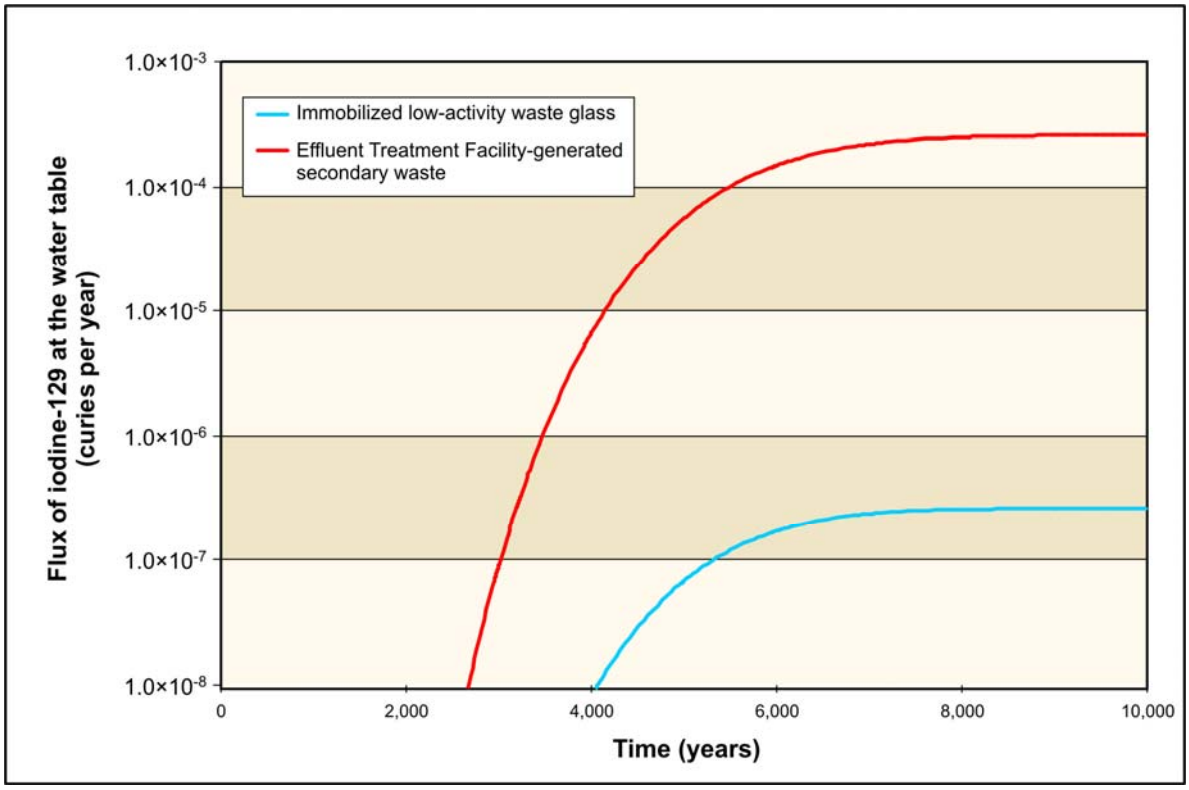


Figure N–154. Fluxes of Iodine-129 at the Water Table for Two Waste Forms for the 20 Percent Partition to Immobilized Low-Activity Waste Glass Case

For the case involving 70 percent partition to ILAW glass, 33.5 curies of iodine-129 would be present in ILAW glass and 12.6 curies in ETF secondary waste. The estimated fluxes of iodine-129 at the water table for the two waste forms for this case are presented as Figure N–155. Cumulative fluxes over the 10,000-year period of analysis are 0.004 and 0.41 for the ILAW glass and ETF secondary waste forms, respectively. The estimated fluxes of iodine-129 at the water table for the cases of 20 and 70 percent partition to ILAW glass are presented as Figure N–156. The results indicate that increasing the portion of the iodine in the ILAW glass from 20 to 70 percent could lead to a reduction in the flux of iodine-129 at the water table by a factor between two and three. The results indicate that implementation of increased retention of iodine-129 in ILAW glass would improve the performance of such an alternative in comparison with alternatives having supplemental waste forms that could not benefit from an equivalent change in process design.

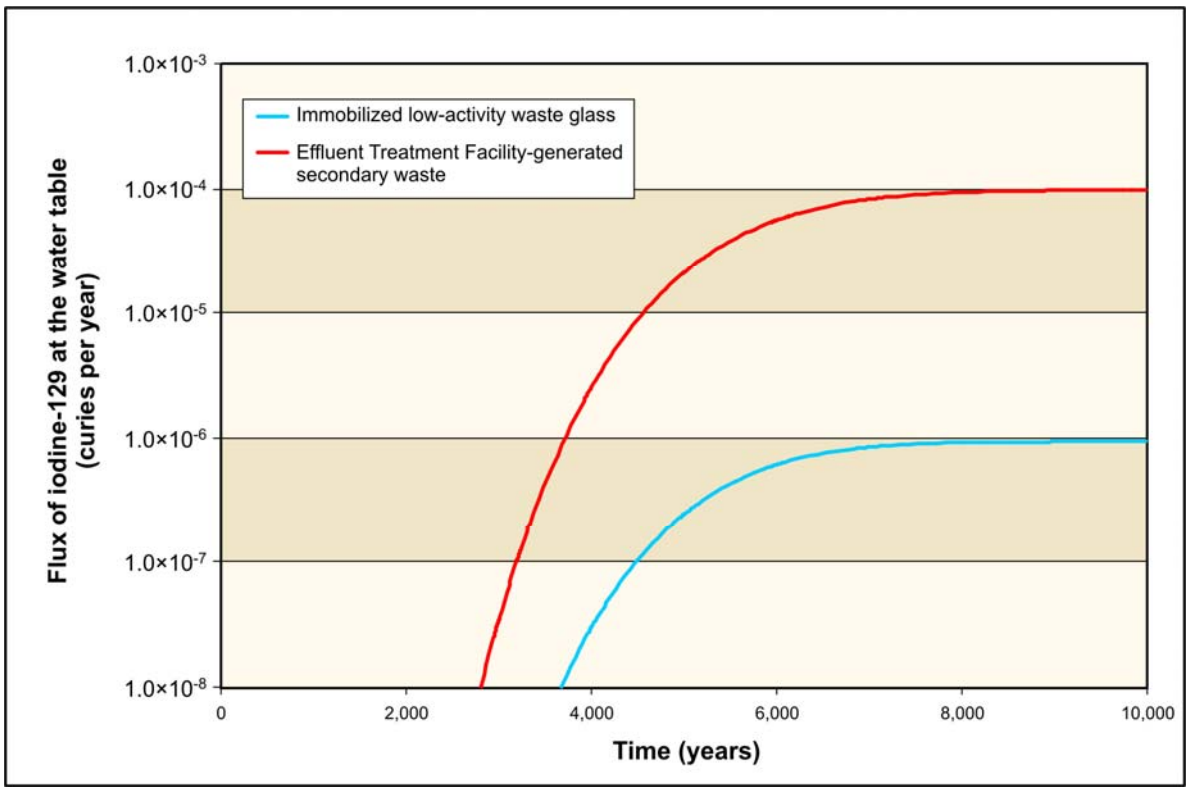


Figure N–155. Fluxes of Iodine-129 at the Water Table for Two Waste Forms for the 70 Percent Partition to Immobilized Low-Activity Waste Glass Case

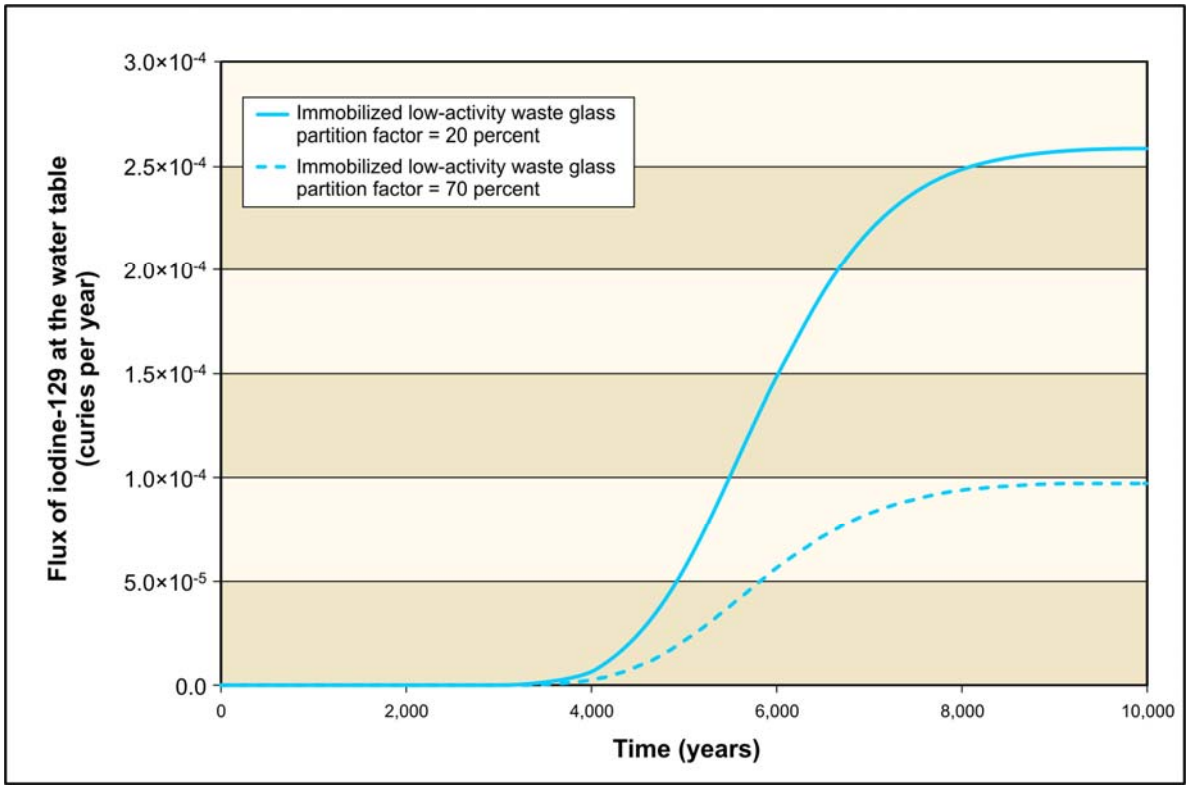


Figure N–156. Fluxes of Iodine-129 at the Water Table for the 20 Percent and 70 Percent Partition to Immobilized Low-Activity Waste Glass Cases

N.4 REFERENCES

Cantrell, K.J., R.J. Serne, and G.V. Last, 2003, *Hanford Contaminant Distribution Coefficient Database and User's Guide*, PNNL-13895, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington, June.

DOE (U.S. Department of Energy), 2005, *Technical Guidance Document for Tank Closure Environmental Impact Statement, Vadose and Groundwater Revised Analyses*, Final Rev. 0, Office of River Protection, Richland, Washington, March 25.

Fayer, M.J., and T.B. Walters, 1995, *Estimated Recharge Rates at the Hanford Site*, PNL-10285, Pacific Northwest Laboratory, Richland, Washington, February.

Hanlon, B.M., 2003, *Waste Tank Summary Report for Month Ending August 31, 2003*, HNF-EP-0182, Rev. 185, CH2M HILL Hanford Group, Inc., Richland, Washington, October.

Hartman, M.J., L.F. Morasch, and W.D. Webber, eds., 2004, *Hanford Site Groundwater Monitoring for Fiscal Year 2003*, PNNL-14548, Pacific Northwest National Laboratory, Richland, Washington, March.

Hartman, M.J., L.F. Morasch, and W.D. Webber, eds., 2006, *Hanford Site Groundwater Monitoring for Fiscal Year 2005*, PNNL-15670, Pacific Northwest National Laboratory, Richland, Washington, March.

Hartman, M.J., and W.D. Webber, eds., 2008, *Hanford Site Groundwater Monitoring for Fiscal Year 2007*, DOE/RL-2008-01, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington, March.

Mualem, Y., 1976, "A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Media," *Water Resources Research*, Vol. 12, pp. 513–522.

Murray, C., A. Ward, and J. Wilson, 2003, *Influence of Clastic Dikes on Vertical Migration of Contaminants in the Vadose Zone at Hanford*, PNNL-14224, Pacific Northwest National Laboratory, Richland, Washington, March.

Van Genuchten, M. Th., 1980, "A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils," *Soil Science Society of America Journal*, Vol. 44, pp. 892–898.

White, M.D., and M. Oostrom, 2000, *STOMP Subsurface Transport Over Multiple Phases, Version 2.0: Theory Guide*, PNNL-12030, Pacific Northwest National Laboratory, Richland, Washington, March.

White, M.D., and M. Oostrom, 2006, *STOMP Subsurface Transport Over Multiple Phases, Version 4.0: User's Guide*, PNNL-15782, Pacific Northwest National Laboratory, Richland, Washington, June.

U.S. Department of Energy Guide

DOE Guide 435.1-1, *Implementation Guide for Use with DOE M 435.1-1*, July 9, 1999.