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Engineering Design File

Groundwater Pathway Risk Assessment for the Engineering Test Reactor Complex Closure

Idaho Cleanup Project

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ENGINEERING DESIGN FILE

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This Engineering Design File documents a screening-level evaluation of contaminated materials in the Engineering Test Reactor (ETR) basements. The evaluation was completed in support of the Environmental Assessment report required for the decommissioning of the ETR.

The ETR operated from 1957 until 1981 at the Reactor Technology Complex, formerly the Test Reactor Area. At the time it entered service, it was the largest, most advanced nuclear fuels and materials test reactor in the United States at 175 MWth.

Based on this streamlined risk assessment, filling the ETR reactor vessel and all belowgrade structures with soil while leaving all current source inventories in place results in predicted groundwater concentrations that meet the required performance criteria by at least a factor of 6 (chromium) for nonradionuclides and 60 (C-14) for radionuclides. For other contaminants of concern, the performance criteria are met by at least several orders of magnitude. For groundwater, the performance criteria are to prevent migration of contaminants from the ETR facility that would cause the Snake River Plain Aquifer to exceed a cumulative carcinogenic risk level of 1×10^{-4} or applicable State of Idaho groundwater quality standards in 2095 and beyond. As discussed in the report, this analysis is conservative.

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ACRONYMS

AGS	annular gas system
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
COC	contaminant of concern
CWI	CH2M-WG Idaho, LLC
DCF	dose conversion factor
DOE	U.S. Department of Energy
EDE	effective dose equivalent
EDF	Engineering Design File
EPA	Environmental Protection Agency
ESRP	Eastern Snake River Plain
ETR	Engineering Test Reactor
GEEL	General Electric Experimental Loop
ICDF	Idaho CERCLA Disposal Facility
ICRP	International Commission on Radiological Protection
INL	Idaho National Laboratory
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MCP	management control procedure
MEPAS	Multimedia Environmental Pollutant Assessment System
MWd	megawatt-day
MWth	megawatt-thermal
NCRP	National Council on Radiation Protection
PCS	primary cooling system
PRG	preliminary remediation goal

RI	remedial investigation
RTC	Reactor Technology Complex
SRPA	Snake River Plain Aquifer
SS	stainless steel
TLD	thermoluminescent detector
TRA	Test Reactor Area

Groundwater Pathway Risk Assessment for the Engineering Test Reactor Complex Closure

1. INTRODUCTION

The Idaho National Laboratory (INL) is a U.S. Department of Energy (DOE) facility located 52 km (32 mi) west of Idaho Falls, Idaho. It occupies 2,305 km^2 (890 mi^2) of the northeastern portion of the Eastern Idaho Snake River Plain. The Engineering Test Reactor (ETR) building at the INL Site and associated buildings are no longer used and will be decommissioned. The ETR is located at the Reactor Technology Complex (RTC), formerly the Test Reactor Area (TRA), which is located in the south-central portion of the INL Site (see Figure 1). The evaluations presented in this report were done to support the final closure of the ETR Complex.

1.1 Engineering Test Reactor Site Description

The ETR operated from 1957 until 1981 at the RTC. At the time it entered service, it was the largest, most advanced nuclear fuels and materials test reactor in the United States at 175 MWth. After initial testing of the reactor, full power operation was achieved in 1958. From then through 1972, the ETR produced approximately 487,728 MWd. In 1972, a decision was made to have the ETR support the DOE's breeder reactor safety program. Conversion of the reactor for this purpose started in May 1973. The new assignment focused on safety programs relating to reactor fuel, core design, and operation for the liquid metal fast breeder reactor program. In December 1981, deactivation began, which included removing the neutron source and all fuel from the reactor, draining the primary cooling system (PCS) (and all other liquid systems in the facility), preparing all major equipment for long-term storage, and performing characterization of the entire ETR facility.

Details regarding the ETR facilities and the characterization of the contamination in the facilities are described in a series of Engineering Design Files (EDFs). The EDFs address characterization of the ETR building (TRA-642), together with the compressor building (TRA-643) and the heat exchanger building (TRA-644), in anticipation of facility decommissioning. The locations of TRA-642, TRA-643, and TRA-644 are shown in Figure 2. The characterization information was documented in a series of EDFs that are described in Sections 2.1 and 2.2. For purposes of this EDF, the ETR Complex includes the following buildings and structures:

1. TRA-642 is the ETR reactor building. It is a steel-framed building with a main floor and two subgrade floors. The building measures 136 × 112 ft and extends 58 ft above grade and 38 ft below grade. As shown in Figure 3, the reactor building houses the multidiameter reactor vessel along with the canal, subpile room, control rod access room, console floor, and experiment cubicles in the basement.

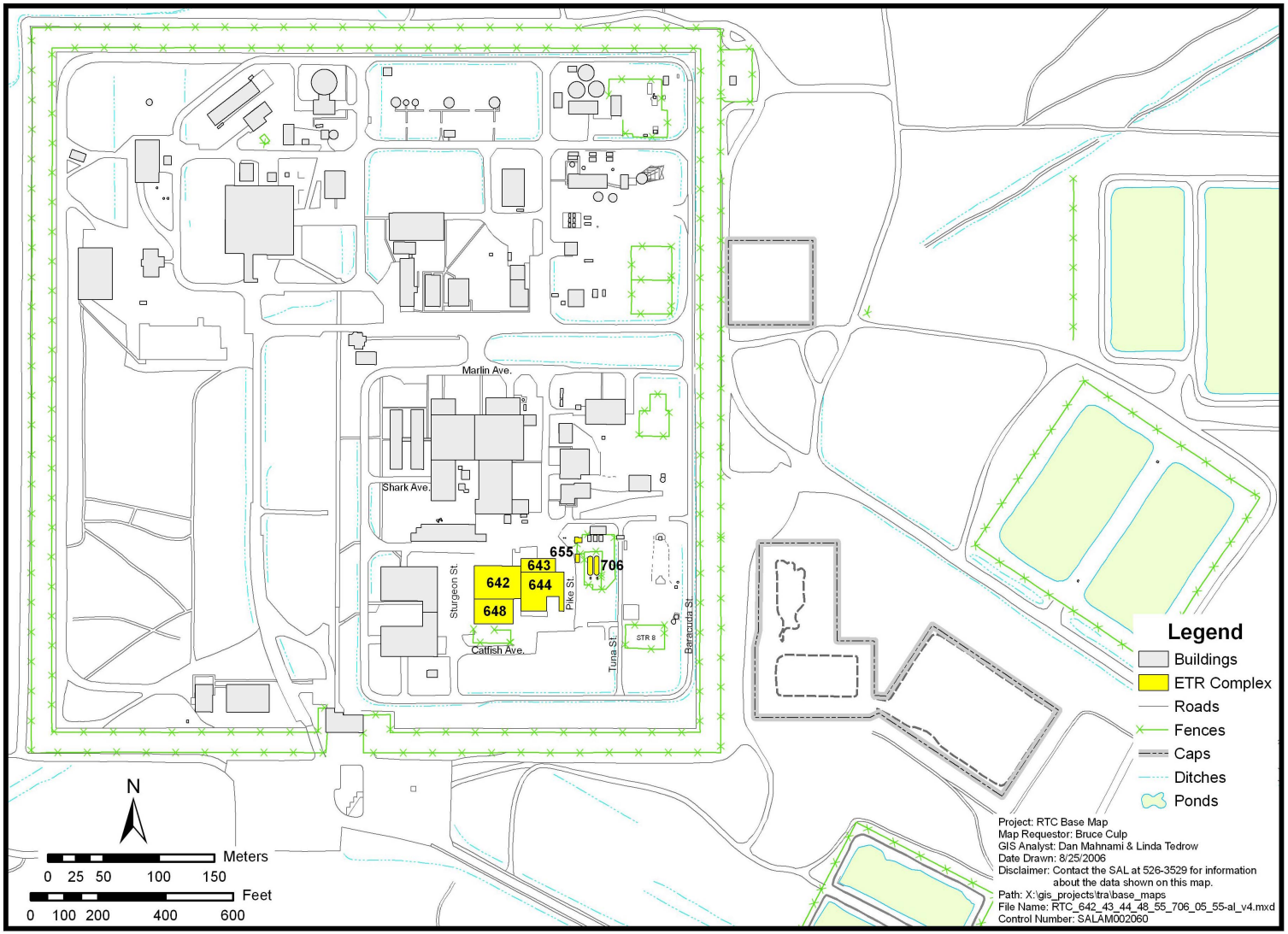

Figure 1. Map of the Idaho National Laboratory Site showing the location of the Engineering Test Reactor Complex and other facilities.

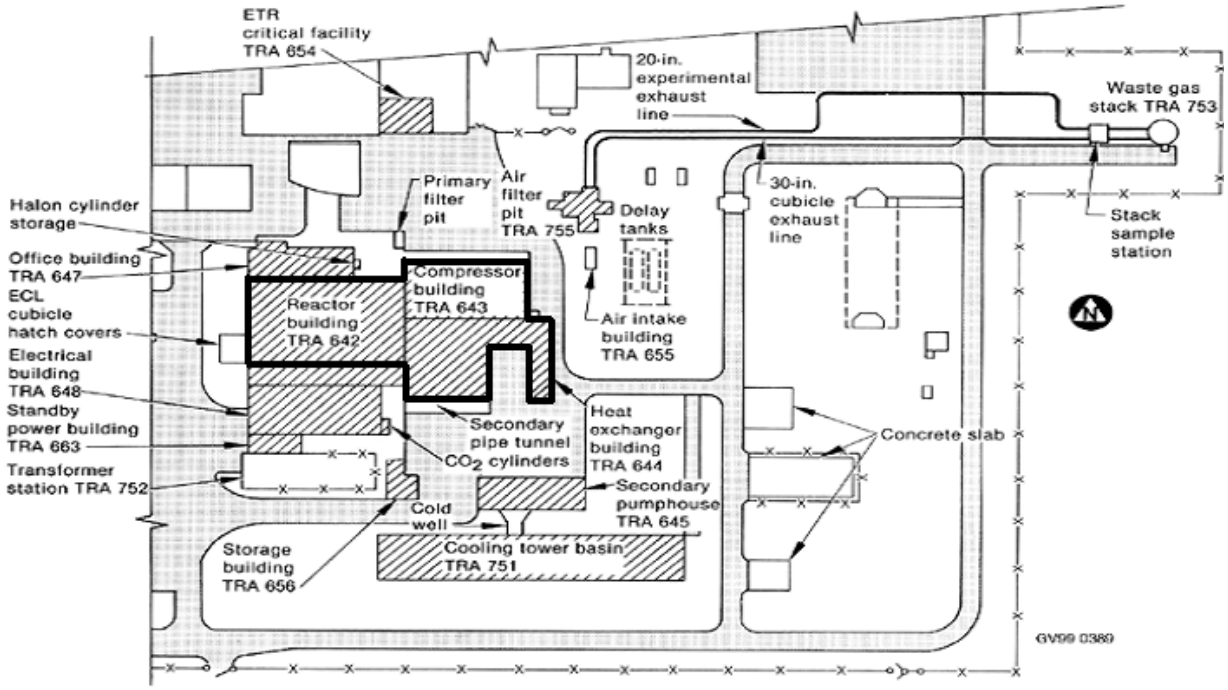

Figure 2. Relative locations in plan view of the TRA-642, TRA-643, and TRA-644 buildings.

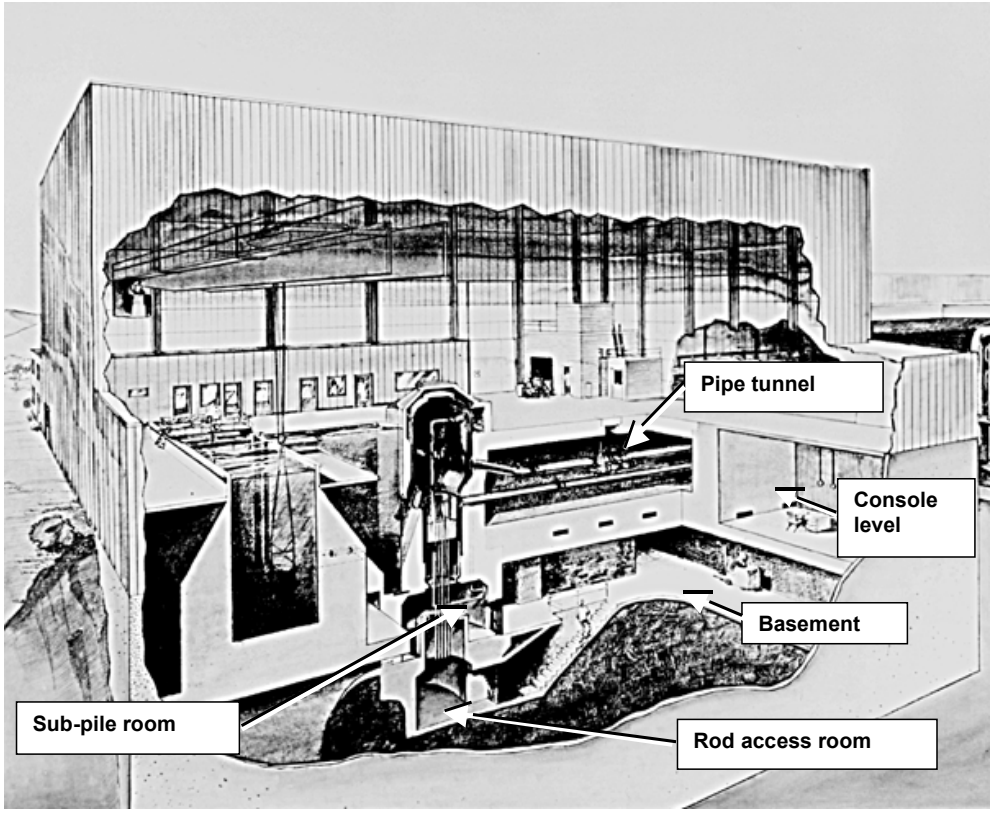

Figure 3. Rendering of the Engineering Test Reactor building configuration looking north.

2. TRA-643 is the ETR compressor building. It adjoins the reactor building along its east side. It measures 124 ft 8 in. from east to west and 108 ft north to south. The building is 30 ft 5 in. in height. The compressor building housed the equipment piping, air filtration units, and air-heating units used to supply large quantities of heated, hydrocarbon-free air to various experiments. The exterior walls consist of pumice block and metal panels above. In the building (Figure 4) is the process control room (at the east end) that was used to control all plant services to the reactor and the sample laboratory (on the south side) that was used to conduct chemistry samples on the reactor's primary and secondary coolant systems. A floor plan of the compressor building is shown in Figure 5. The storage area contained primarily experiment spare parts, handling tools, and lifting fixtures.

3. TRA-644 is the ETR heat exchanger building. It is located immediately south of the compressor building and includes 12 primary coolant/secondary coolant system heat exchangers and associated piping as well as a degassing tank room, cubicle exhaust booster blower room, demineralizer wing, and secondary pipe pit. The heat exchangers and associated piping have been drained. Figure 6 shows an artist's cutaway rendering of the heat exchanger building.

4. The TRA-648 ETR electrical building housed the major electrical equipment for the ETR facility, consisting of the 13.8-kV, 4,160-V, and 480-V switchgear; No. 1 emergency diesel generator; five motor generator units; and one lead-acid storage battery bank (removed). The building is a two-level structure consisting of the upper story and a basement level (referred to as the cable vault). The building, measuring 54 × 115 × 16.5 ft high, adjoins the reactor building along its north wall.

5. The TRA-704 ETR primary filter pit was constructed in 1960 as part of the General Electric Experimental Loop (GEEL) Loop 99 upgrade. The 8-in. Loop 99 exhaust line was connected to these two filters located inside the filter pit, which were operated in parallel.

6. The TRA-705 ETR secondary filter pit, constructed as part of the ETR GEEL Loop 99 upgrade, contains two polishing filters connected in parallel. The effluent piping from these polishing filters is connected to the filter plant exhaust line that was routed to the ETR stack. Both sets of polishing filters are equipped with 8-in. bypass lines. These filters have been removed.

7. The TRA-706 ETR delay tanks are two tanks operated in series that provided holding capacity for Loop 99 exhaust gas (originally installed in 1960 as part of the ETR GEEL Loop 99 modifications) to allow decay of radionuclides. The delay tanks have a capacity of 35,000 gal each and are 10 ft inside diameter by 60 ft in length. The tanks are fitted with five baffles spaced 10 ft apart to increase holding time of air in the tank. The east tank received effluent from the first (west) delay tank and discharged to the secondary filters (TRA-705).

8. The GEEL pipe tunnel begins beneath the reactor building's basement floor, runs under the annular gas system (AGS) cubicle, and terminates at the delay tanks. The GEEL system, designed as an integral part of the ETR, consisted of three in-pile tubes: Loop 33, Loop 66, and Loop 99. The loop exhaust lines are 4 in., 8 in., and 8 in. in diameter for Loops 33, 66, and 99, respectively. These pipes exit the subpile room through the northwest wall and enter the GEEL cubicle. The lines turn downward in the cubicle and enter the GEEL exhaust tunnel. These three pipes pass through the GEEL exhaust tunnel to the filter plant (TRA-755), located north-northwest of TRA-643. During the Loop 99 upgrade in 1960, a new 8-in. exhaust line was routed through a new tunnel to the primary filter vault (TRA-704), located north of the compressor building. The GEEL tunnel system was taken out of service in 1964.

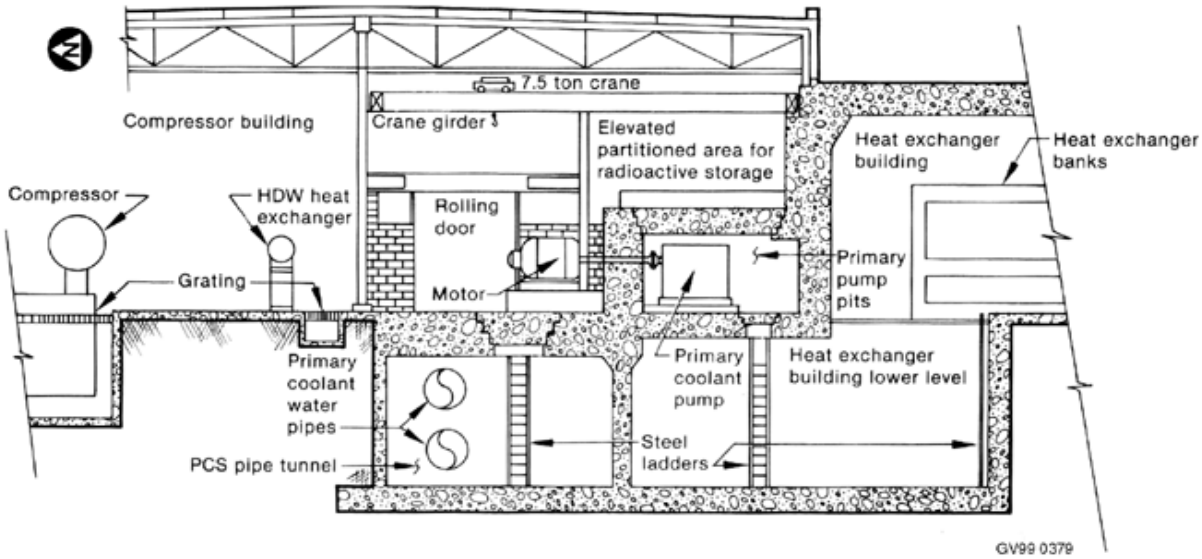

Figure 4. Elevation cutaway drawing of the Engineering Test Reactor compressor building (TRA-643).

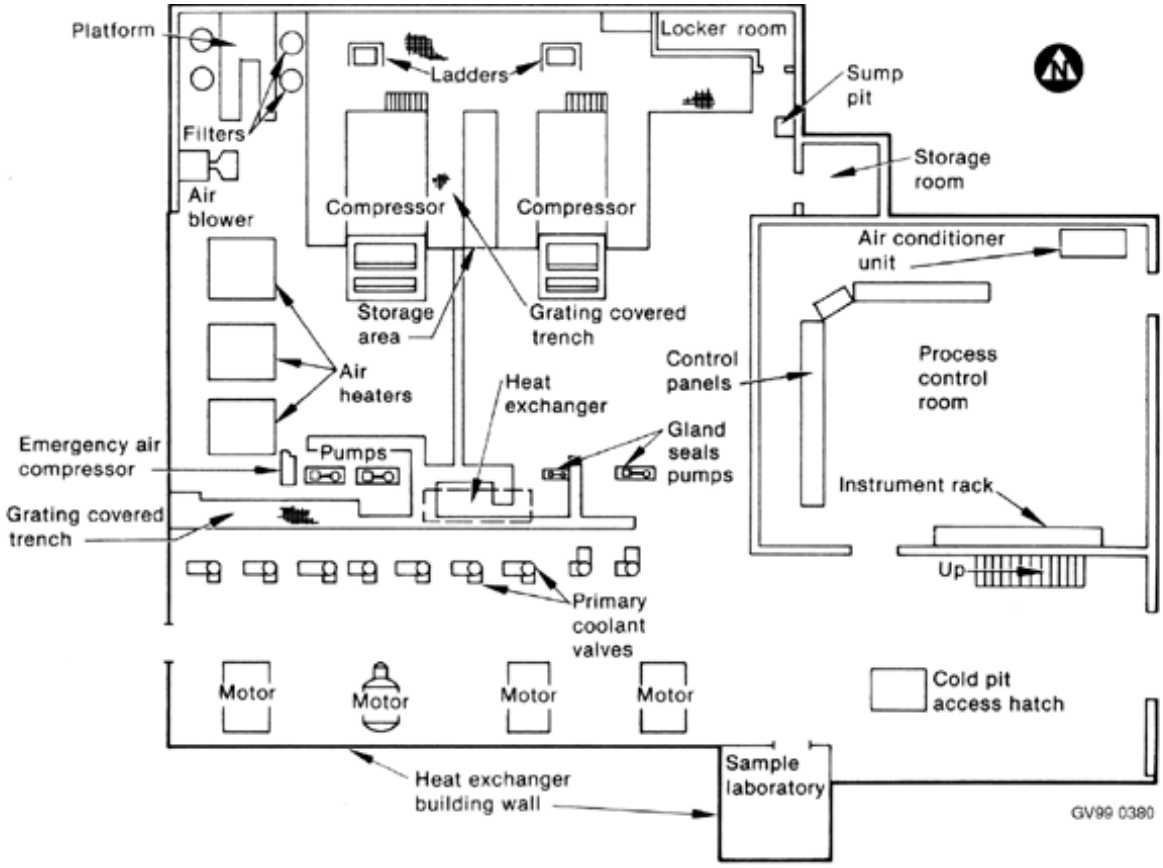

Figure 5. Floor plan of the Engineering Test Reactor compressor building (TRA-643).

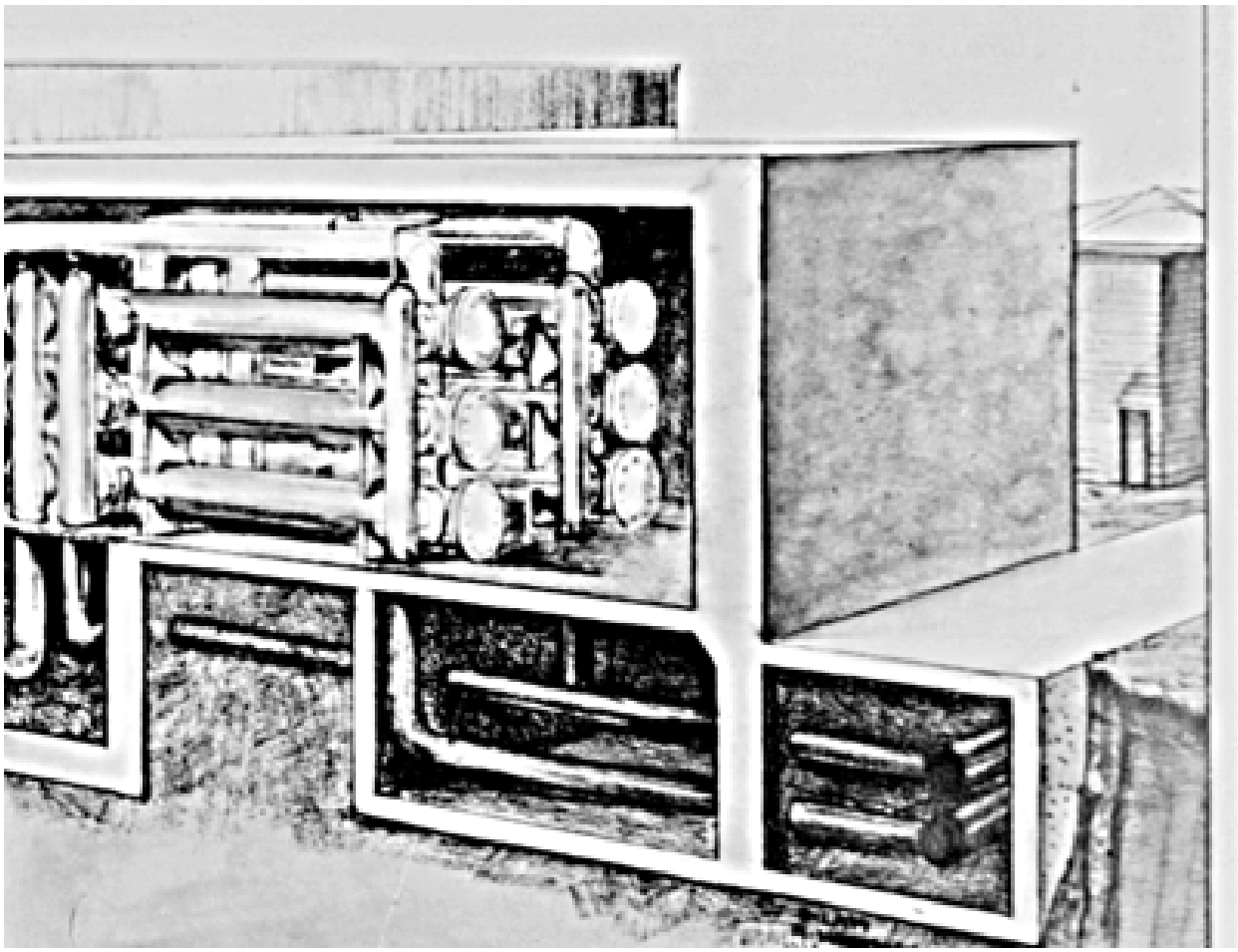

Figure 6. Artist's cutaway rendering of the Engineering Test Reactor heat exchanger building (TRA-644).

1.2 Objectives and Analysis Plan

The primary objective of this streamlined risk assessment is to show whether leaving the currently estimated contaminant inventories in place would be acceptable in terms of groundwater protection. If it is not acceptable to leave the inventory in place, the contaminant inventory that could be left must be estimated. This analysis assumes the primary structure above grade will be removed and everything below grade will be left in place. The remaining ETR structure and contents below grade will be stabilized by filling the reactor and all void space within the facility with native soil. This is a conservative assumption if the final action is to fill any part of the facility with grout.

1.3 Physical and Hydrogeologic Setting

The RTC is located below the foothills of the Lost River Range on the northeastern edge of a large, fan-shaped regional watershed. The topography of this area is generally low-lying and flat with few defined natural drainage channels.

Native soils in the RTC area are primarily sandy silt loam with sand fractions ranging in size from very fine to very coarse. Soil depths range from very shallow to very deep and are intermixed with basalt flows. Regional data indicate that the soils in this area are primarily loess and are characterized as having moderate infiltration rates. The INL Site's surficial deposits are quite variable and include eolian (loess

and sand dunes); alluvial (gravel, sand, and silt); and lacustrine (clay, silt, and sand) deposits. The surface soils vary widely in thickness and in water-holding capacity. Sedimentary interbeds within the subsurface basalt stratigraphy exhibit the same characteristics as the surficial sediments.

The INL Site is located near the northwest margin of the Eastern Snake River Plain (ESRP), which is a prominent, relatively flat arc-shaped feature of southeastern Idaho. The ESRP has an average elevation of about 4,920 ft (1,500 m) above mean sea level. Elevations within the INL Site generally range from 4,760 to 5,200 ft (1,450 to 1,585 m) above mean sea level. A broad topographic ridge extends to the northeast along the central axis of the ESRP. This ridge effectively separates the drainage of the mountain ranges north and west of the INL Site from the Snake River.

This section provides a brief background regarding the hydrologic setting at the RTC. This background information, including the figures, was summarized from a recent study: *Response to the First Five-Year Review Report for the Test Reactor Area, Operable Unit 2-13, at the Idaho National Engineering and Environmental Laboratory* (DOE-NE-ID 2005).

Figure 7 is a general map of the RTC and surrounding vicinity with monitoring wells and waste disposal ponds. For reference, the area within the double security fence at the RTC is about 1,700 × 1,900 ft (518 × 579 m or approximately 70 acres). The RTC is located on an alluvial plain that consists of surficial sediment with thickness ranging from 30 to 75 ft (9.1 to 22.9 m). Perched water bodies of variable size exist in the vadose zone beneath the RTC. The extensive perched water bodies are primarily a result of infiltration from anthropogenic sources and a complex heterogeneous geology. The perched water bodies are present at different depths in the thick vadose zone (approximately 450 ft or 137 m thick).

1.3.1 Physiographic Setting

The land surface at the RTC is gently sloped to the southwest and is relatively flat with elevations ranging from 4,945 ft (1,507 m) on top of a rubble pile in the cold waste pond to 4,908 ft (1,496 m) at the bottom of the chemical waste pond. The RTC is located on thick deposits of alluvial gravels associated with the relatively flat flood plain of the Big Lost River.

The Big Lost River flood plain overlies the eastern Snake River basalt plain (Greeley 1982), formed by eruption of basalts from low-shield volcanoes and vents. Overlapping flows and sedimentary deposits produced the complex stratigraphy underlying the RTC.

1.3.2 Stratigraphy/Lithology at the Reactor Technology Complex

The stratigraphy at the RTC consists of a complex stack of basalt flows and sedimentary deposits, as shown in Figure 8. The cross section shown in Figure 8 is for wells to the south of the RTC and does not provide a detailed stratigraphy for the RTC interbeds. Rather, it gives the reader an example to help visualize the subsurface geologic system. The interbeds are not modeled individually in this risk assessment; therefore, the RTC stratigraphy was not characterized in detail for this report.

The upper portion of the basalt-sediment stack is capped with a thick section of surficial alluvial/fluvial deposits. The surficial alluvial deposits are unconsolidated sediments. The alluvial deposits (chiefly sands and gravels) rest atop the undulating surface of a massive basalt flow group; hence, the thickness of the alluvium varies throughout the area. Finer-grained sediments seem to have settled into depressions in the basalt surface. In general, thickness of the alluvium ranges from about 32 ft (9.75 m) in the northwest section of the RTC to about 55 ft (16.8 m) to the south with a mean thickness of 49 ft (14.9 m) (Anderson 1991).

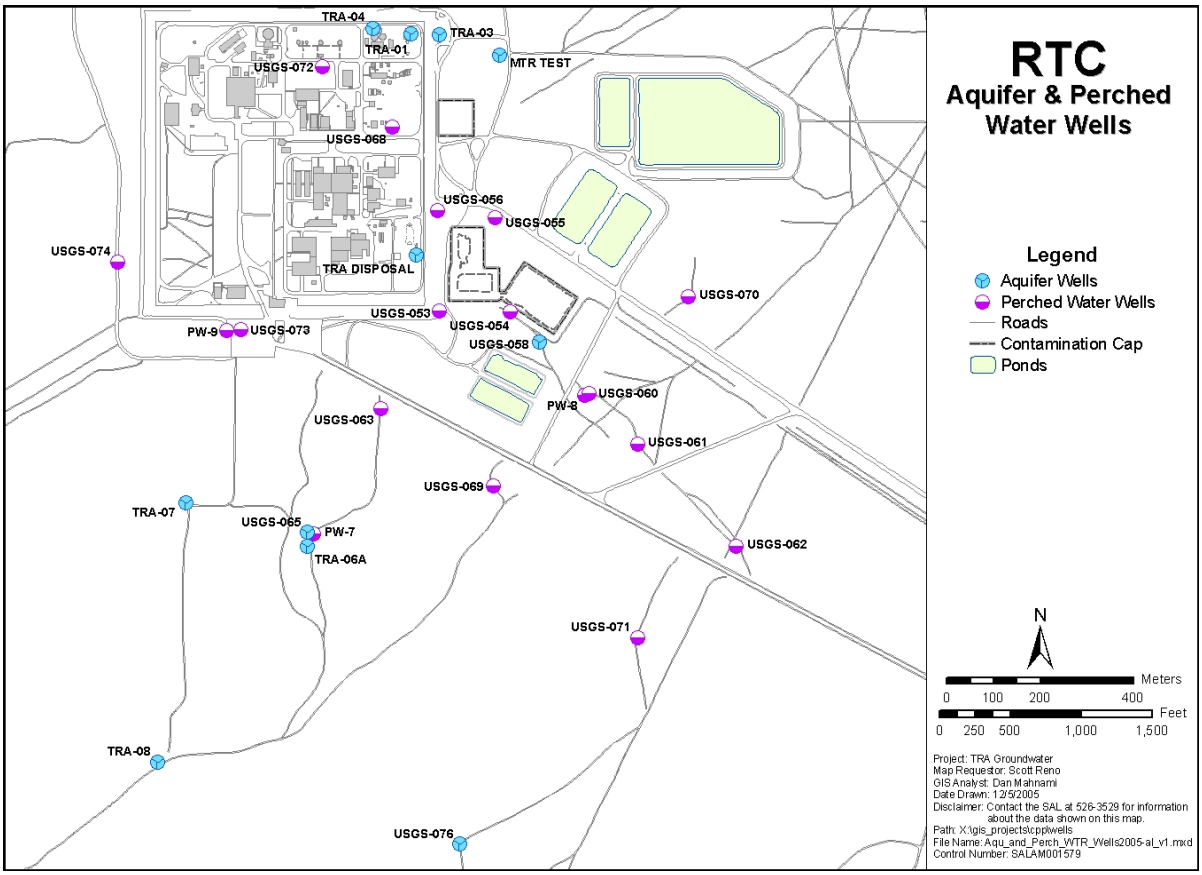

Figure 7. Map of the Reactor Technology Complex.

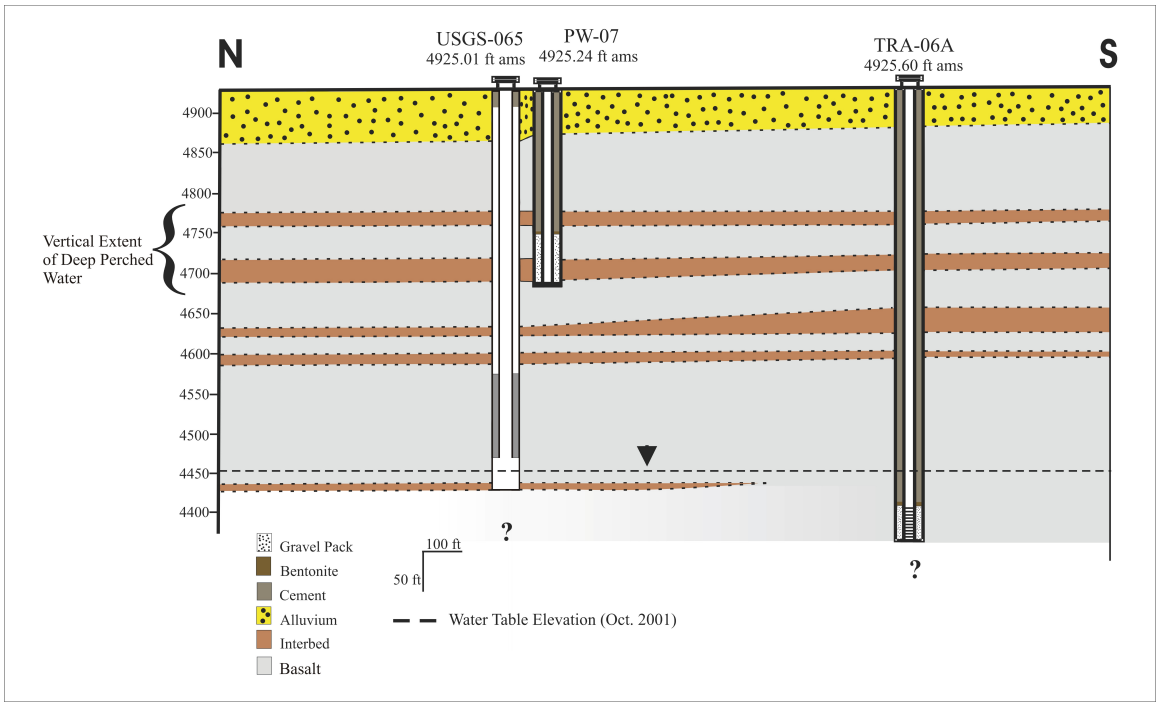

Figure 8. Generalized cross section showing the stratigraphy at USGS-065, PW-07, and TRA-06A.

A thick sequence of basalt flows and sedimentary interbeds lies beneath the surficial alluvium at the RTC, extending to depths of 2,000 to 3,000 ft (610 to 914 m) below land surface. The basalt stratigraphy at the RTC has been determined by thorough evaluation of cores and cuttings and by correlation of geophysical logs from over 70 wells completed in the eastern Snake River Plain Aquifer (SRPA). A total of 17 basalt flow groups were identified along with at least eight sedimentary interbeds. The basalt flows increase in thickness and decrease in hydraulic conductivity with depth. This decrease can be partially attributed to decreased interflow rubble zones and to secondary mineralization within fractures and other porous regions of the flows. From a hydrologic perspective, two interbeds are of primary concern. The first is located at an approximate depth of 140 to 200 ft (42.7 to 61 m). The thickness of this sedimentary interbed is approximately 60 ft (18.3 m), and it has been encountered in 14 of 17 wells drilled in the area. A second significant sedimentary interbed is encountered in the USGS-65 well at about 500 ft (152.4 m) below land surface (INEEL 2003). It is estimated that another 30 ft (9.14 m) of interbed is distributed throughout the vadose zone beneath the ETR at the RTC.

1.3.3 Perched Water at the Reactor Technology Complex

A series of basalt flows interbedded with sedimentary deposits underlie the surficial sediments and make up the subsurface geologic system. The sedimentary interbeds vary in both thickness and lateral extent. The basalt contacts—often rubbly and highly vesicular—are usually very permeable, water-bearing intervals in both the perched water zones and the underlying SRPA. The basalt/sediment interfaces have much lower permeabilities and act as aquitards and perching layers.

Perched water forms in the vadose zone when the rate of infiltrating water exceeds the capacity of a low-permeability layer (such as sediments of massive basalt) to transmit water. The size or “footprint” of the perched water body expands until sufficient area is wetted to transmit the flux of infiltrating water. Alternatively, water can “spill” over the edge of a perching layer that is not laterally extensive. Thus, widespread layers with very low permeability can form larger perched water bodies if there is a large source of water infiltration. The footprint and depth of the perched water body will increase or decrease as the rate of infiltration increases or decreases. A conceptual drawing illustrating the development of perched water beneath the RTC is shown in Figure 9.

Water discharge to past and present RTC ponds has resulted in the formation of relatively large perched water bodies in the vadose zone beneath the RTC. After closure of the facility, there will be no large surface-water discharges and the perched water bodies are expected to largely disappear. Since the ETR is not close to the ponds and the perched water is expected to largely disappear after closure, effects of the ponds on contaminant transport are not included in this analysis.

As a result of comments received during the first 5-year review, the document *Response to the First Five-Year Review Report for the Test Reactor Area, Operable Unit 2-13, at the Idaho National Engineering and Environmental Laboratory* (DOE-NE-ID 2005) was prepared. This report summarized the efforts conducted, such as new groundwater modeling, to address the extended operational life of the TRA (RTC) facility, as follows:

> Simulations were run using the original [Operable Unit 2-13] modeling code and assumptions in confirmation of the original predictions. The model was then run using updated assumptions, most importantly the extended operational life of TRA, which includes extended period of discharge to the Cold Waste Ponds. The updated assumptions also were used in a second set of simulations that employed a state-of-the-art, commercially available modeling code. The input from both modeling codes indicated that the remedy would remain protective of human health and the environment, even with the extended operational life of the TRA. New modeling, assuming an extended operational life of 2024, predicted that all contaminants of concern were projected to be well below their MCLs by 2115, the date used for the future-use risk assessment.

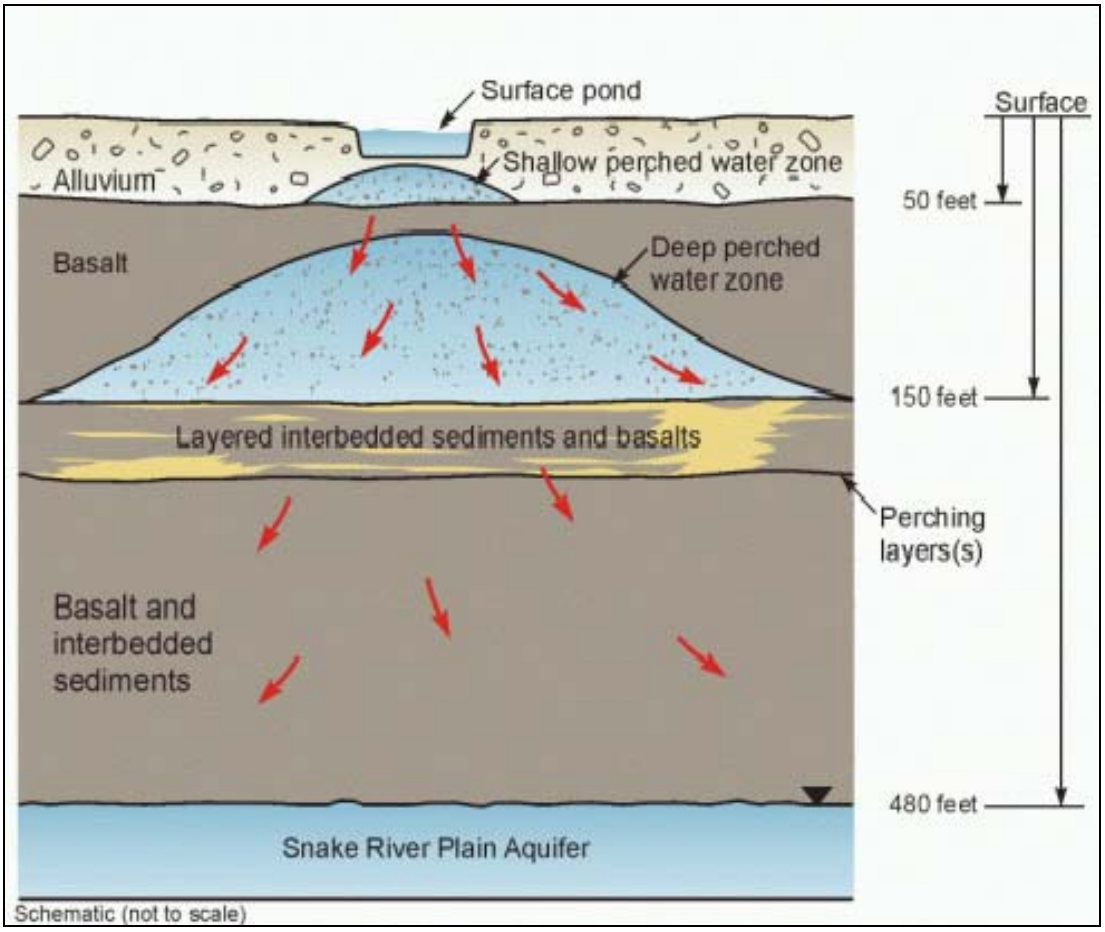

Figure 9. Conceptual diagram demonstrating the perched water formation.

1.3.4 Snake River Plain Aquifer beneath the Reactor Technology Complex

The SRPA is defined as the series of water-bearing basalt flows and sedimentary layers that underlie the ESRP. The SRPA is approximately 200 mi long, 40 to 60 mi wide, and covers an area of 9,600 mi^2 (approximately 25,000 km^2) (Hull 1989). The aquifer is relatively permeable because of the presence of fractures, fissures, and rubble zones at contacts between individual basalt flows. At the RTC, the SRPA occurs at approximately 480 ft (146.3 m) below land surface.

Generally, groundwater in the SRPA flows to the southwest under the ambient hydraulic gradient (Figure 10). The figure is a copy out of the *Response to the First Five-Year Review Report for the Test Reactor Area, Operable Unit 2-13, at the Idaho National Engineering and Environmental Laboratory* (DOE-NE-ID 2005). The RTC is shown with its previous name, TRA, in the figure. Figure 11 depicts the aquifer water table at the RTC in June 2004. The inherent heterogeneity of the fractured basalt aquifer makes it very difficult to contour the water table, and local flow directions may vary significantly. Figure 11 also shows the inferred direction of groundwater flow beneath the RTC. The direction of flow is inferred, because the aquifer's highly heterogeneous nature creates anisotropy that can result in flow paths not perpendicular to the water level contours. Fluctuating water levels caused by recharge and pumping further complicate determination of the aquifer flow directions. Groundwater flow beneath the RTC is generally to the southwest (Figure 11), but the direction and water table gradient vary in both time and space.

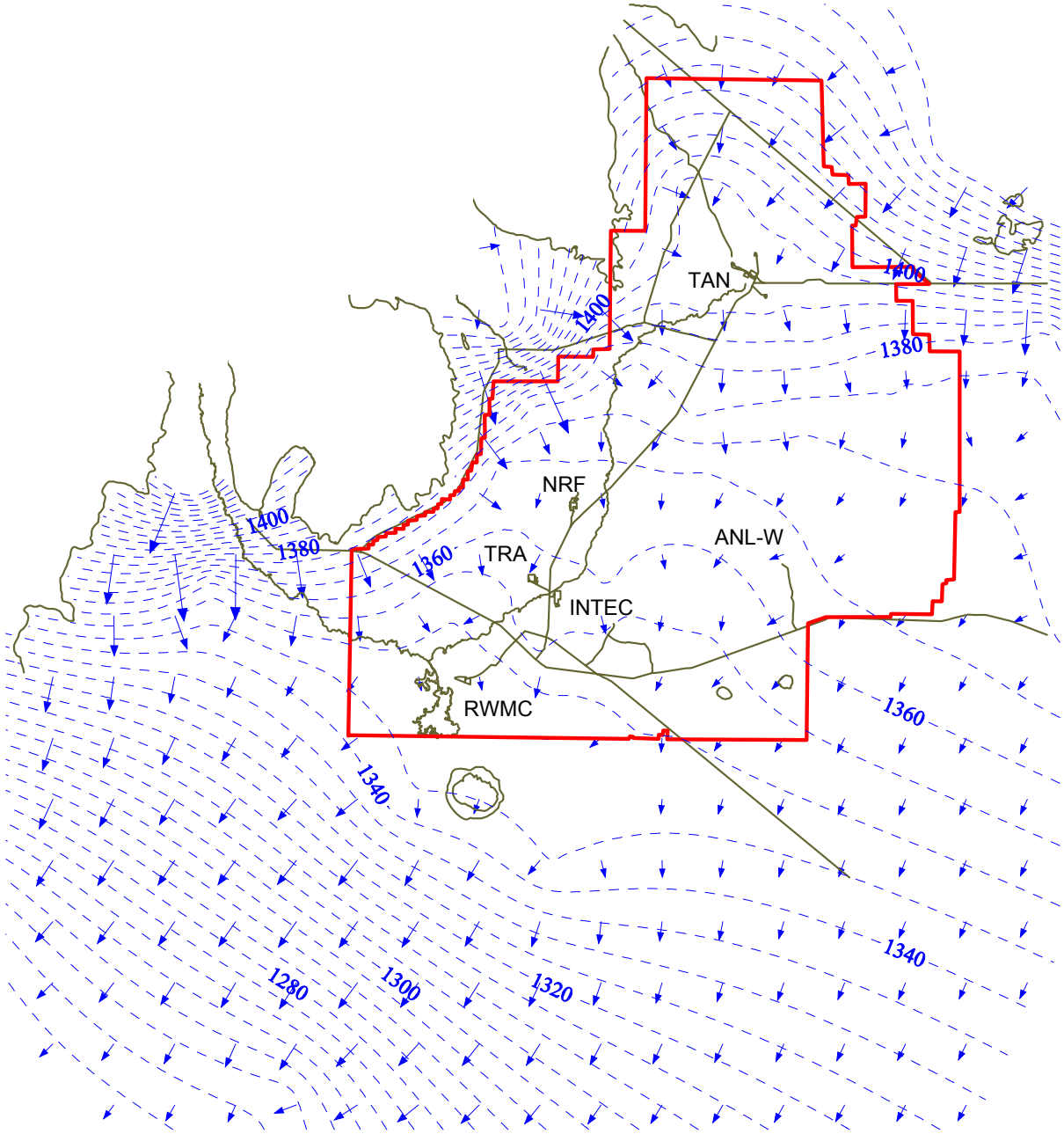

Figure 10. June 2004 water table elevation contour map (meters above mean sea level) for the Snake River Plain Aquifer in the vicinity of the Idaho National Laboratory Site with hydraulic gradient vectors (shown proportional to gradient magnitude). (Figure is from DOE/NE-ID-11189 [DOE-NE-ID 2005]. The Test Reactor Area is the former name for the Reactor Technology Complex and Argonne National Laboratory-West is the former name for the Materials and Fuels Complex.)

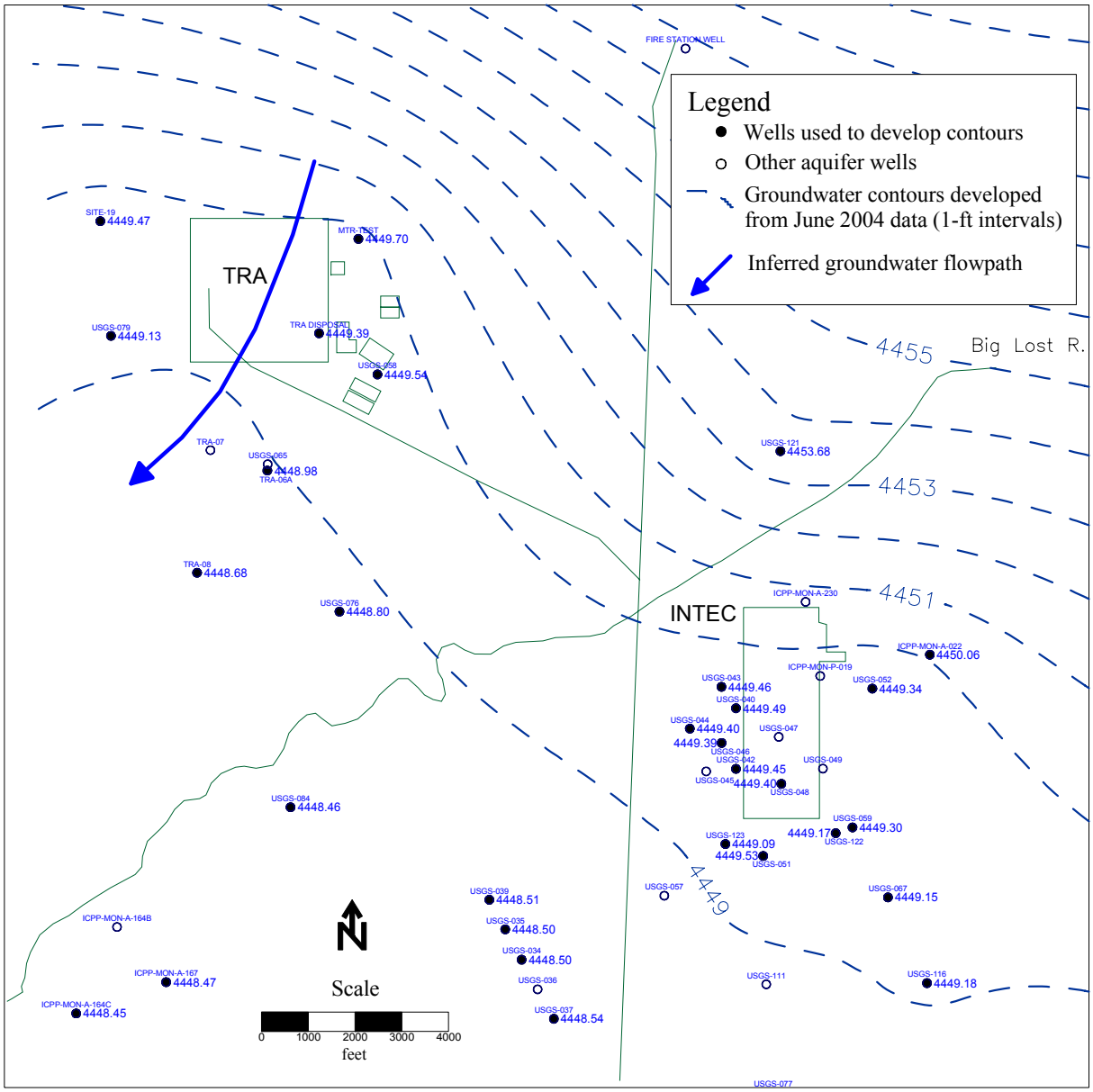

Figure 11. Aquifer water table configuration for June 2004 in the vicinity of the Reactor Technology Complex. (Figure is from DOE/NE-ID-11189 [DOE-NE-ID 2005].)

2. CONTAMINANT INVENTORY

The ETR contains both radionuclide and nonradionuclide contaminants. Evaluations of the radionuclide inventory are presented in the following EDFs:

- EDF-6133, "ETR Reactor Source Term and External Dose Rates"
- EDF-6138, "Radiological Characterization of the ETR Complex External Surfaces"
- EDF-6291, "Radiological Characterization of the Engineering Test Reactor (ETR) Complex Internal Surfaces"
- EDF-6304, "ETR Complex Activity vs. Depth."

For the nonradionuclides, inventory calculations are presented in EDF-6225, "ETR Complex Chemical Constituent Source Term." A short summary of the radionuclide inventory and summary tables for the radionuclide and nonradionuclide inventories are presented in Sections 2.1 and 2.2.

2.1 Radionuclides at the Engineering Test Reactor

As stated previously, detailed studies have been performed to characterize the radiological contamination remaining in the ETR and associated buildings (TRA-642, TRA-643, and TRA-644). Major contamination groups include activated structures inside the ETR vessel and surface contamination on facility walls and other surfaces. Table 1 lists the structures within the ETR vessel and nearby that underwent significant activation during ETR operation. Only the activated portions making a significant contribution to the total inventory are included in mass and volume listings. Some of these (e.g., the beryllium reflector and the black control rod poison assemblies) experienced different irradiation histories because of different installation times.

Table 1. ETR core structures with significant activation (EDF-6958, Tables 1 and 5).

Component	Main Materials	Volume (m^3)	Mass (kg)
External thermal shield [a]	Pb, 304-SS	0.353	2,760
External tank	304-SS, steel	0.87	6,860
Gray control rod poison	Type A nickel	0.017	154
Black control rod poison	Hafnium, 304-SS	0.0047	37.3
Internal thermal shields	304-SS	1.03	8,250
Inner tank	304-SS, steel	0.478	2,770
Grid plate	304-SS	0.445	2,280
Upper support frame	304-SS	0.028	220
Beryllium reflector	Beryllium	0.421	714
C-7 in-pile tube	304-SS	0.0093	73.7
F-10 in-pile tube	304-SS	0.0043	34.4
M-13 in-pile tube	304-SS	0.0043	34.4
N-14 in-pile tube	304-SS	0.0043	34.4
Core and shield support I-beams	304-SS	0.0049	108

a. Lead in the external thermal shield was removed and 304-SS stands for stainless steel.

A radiologic characterization of the ETR Complex's external surfaces included surfaces not inside piping, equipment, tanks, or the reactor. The external surfaces were characterized and a source term was calculated in EDF-6138. Contamination survey results were used to calculate the external surfaces' source term. Table 2 summarizes the nuclide inventory estimated for the ETR Complex's external surfaces.

A radiological characterization of the ETR Complex's (TRA-642, TRA-643, and TRA-644) internal surfaces (the surfaces inside piping, equipment, tanks, and the reactor) and a source term for these surfaces are presented in EDF-6291. The source term calculations were based on radiological surveys performed throughout the ETR on the primary and waste drain piping, a sample consisting of activated corrosion products taken from the primary system at a heat exchanger low-point drain, and the following assumptions:

1. The relative ratios between the radionuclides are the same on the internal surfaces as they are in the corrosion products that were sampled.

2. The contamination is uniformly distributed throughout these contaminated systems.

Table 3 summarizes the nuclide inventory estimated for the ETR Complex's internal surfaces.

The source term of the ETR vessel (located in TRA-642) was calculated in EDF-6133 based on dose measurements performed inside of the reactor and internal surface contamination survey results presented in EDF-6291. For the modeling of the reactor in EDF-6133, the activated portion of the reactor was divided into seven different regions and the gamma radiation was measured with thermoluminescent detectors (TLDs). The first set of TLD chips was placed 2 in. above the grid plate at the bottom of the core (Station Point #1). The model for this region included the materials from the bottom surface of the grid plate to a location halfway between Station Point #1 and Station Point #2. Activated materials located below the grid plate were modeled as if they were included in this first region. The other regions (2-7) were each of 2 ft in height representing the volume from 1 ft below the TLD station to 1 ft above the TLD station. The locations of the station points are shown in Figure 12. Table 4 summarizes the nuclide inventory of the ETR vessel calculated based on the station point measurements.

The total source term of the ETR Complex is presented in EDF-6304 with the addition of the inventory from the TRA-648 building and the inventory from the filter vaults associated with the ETR exhaust air system (TRA-704, TRA-705, and TRA-706). Furthermore, the source term is divided based on depth relative to grade level and presented in separate tables. The source term data used in the calculations were taken from EDF-5965, "Radionuclide Inventory for Two ETR Filters from TRA-705 Vault"; EDF-6133; EDF-6138; and EDF-6291. Table 5 summarizes the nuclide inventory in the vaults associated with the ETR exhaust air system.

Table 6 summarizes the inventory used for the ETR Complex's groundwater-pathway risk assessment. The total inventory comprises the ETR and the contaminated internal and external surfaces, as explained above and presented in Tables 2, 3, 4, and 5.

2.2 Nonradionuclides at the Engineering Test Reactor

The nonradionuclide inventory for the ETR facilities was estimated and documented in EDF-6225. The inventory shown in Table 7 is taken from Table 3 in EDF-6225, which summarizes the estimated quantities of chemical constituents in the portions of the ETR Complex that are projected to be left in place with the exception of uranium. The uranium mass was calculated based on the total activity of uranium isotopes listed in Table 6.

Table 2. Estimated activity of the Engineering Test Reactor Complex external surfaces (EDF-6138, Table 7).

Components in Buildings	Ag-108m (Ci)	C-14 (Ci)	Co-60 (Ci)	Cs-137 (Ci)	I-129 (Ci)	Ni-63 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Sr-90 (Ci)	Tc-99 (Ci)	U-233/U-234/ Np-237[a] (Ci)
Reactor Building (TRA-642)											
Reactor vessel	6.49E-07	8.23E-07	1.29E-05	1.09E-04	6.38E-08	7.86E-06	1.66E-08	2.09E-08	5.71E-07	9.81E-08	1.32E-09
Nozzle trench	1.51E-07	1.92E-07	3.00E-06	2.53E-05	1.49E-08	1.83E-06	3.86E-09	4.88E-09	1.33E-07	2.29E-08	3.08E-10
Biological shield (over cap)	1.09E-07	1.38E-07	2.15E-06	1.82E-05	1.07E-08	1.32E-06	2.77E-09	3.51E-09	9.56E-08	1.64E-08	2.21E-10
Canal	1.24E-06	1.58E-06	2.46E-05	2.08E-04	1.22E-07	1.51E-05	3.17E-08	4.01E-08	1.09E-06	1.88E-07	2.53E-09
Main room	1.53E-05	1.94E-05	3.03E-04	2.56E-03	1.50E-06	1.85E-04	3.90E-07	4.94E-07	1.35E-05	2.31E-06	3.12E-08
Console floor	8.67E-06	1.10E-05	1.72E-04	1.45E-03	8.53E-07	1.05E-04	2.21E-07	2.80E-07	7.64E-06	1.31E-06	1.77E-08
Balcony	1.45E-06	1.84E-06	2.87E-05	2.42E-04	1.42E-07	1.75E-05	3.69E-08	4.67E-08	1.27E-06	2.19E-07	2.95E-09
Emergency cooling loop cubicles	2.72E-05	3.46E-05	5.40E-04	4.56E-03	2.68E-06	3.30E-04	6.95E-07	8.79E-07	2.40E-05	4.12E-06	5.55E-08
PCS pipe tunnel	8.75E-06	1.11E-05	1.74E-04	1.47E-03	8.60E-07	1.06E-04	2.23E-07	2.83E-07	7.71E-06	1.32E-06	1.78E-08
Hot waste pit	6.55E-06	3.44E-04	5.38E-03	2.25E-02	1.32E-05	3.29E-03	3.43E-06	4.34E-06	2.82E-03	2.03E-05	2.73E-07
P-7 primary cubicle	1.11E-07	1.41E-07	2.21E-06	1.87E-05	1.10E-08	1.35E-06	2.84E-09	3.60E-09	9.82E-08	1.69E-08	2.27E-10
J-10/L-10 primary cubicle	2.07E-07	2.63E-07	4.11E-06	3.48E-05	2.04E-08	2.52E-06	5.30E-09	6.70E-09	1.83E-07	3.14E-08	4.23E-10
C-7/M-13/N-14 primary cubicle	6.83E-06	8.66E-06	1.35E-04	1.14E-03	6.71E-07	8.27E-05	1.74E-07	2.20E-07	6.01E-06	1.03E-06	1.39E-08
C-7/M-13/N-14 secondary cubicle	1.52E-06	1.93E-06	3.01E-05	2.54E-04	1.49E-07	1.84E-05	3.88E-08	4.90E-08	1.34E-06	2.30E-07	3.09E-09
F-10/H-10 primary cubicle	1.04E-05	1.33E-05	2.07E-04	1.75E-03	1.03E-06	1.27E-04	2.67E-07	3.37E-07	9.20E-06	1.58E-06	2.13E-08
F-10/H-10 auxiliary cubicle	7.71E-07	9.79E-07	1.53E-05	1.29E-04	7.58E-08	9.35E-06	1.97E-08	2.49E-08	6.79E-07	1.17E-07	1.57E-09
F-10/H-10 secondary cubicle	2.96E-06	3.76E-06	5.87E-05	4.96E-04	2.91E-07	3.59E-05	7.56E-08	9.56E-08	2.61E-06	4.48E-07	6.03E-09
Helium system cubicle	2.34E-07	2.98E-07	4.65E-06	3.93E-05	2.31E-08	2.84E-06	5.99E-09	7.57E-09	2.07E-07	3.55E-08	4.78E-10
L-12/M-7 primary cubicle	4.81E-07	6.10E-07	9.53E-06	8.05E-05	4.72E-08	5.83E-06	1.23E-08	1.55E-08	4.23E-07	7.27E-08	9.79E-10
L-12/M-7 secondary cubicle	1.15E-06	1.46E-06	2.28E-05	1.92E-04	1.13E-07	1.39E-05	2.93E-08	3.71E-08	1.01E-06	1.74E-07	2.34E-09
C-13/G-16 primary cubicle	1.38E-07	1.75E-07	2.73E-06	2.31E-05	1.35E-08	1.67E-06	3.52E-09	4.45E-09	1.21E-07	2.08E-08	2.81E-10
C-13/G-16 secondary cubicle	1.26E-07	1.60E-07	2.49E-06	2.11E-05	1.24E-08	1.52E-06	3.21E-09	4.06E-09	1.11E-07	1.90E-08	2.56E-10
Crud generator cubicle	4.29E-07	5.44E-07	8.51E-06	7.19E-05	4.22E-08	5.20E-06	1.10E-08	1.39E-08	3.78E-07	6.49E-08	8.74E-10
Subpile room entryway	4.99E-08	6.34E-08	9.90E-07	8.36E-06	4.91E-09	6.05E-07	1.27E-09	1.61E-09	4.40E-08	7.55E-09	1.02E-10
AGS cubicle	1.01E-07	1.28E-07	2.00E-06	1.69E-05	9.90E-09	1.22E-06	2.57E-09	3.25E-09	8.87E-08	1.52E-08	2.05E-10
GEEL pipe tunnel	4.05E-06	5.14E-06	8.04E-05	6.79E-04	3.99E-07	4.91E-05	1.03E-07	1.31E-07	3.57E-06	6.13E-07	8.26E-09
M-3 primary cubicle	1.37E-07	1.73E-07	2.71E-06	2.29E-05	1.34E-08	1.66E-06	3.49E-09	4.42E-09	1.20E-07	2.07E-08	2.78E-10
M-3/P-7 secondary cubicle	6.97E-08	8.85E-08	1.38E-06	1.17E-05	6.86E-09	8.45E-07	1.78E-09	2.25E-09	6.14E-08	1.05E-08	1.42E-10
Warm waste pit	7.45E-06	9.46E-06	1.48E-04	1.25E-03	7.33E-07	9.03E-05	1.90E-07	2.41E-07	6.56E-06	1.13E-06	1.52E-08
Subpile room	1.70E-07	2.16E-07	3.38E-06	2.85E-05	1.68E-08	2.07E-06	4.35E-09	5.51E-09	1.50E-07	2.58E-08	3.47E-10

Table 2. (continued).

Components in Buildings	Ag-108m (Ci)	C-14 (Ci)	Co-60 (Ci)	Cs-137 (Ci)	I-129 (Ci)	Ni-63 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Sr-90 (Ci)	Tc-99 (Ci)	U-233/U-234/ Np-237[a] (Ci)
Rod access room	6.06E-08	7.69E-08	1.20E-06	1.02E-05	5.96E-09	7.35E-07	1.55E-09	1.96E-09	5.34E-08	9.17E-09	1.23E-10
Other basement areas	3.05E-06	3.87E-06	6.04E-05	5.11E-04	3.00E-07	3.69E-05	7.78E-08	9.85E-08	2.68E-06	4.61E-07	6.21E-09
Total	1.11E-04	4.76E-04	7.44E-03	3.99E-02	2.34E-05	4.55E-03	6.08E-06	7.70E-06	2.92E-03	3.60E-05	4.85E-07
Compressor Building (TRA-643)											
GEEL tunnel (part)	1.01E-06	1.28E-06	2.00E-05	1.69E-04	9.92E-08	1.22E-05	2.57E-08	3.26E-08	8.88E-07	1.53E-07	2.05E-09
PCS pipe tunnel	1.80E-06	2.28E-06	3.56E-05	3.01E-04	1.77E-07	2.18E-05	4.58E-08	5.80E-08	1.58E-06	2.72E-07	3.66E-09
Storage area	4.23E-07	5.37E-07	8.38E-06	7.08E-05	4.16E-08	5.13E-06	1.08E-08	1.37E-08	3.72E-07	6.40E-08	8.61E-10
Total	3.23E-06	4.10E-06	6.40E-05	5.41E-04	3.17E-07	3.91E-05	8.24E-08	1.04E-07	2.84E-06	4.88E-07	6.57E-09
Heat Exchanger Building (TRA-644)											
Bypass valve room	1.14E-07	1.45E-07	2.26E-06	1.91E-05	1.12E-08	1.38E-06	2.91E-09	3.69E-09	1.01E-07	1.73E-08	2.32E-10
Tank room	9.38E-08	1.19E-07	1.86E-06	1.57E-05	9.22E-09	1.14E-06	2.39E-09	3.03E-09	8.26E-08	1.42E-08	1.91E-10
Main room	7.47E-07	9.48E-07	1.48E-05	1.25E-04	7.34E-08	9.05E-06	1.91E-08	2.41E-08	6.58E-07	1.13E-07	1.52E-09
Basement	1.44E-06	1.83E-06	2.85E-05	2.41E-04	1.42E-07	1.74E-05	3.67E-08	4.65E-08	1.27E-06	2.18E-07	2.93E-09
Degassing tank	6.57E-08	8.34E-08	1.30E-06	1.10E-05	6.46E-09	7.96E-07	1.68E-09	2.12E-09	5.78E-08	9.93E-09	1.34E-10
Primary pump pits	3.98E-07	5.05E-07	7.89E-06	6.67E-05	3.91E-08	4.83E-06	1.02E-08	1.29E-08	3.51E-07	6.02E-08	8.11E-10
Emergency shutdown pump pits	6.46E-08	8.20E-08	1.28E-06	1.08E-05	6.35E-09	7.83E-07	1.65E-09	2.09E-09	5.69E-08	9.77E-09	1.32E-10
Degasified pump pits	6.26E-08	7.94E-08	1.24E-06	1.05E-05	6.15E-09	7.59E-07	1.60E-09	2.02E-09	5.51E-08	9.47E-09	1.27E-10
Total	2.98E-06	3.79E-06	5.92E-05	5.00E-04	2.93E-07	3.62E-05	7.62E-08	9.64E-08	2.63E-06	4.51E-07	6.08E-09
External Surfaces Grand Total	1.17E-04	4.84E-04	7.57E-03	4.10E-02	2.40E-05	4.63E-03	6.24E-06	7.90E-06	2.92E-03	3.70E-05	4.98E-07

a. Analysis did not discriminate between U-233, U-234, and Np-237. However, the total is orders of magnitude lower than the activity from the other sources. Therefore, no effort was taken to identify the individual activities.

AGS = annular gas system.
GEEL = General Electric Experimental Loop.
PCS = primary cooling system.
TRA = Test Reactor Area.

Table 3. Estimated activity of the Engineering Test Reactor Complex internal surfaces (inside piping, equipment, tanks, and reactor) (EDF-6291, Table 2).

Area Description	Am-241 (Ci)	C-14 (Ci)	Co-60 (Ci)	Cs-137 (Ci)	Fe-55 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Sr-90 (Ci)	U-233 (Ci)	U-235 (Ci)
Reactor vessel	1.68E-6	2.69E-6	4.88E-3	3.49E-5	6.63E-3	1.25E-4	1.19E-2	1.93E-6	2.99E-6	3.27E-5	2.94E-7	7.85E-9
Nozzle trench	1.64E-7	2.63E-7	4.77E-4	3.41E-6	6.48E-4	1.22E-5	1.16E-3	1.88E-7	2.92E-7	3.19E-6	2.87E-8	7.67E-10
Canal	1.06E-6	1.69E-6	3.07E-3	2.20E-5	4.17E-3	7.86E-5	7.49E-3	1.21E-6	1.88E-6	2.06E-5	1.85E-7	4.94E-9
Console floor	5.36E-8	8.61E-8	1.56E-4	1.12E-6	2.12E-4	3.99E-6	3.80E-4	6.16E-8	9.56E-8	1.04E-6	9.39E-9	2.51E-10
Reactor basement	3.39E-6	5.44E-6	9.85E-3	7.05E-5	1.34E-2	2.52E-4	2.40E-2	3.89E-6	6.04E-6	6.60E-5	5.93E-7	1.59E-8
Waste tank pits	1.51E-6	2.42E-6	4.38E-3	3.14E-5	5.96E-3	1.12E-4	1.07E-2	1.73E-6	2.68E-6	2.93E-5	2.64E-7	7.05E-9
AGS cubicle	1.52E-7	2.45E-7	4.43E-4	3.17E-6	6.03E-4	1.13E-5	1.08E-3	1.75E-7	2.72E-7	2.97E-6	2.67E-8	7.14E-10
M-3/P-7 cubicles	3.62E-6	5.81E-6	1.05E-2	7.53E-5	1.43E-2	2.69E-4	2.57E-2	4.15E-6	6.45E-6	7.05E-5	6.33E-7	1.69E-8
C-7/M-13/N-14 cubicles	1.98E-6	3.18E-6	5.76E-3	4.13E-5	7.84E-3	1.48E-4	1.41E-2	2.28E-6	3.53E-6	3.86E-5	3.47E-7	9.28E-9
F-10/H-10 cubicles	1.12E-6	1.79E-6	3.25E-3	2.33E-5	4.42E-3	8.32E-5	7.93E-3	1.28E-6	1.99E-6	2.18E-5	1.96E-7	5.24E-9
L-12/M-7	3.92E-6	6.30E-6	1.14E-2	8.17E-5	1.55E-2	2.92E-4	2.78E-2	4.51E-6	6.99E-6	7.64E-5	6.87E-7	1.84E-8
C-13/G-16	1.88E-6	3.01E-6	5.46E-3	3.91E-5	7.42E-3	1.40E-4	1.33E-2	2.15E-6	3.34E-6	3.66E-5	3.28E-7	8.78E-9
Control rod access room	2.95E-7	4.74E-7	8.58E-4	6.14E-6	1.17E-3	2.20E-5	2.09E-3	3.39E-7	5.26E-7	5.75E-6	5.16E-8	1.38E-9
Subpile	1.92E-6	3.07E-6	5.57E-3	3.99E-5	7.57E-3	1.43E-4	1.36E-2	2.20E-6	3.41E-6	3.73E-5	3.35E-7	8.96E-9
GEEL tunnel and delay tanks	1.43E-5	2.29E-5	4.15E-2	2.97E-4	5.64E-2	1.06E-3	1.01E-1	1.64E-5	2.54E-5	2.78E-4	2.50E-6	6.68E-8
PCS piping tunnel	5.07E-6	8.14E-6	1.47E-2	1.06E-4	2.01E-2	3.78E-4	3.60E-2	5.83E-6	9.04E-6	9.88E-5	8.88E-7	2.37E-8
HX building bypass demineralizer tank and valve room	2.84E-6	4.55E-6	8.24E-3	5.90E-5	1.12E-2	2.11E-4	2.01E-2	3.26E-6	5.05E-6	5.52E-5	4.96E-7	1.33E-8
HX building main floor and lower level	8.76E-5	1.41E-4	2.55E-1	1.82E-3	3.46E-1	6.52E-3	6.21E-1	1.01E-4	1.56E-4	1.71E-3	1.53E-5	4.10E-7
Degassing room	1.37E-6	2.19E-6	3.98E-3	2.85E-5	5.41E-3	1.02E-4	9.70E-3	1.57E-6	2.44E-6	2.66E-5	2.39E-7	6.40E-9
Pump pits	3.34E-6	5.37E-6	9.72E-3	6.96E-5	1.32E-2	2.49E-4	2.37E-2	3.84E-6	5.96E-6	6.51E-5	5.85E-7	1.57E-8
Cubicle exhaust booster blower room	1.26E-6	2.03E-6	3.67E-3	2.63E-5	4.99E-3	9.40E-5	8.95E-3	1.45E-6	2.25E-6	2.46E-5	2.21E-7	5.91E-9
Total	1.38E-4	2.22E-4	4.03E-1	2.88E-3	5.47E-1	1.03E-2	9.82E-1	1.59E-4	2.47E-4	2.70E-3	2.42E-5	6.48E-7
Total without reactor	1.37E-4	2.20E-4	3.98E-1	2.84E-3	5.41E-1	1.02E-2	9.70E-1	1.58E-4	2.44E-4	2.67E-3	2.39E-5	6.40E-7

AGS = annular gas system.
GEEL = General Electric Experimental Loop.
PCS = primary cooling system.

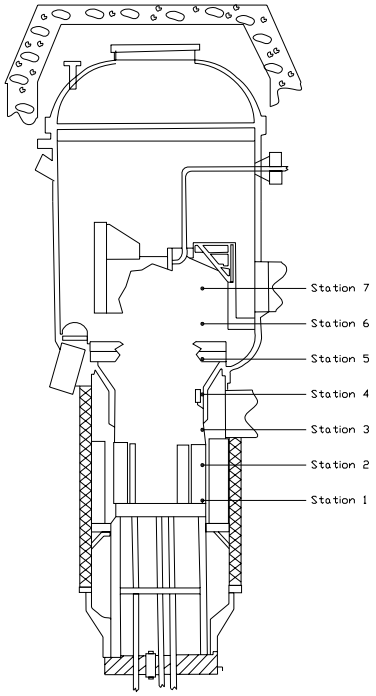

Figure 12. Locations of station points in the ETR reactor. Station Point #1 is 2 in. above the grid plate.

Table 4. Estimated nuclide inventory in the Engineering Test Reactor (EDF-6133, Table 5).

Nuclide	Station Point #1 (Ci)	Station Point #2 (Ci)	Station Point #3 (Ci)	Station Point #4 (Ci)	Station Point #5 (Ci)	Station Point #6 (Ci)	Station Point #7 (Ci)	Total (Ci)
Ac-227	4.55E-07	4.71E-07	5.40E-08	2.07E-08	7.13E-09	2.52E-09	2.41E-09	1.01E-06
Ag-108m	1.09E-01	1.13E-01	1.29E-02	4.96E-03	1.71E-03	6.03E-04	5.76E-04	2.42E-01
Ag-110m	3.32E-11	3.44E-11	3.94E-12	1.51E-12	5.21E-13	1.84E-13	1.76E-13	7.40E-11
Am-241	8.15E-02	8.45E-02	9.67E-03	3.72E-03	1.28E-03	4.52E-04	4.31E-04	1.82E-01
Am-243	1.24E-03	1.29E-03	1.47E-04	5.66E-05	1.95E-05	6.88E-06	6.57E-06	2.76E-03
Be-10	1.67E-01	1.74E-01	1.99E-02	7.64E-03	2.63E-03	9.28E-04	8.87E-04	3.73E-01
C-14	5.96E+00	6.18E+00	7.08E-01	2.72E-01	9.35E-02	3.30E-02	3.16E-02	1.33E+01
Ce-144	1.02E-09	1.05E-09	1.21E-10	4.64E-11	1.60E-11	5.64E-12	5.38E-12	2.26E-09
Cl-36	5.66E-02	5.87E-02	6.72E-03	2.58E-03	8.88E-04	3.14E-04	3.00E-04	1.26E-01
Cm-243	2.26E-04	2.35E-04	2.69E-05	1.03E-05	3.55E-06	1.25E-06	1.20E-06	5.04E-04
Cm-244	1.44E-01	1.49E-01	1.71E-02	6.55E-03	2.25E-03	7.97E-04	7.61E-04	3.20E-01
Cm-245	2.72E-05	2.82E-05	3.22E-06	1.24E-06	4.26E-07	1.51E-07	1.44E-07	6.05E-05
Cm-246	3.00E-05	3.11E-05	3.56E-06	1.37E-06	4.71E-07	1.66E-07	1.59E-07	6.68E-05
Cm-247	2.11E-10	2.19E-10	2.51E-11	9.63E-12	3.31E-12	1.17E-12	1.12E-12	4.71E-10
Cm-248	3.79E-09	3.93E-09	4.50E-10	1.73E-10	5.95E-11	2.10E-11	2.01E-11	8.45E-09
Co-60	8.85E+02	9.17E+02	1.05E+02	4.03E+01	1.39E+01	4.90E+00	4.68E+00	1.97E+03
Cs-134	1.32E-03	1.37E-03	1.57E-04	6.03E-05	2.07E-05	7.33E-06	7.00E-06	2.95E-03

Table 4. (continued).

Nuclide	Station Point #1 (Ci)	Station Point #2 (Ci)	Station Point #3 (Ci)	Station Point #4 (Ci)	Station Point #5 (Ci)	Station Point #6 (Ci)	Station Point #7 (Ci)	Total (Ci)
Cs-137	1.21E+00	1.26E+00	1.44E-01	5.54E-02	1.91E-02	6.73E-03	6.43E-03	2.71E+00
Eu-152	8.17E-02	8.47E-02	9.70E-03	3.72E-03	1.28E-03	4.53E-04	4.32E-04	1.82E-01
Eu-154	4.70E-01	4.87E-01	5.58E-02	2.14E-02	7.37E-03	2.60E-03	2.49E-03	1.05E+00
Fe-55	—	—	—	—	—	—	—	0.00E+00
H-3	1.48E+04	1.53E+04	1.76E+03	6.74E+02	2.32E+02	8.20E+01	7.83E+01	3.29E+04
I-129	1.91E-06	1.98E-06	2.26E-07	8.69E-08	2.99E-08	1.06E-08	1.01E-08	4.24E-06
Mn-54	1.44E-06	1.49E-06	1.71E-07	6.57E-08	2.26E-08	7.99E-09	7.63E-09	3.21E-06
Nb-94	2.17E+00	2.25E+00	2.58E-01	9.89E-02	3.40E-02	1.20E-02	1.15E-02	4.83E+00
Ni-59	5.94E+01	6.16E+01	7.05E+00	2.71E+00	9.32E-01	3.29E-01	3.15E-01	1.32E+02
Ni-63	1.09E+04	1.13E+04	1.29E+03	4.95E+02	1.70E+02	6.02E+01	5.75E+01	2.42E+04
Np-237	9.64E-07	9.99E-07	1.14E-07	4.39E-08	1.51E-08	5.34E-09	5.10E-09	2.15E-06
Pa-231	6.66E-07	6.90E-07	7.90E-08	3.04E-08	1.04E-08	3.69E-09	3.53E-09	1.48E-06
Pb-210	3.09E-11	3.21E-11	3.67E-12	1.41E-12	4.85E-13	1.71E-13	1.64E-13	6.89E-11
Pu-238	3.75E-02	3.89E-02	4.46E-03	1.71E-03	5.89E-04	2.08E-04	1.99E-04	8.36E-02
Pu-239	8.15E-03	8.45E-03	9.67E-04	3.72E-04	1.28E-04	4.52E-05	4.31E-05	1.82E-02
Pu-240	1.00E-02	1.04E-02	1.19E-03	4.56E-04	1.57E-04	5.54E-05	5.29E-05	2.23E-02
Pu-241	8.15E-01	8.45E-01	9.67E-02	3.72E-02	1.28E-02	4.52E-03	4.31E-03	1.82E+00
Pu-242	1.28E-04	1.32E-04	1.52E-05	5.82E-06	2.00E-06	7.08E-07	6.76E-07	2.84E-04
Pu-244	1.20E-10	1.24E-10	1.42E-11	5.47E-12	1.88E-12	6.65E-13	6.35E-13	2.67E-10
Ra-226	5.00E-11	5.18E-11	5.93E-12	2.28E-12	7.84E-13	2.77E-13	2.65E-13	1.11E-10
Ru-106	1.41E-07	1.46E-07	1.67E-08	6.42E-09	2.21E-09	7.80E-10	7.45E-10	3.13E-07
Sb-125	2.96E-03	3.07E-03	3.52E-04	1.35E-04	4.65E-05	1.64E-05	1.57E-05	6.60E-03
Sr-90	3.79E-01	3.93E-01	4.50E-02	1.73E-02	5.95E-03	2.10E-03	2.01E-03	8.45E-01
Tc-99	2.85E-03	2.95E-03	3.38E-04	1.30E-04	4.47E-05	1.58E-05	1.51E-05	6.34E-03
Th-228	8.05E-05	8.35E-05	9.56E-06	3.67E-06	1.26E-06	4.46E-07	4.26E-07	1.79E-04
Th-229	5.39E-07	5.59E-07	6.40E-08	2.46E-08	8.46E-09	2.99E-09	2.86E-09	1.20E-06
Th-230	5.26E-09	5.46E-09	6.25E-10	2.40E-10	8.26E-11	2.92E-11	2.79E-11	1.17E-08
Th-232	9.20E-07	9.54E-07	1.09E-07	4.20E-08	1.44E-08	5.10E-09	4.87E-09	2.05E-06
U-232	7.75E-05	8.04E-05	9.20E-06	3.53E-06	1.22E-06	4.30E-07	4.11E-07	1.73E-04
U-233	1.53E-04	1.59E-04	1.82E-05	6.97E-06	2.40E-06	8.48E-07	8.10E-07	3.41E-04
U-234	1.38E-05	1.43E-05	1.64E-06	6.29E-07	2.16E-07	7.64E-08	7.30E-08	3.07E-05
U-235	1.14E-07	1.18E-07	1.35E-08	5.20E-09	1.79E-09	6.33E-10	6.04E-10	2.54E-07
U-236	3.24E-07	3.36E-07	3.85E-08	1.48E-08	5.09E-09	1.80E-09	1.72E-09	7.23E-07
U-238	3.83E-06	3.97E-06	4.55E-07	1.75E-07	6.01E-08	2.12E-08	2.03E-08	8.53E-06
Zn-65	7.68E-11	7.96E-11	9.11E-12	3.50E-12	1.20E-12	4.26E-13	4.07E-13	1.71E-10

Table 5. Estimated nuclide inventory associated with the Engineering Test Reactor exhaust air system (Loop 99) (EDF-6304).

	Am-241 (Ci)	Co-60 (Ci)	Cs-137 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-241 (Ci)	Sr-90 (Ci)	U-233 (Ci)	U-235 (Ci)	U-238 (Ci)
Delay tank (TRA-706)	2.02E-07	1.21E-05	1.05E-04	5.04E-08	4.15E-07	5.84E-06	7.28E-06	1.68E-08	1.14E-09	3.72E-08
Primary filter pit (TRA-704)	2.92E-08	1.76E-06	1.52E-05	7.29E-09	6.00E-08	8.45E-07	1.05E-06	2.42E-09	1.65E-10	5.39E-09
Secondary filter pit (TRA-705)	2.92E-08	1.76E-06	1.52E-05	7.29E-09	6.00E-08	8.45E-07	1.05E-06	2.42E-09	1.65E-10	5.39E-09
GEEL tunnel and delay tanks	1.42E-05	8.54E-04	7.38E-03	3.54E-06	2.91E-05	4.10E-04	5.12E-04	1.18E-06	0.00E+00	2.62E-06
Total	1.44E-05	8.69E-04	7.51E-03	3.60E-06	2.97E-05	4.18E-04	5.21E-04	1.20E-06	1.47E-09	2.67E-06

GEEL = General Electric Experimental Loop.
TRA = Test Reactor Area.

Table 6. Total inventory in the Engineering Test Reactor Complex (summary of the nuclide inventory in Tables 2, 3, 4, and 5).

		ETR Complex Surfaces			
Nuclide	ETR Reactor Inventory (EDF-6133) (Ci)	Total ETR Internal Inventory (EDF-6291) (Ci)	External Inventory (EDF-6138) (Ci)	Vaults/Tanks Inventory (EDF-6304) (Ci)	ETR Complex Total Inventory (Ci)
Ac-227	1.01E-06	—[a]	—	—	1.01E-06
Ag-108m	2.42E-01	—	1.17E-04	—	2.42E-01
Ag-110m	7.40E-11	—	—	—	7.40E-11
Am-241	1.82E-01	1.38E-04	—	1.44E-05	1.82E-01
Am-243	2.76E-03	—	—	—	2.76E-03
Be-10	3.73E-01	—	—	—	3.73E-01
C-14	1.33E+01	2.22E-04	4.84E-04	—	1.33E+01
Ce-144	2.26E-09	—	—	—	2.26E-09
Cl-36	1.26E-01	—	—	—	1.26E-01
Cm-243	5.04E-04	—	—	—	5.04E-04
Cm-244	3.20E-01	—	—	—	3.20E-01
Cm-245	6.05E-05	—	—	—	6.05E-05
Cm-246	6.68E-05	—	—	—	6.68E-05
Cm-247	4.71E-10	—	—	—	4.71E-10

Table 6. (continued).

Nuclide	ETR Reactor Inventory (EDF-6133) (Ci)	ETR Complex Surfaces: Total ETR Internal Inventory (EDF-6291) (Ci)	ETR Complex Surfaces: External Inventory (EDF-6138) (Ci)	Vaults/Tanks Inventory (EDF-6304) (Ci)	ETR Complex Total Inventory (Ci)
Cm-248	8.45E-09	—	—	—	8.45E-09
Co-60	1.97E+03	4.03E-01	7.56E-03	8.69E-04	1.97E+03
Cs-134	2.95E-03	—	—	—	2.95E-03
Cs-137	2.71E+00	2.88E-03	4.10E-02	7.51E-03	2.76E+00
Eu-152	1.82E-01	—	—	—	1.82E-01
Eu-154	1.05E+00	—	—	—	1.05E+00
Fe-55	6.63E-03	5.47E-01	—	—	5.47E-01
H-3	3.29E+04	—	—	—	3.29E+04
I-129	4.24E-06	—	2.40E-05	—	2.82E-05
Mn-54	3.21E-06	—	—	—	3.21E-06
Nb-94	4.83E+00	—	—	—	4.83E+00
Ni-59	1.32E+02	1.03E-02	—	—	1.32E+02
Ni-63	2.42E+04	9.82E-01	4.62E-03	—	2.42E+04
Np-237	2.15E-06	—	4.98E-07	—	2.65E-06
Pa-231	1.48E-06	—	—	—	1.48E-06
Pb-210	6.89E-11	—	—	—	6.89E-11
Pu-238	8.36E-02	1.59E-04	6.24E-06	3.60E-06	8.38E-02
Pu-239	1.82E-02	2.47E-04	7.90E-06	2.97E-05	1.85E-02
Pu-240	2.23E-02	—	—	—	2.23E-02
Pu-241	1.82E+00	—	—	4.18E-04	1.82E+00
Pu-242	2.84E-04	—	—	—	2.84E-04
Pu-244	2.67E-10	—	—	—	2.67E-10
Ra-226	1.11E-10	—	—	—	1.11E-10
Ru-106	3.13E-07	—	—	—	3.13E-07
Sb-125	6.60E-03	—	—	—	6.60E-03

Table 6. (continued).

Nuclide	ETR Reactor Inventory (EDF-6133) (Ci)	ETR Complex Surfaces: Total ETR Internal Inventory (EDF-6291) (Ci)	ETR Complex Surfaces: External Inventory (EDF-6138) (Ci)	Vaults/Tanks Inventory (EDF-6304) (Ci)	ETR Complex Total Inventory (Ci)
Sr-90	8.45E-01	2.70E-03	2.92E-03	5.21E-04	8.51E-01
Tc-99	6.34E-03	—	3.70E-05	—	6.38E-03
Th-228	1.79E-04	—	—	—	1.79E-04
Th-229	1.20E-06	—	—	—	1.20E-06
Th-230	1.17E-08	—	—	—	1.17E-08
Th-232	2.05E-06	—	—	—	2.05E-06
U-232	1.73E-04	—	—	—	1.73E-04
U-233	3.41E-04	2.42E-05	4.98E-07	1.20E-06	3.67E-04
U-234	3.07E-05	—	4.98E-07	—	3.12E-05
U-235	2.54E-07	6.48E-07	—	1.47E-09	9.04E-07
U-236	7.23E-07	—	—	—	7.23E-07
U-238	8.53E-06	—	—	2.67E-06	1.12E-05
Zn-65	1.71E-10	—	—	—	1.71E-10

a. "—" indicates nuclide not present.

EDF = Engineering Design File.
ETR = Engineering Test Reactor.

Table 7. Summary of chemical constituent quantities to be left in place in the Engineering Test Reactor Complex (from EDF-6225, Table 3).

Chemical Constituent	Location(s)	Use/Form	Quantity (kg)
Aluminum	ETR vessel	Reactor components	3,340
Antimony	Concrete walls and floors	Alloy used in concrete wall lag shield anchors	0.6
Barium (and compounds)	High-density concrete used in cubicle walls	Additive for heavy concrete used in nuclear shielding (cubicle walls), paint pigment	101,810
Beryllium (and compounds)	ETR vessel	Neutron reflector in the pressure vessel	700
Boron	Shielding for ion chamber drive assembly	Shielding in the ion chamber drive assembly, added to concrete	0.5
Chromium	Piping and other operations components throughout the ETR Complex	Piping, vessels, and other components constructed of stainless steel	35,420
Copper (and compounds)	ETR Complex	Wiring, tubing, rotors, bearings, brass and bronze components, and electrical equipment	36,840
Lead	Wall anchors, floor anchors, and piping	Shielding, alloy of concrete wall lag shield anchors, pipe packing, and brass alloy	40
Manganese (and compounds)	Piping and other operations components throughout ETR Complex	Metal alloy found in piping, vessels, and other components constructed of stainless steel	7,670
Nickel	Piping and other operations components throughout the ETR Complex and gray control rod poison	Metal alloy found in piping, vessels, and other components constructed of stainless steel	19,610
Silver (and compounds)	Electrical control panels	Electrical contacts	40
Tin	ETR Complex	Alloy of bronze (used in gauges, bearings, and flow indicators)	80
Uranium	ETR Complex	Metallic uranium calculated from the activities of the uranium isotopes	0.0338
Zinc	ETR Complex	Significant alloy of brass	740

3. RADIONUCLIDE CONTAMINANT EVALUATION

The inventory for the ETR consisted of 52 individual radionuclides and 15 nonradionuclides. The large number of contaminants presents difficulties in estimating future dose impacts and dilutes resources from those nuclides that are most important. Therefore, contaminant screening was performed to reduce the number of contaminants to a manageable level and focus resources on those contaminants that are most important. Contaminant screening and the conservative risk assessment analysis used are discussed below.

Contaminant transport evaluation and risk assessment were performed through a series of two screening phases, followed by a more detailed risk assessment (presented in Section 4). Each screening phase begins with conservative assumptions. The conservative assumptions are lessened through each phase of the screening process. The two screening analysis phases are as follows:

- Phase 1 screening is only used for radionuclides. It used screening factors developed by the National Council on Radiation Protection (NCRP) (NCRP 1996) together with the estimated contaminant inventory. This screening approach has been used in a variety of past INL studies, including the engineering evaluation/cost analysis for CPP-603 (DOE-NE-ID 2004, EDF-4488) and the Idaho CERCLA Disposal Facility (ICDF) performance assessment (DOE-ID 2003).

- Phase 2 screening used a simple and conservative application of the GWSCREEN (Rood 2003) model to calculate a screening dose, risk, or concentration, based on the contaminant radionuclide or nonradionuclide inventory. The GWSCREEN application considers dispersion and unsaturated transit time, whereas the NCRP does not. The Phase 2 screening application of GWSCREEN is based on the Track 2 screening approach used in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process at the INL Site (DOE-ID 1994). The Track 2 screening approach is documented in *Track 2 Sites: Guidance for Assessing Low Probability Hazard Sites at the INEL* (DOE-ID 1994). The methodology was originally developed to perform conservative analysis on low-probability CERCLA sites with the goal to systematically eliminate No Action sites from further evaluation. Since that time, the methodology has regularly been used for contaminant screening at the INL.

In order to screen nonradionuclides and to calculate a total impact from nonradionuclides, fractions were calculated that are defined as the fraction of the predicted nonradionuclide concentrations to the maximum contaminant levels (MCLs) for each contaminant of concern (COC). For the conservative screening, a peak constituent-specific fraction of 0.1 (peak concentration equal to one-tenth the MCL) was used to eliminate COCs that will not significantly contribute to the total aquifer contamination. For the risk assessment (Section 4), each of the COC fractions is added to calculate a sum of fractions or a measure of the total impact from nonradionuclides at the ETR.

As will be discussed later in this document, not all of the nonradionuclides have an MCL. Yet some measure of the impact on groundwater quality is needed for each nonradionuclide. For purposes of this analysis, constituents with no MCL are conservatively evaluated using other standards. The other standards include secondary MCLs, action levels, maximum contaminant level goals (MCLGs), remanded MCLs, and preliminary remediation goals (PRGs). The U.S. Environmental Protection Agency (EPA) refers to a secondary MCL as a National Secondary Drinking Water Regulation and is a nonenforceable guideline regulating contaminants that might cause cosmetic effects (such as taste, odor, or color) in drinking water. Action levels are related to a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, then water systems must take additional steps to control pipe corrosion. An MCLG is a nonenforceable concentration of a drinking water contaminant that is protective of adverse human health effects and allows an adequate

margin of safety. A remanded MCL is an MCL that was adopted in the past and then removed as an MCL. The MCL for nickel was remanded on February 9, 1995. This means that while many water suppliers continue to monitor nickel levels in their water, there is currently no EPA legal limit on the amount of nickel in drinking water. The EPA is reconsidering the limit on nickel. A PRG is defined by EPA's Region 9 office as a nonenforceable, generic standard for evaluating and cleaning up contaminated sites. It is a risk-based concentration that is intended to assist risk assessors and others in initial screening-level evaluations of environmental measurements.

The nonradionuclide ETR Complex results are presented as fractions relative to the respective MCLs. However, if no MCL is available, the results are presented relative to their secondary MCL (aluminum, manganese, silver, and zinc), EPA-defined action level (copper and lead), EPA-defined MCLG (boron), remanded MCL (nickel), or PRG (tin). The sum of fractions relative to the MCL is calculated for all nonradionuclides regardless of the MCL status, thereby resulting in a conservative representation of the predicted contamination in the aquifer.

3.1 Phase 1 Screening (Radionuclide Only)

The NCRP provides a series of simple screening techniques and factors that can be used to demonstrate compliance with environmental standards or other administratively set reference levels for releases of radionuclides to the atmosphere, surface water, or groundwater. The NCRP screening factor is the product of an environmental transfer factor, exposure factor, and a dose conversion factor (DCF) having units of total effective dose equivalent (EDE) per unit of activity in sieverts per Becquerel (Sv/Bq). These factors incorporate radionuclide fate and transport processes and an assumed exposure scenario to calculate the annual total EDE to a hypothetical receptor per unit of activity in the source volume. The screening factors applicable to groundwater exposure consider leaching and subsequent dilution of radionuclides in groundwater from a generic waste site. Factors are calculated for six delay times: 0, 2, 10, 30, 100, and 1,000 years. During the delay time, radionuclides are decayed and ingrown. The maximum of the six values is then reported in the screening factor tables for groundwater.

The exposure scenario essentially has the entire waste inventory susceptible to leaching over a period of 1 year into a water volume equal to the annual average per capita use of groundwater in rural regions of the United States (91,000 L). The receptor is then assumed to drink 800 L of this contaminated water over a period of 1 year and his/her dose is computed for that intake.

The screening factor for groundwater is given in Equation (1) by (NCRP 1996):

$$SF = \lambda_L \, A_o \frac{U_{DW}}{V} \sum_{i=0}^{N} X_i \, DCF_{ing,i} \tag{1}$$

where

SF	=	groundwater screening factor (Sv/Bq)
λ_L	=	leach rate constant (yr^{-1})
A_o	=	initial activity (Bq)
U_{DW}	=	consumption of drinking water (assumed to be 800 L/yr)
V	=	dilution volume (assumed to be 91,000 L)
X_i	=	annual average fraction of the original parent activity for decay chain member (i)

DCF_{ing} = ingestion dose conversion factor (Sv/Bq)

N = number of progeny in the decay chain.

Assuming there is 100% containment of the waste during the delay time and the release of radioactivity is averaged over the first year of the release following the delay time, the fraction of the original parent activity leached to the dilution volume over 1 year for the parent (X_0) is given in Equation (2) by:

$$X_0 = \frac{\left(1 - e^{-\left(\lambda + \lambda_0^r\right)T_{avg}}\right) e^{-\lambda_0^r T_{del}}}{T_{avg}\left(\lambda_L + \lambda_0^r\right)} \tag{2}$$

where

$\lambda^r{}_o$ = radioactive decay rate constant for parent (yr^{-1})

T_{avg} = averaging time (1 yr)

T_{del} = delay time (yr).

A typographical error in Equation (2) was noted in the NCRP text. The fraction of progeny activity relative to the parent that is leached to the dilution volume is given in Equation (3) by:

$$X_i = \frac{1}{T_{avg}}\left(\prod_{j=1}^{K} \lambda_j^r f_j\right)\sum_{h=0}^{N} \frac{\left(1 - e^{-\lambda_h^r T_{avg}}\right) e^{-\lambda_h^r T_{del}}}{\lambda_h^r \prod_{\substack{p=0 \\ p \neq h}}^{K}\left(\lambda_p^r + \lambda_h^r\right)} \tag{3}$$

where

f_j = fraction of parent decaying to *jth* progeny

$\lambda^r{}_h$ = radioactive decay rate constant for *jth* progeny parent (yr^{-1}).

The leach rate constant is taken from a formulation described in "A Proposal for Estimation of Soil Leaching and Leaching Constants for Use in Assessment Models" (Baes and Sharp 1983) and used in the models RESRAD (Yu et al. 2001), Multimedia Environmental Pollutant Assessment System (MEPAS) (Whelan et al. 1996), and GWSCREEN (Rood 2003). The leach rate constant is given in Equation (4) by:

$$\lambda_L = \frac{I}{H\,\theta\left(1 + \frac{K_d \rho}{\theta}\right)} \tag{4}$$

where

I = assumed infiltration rate (0.18 m yr^{-1})

H = assumed waste thickness (0.5 m)

ρ = bulk density (cm^3/g)

K_d = sorption coefficient (cm^3/g)

θ = moisture content (0.3 m^3/m^3).

Values for the sorption coefficient used in the NCRP screening were taken from the *Residual Radioactive Contamination from Decommissioning* (Kennedy and Strenge 1992). The assumed infiltration rate represents the upper-bound infiltration rate determined for low-level radioactive waste sites located in the southeastern United States.

The assumption is made in Equation (3) that the unsaturated travel time is instantaneous. For the INL Site, this is an extremely conservative assumption, because unsaturated contaminant travel times have been estimated to take from several years to hundreds of thousands of years depending on the sorption properties of the contaminant. Under these assumptions, the NCRP groundwater-screening model provides a conservative estimate of the potential dose.

Nuclides with an NCRP screening dose of less than 1 mrem (1×10^{-5} Sv) were removed from further consideration. These nuclides are identified in Table 8 along with their NCRP screening dose value. The NCRP screening dose is calculated by multiplying the radionuclide inventory by the NCRP screening dose factor. For example, the NCRP screening dose for Ac-227 is shown in Equation (5):

$$SD = 1.01 \times 10^{-6}\ \text{Ci} \times 3.7 \times 10^{10}\ \frac{\text{Bq}}{\text{Ci}} \times 8.1 \times 10^{-12}\ \frac{\text{Sv}}{\text{Bq}} = 3.03 \times 10^{-7}\ \text{Sv} \quad . \tag{5}$$

Of the 52 nuclides for which inventories are reported in Section 2 and repeated in Table 8, almost half of the nuclides were screened in Phase 1, leaving 28 nuclides for further evaluation. These 28 nuclides were retained for the Phase 2 evaluation.

Table 8. Phase 1 screening results for radionuclides using the National Council on Radiation Protection screening factors.[a]

Radionuclide	Radioactive Half-Life (yr)	ETR Inventory (Ci)	ETR Inventory (Bq)	Groundwater Ingestion NCRP Screening Factor (Sv/Bq)	Screening Dose (Sv)	Is Screening Dose >1 mrem? (>1 × 10^{-5} Sv?)
Ac-227	2.18E+01	1.01E-06	3.74E+04	8.1E-12	3.0E-07	No
Ag-108m	**4.18E+02**	**2.42E-01**	**8.96E+09**	**4.2E-14**	**3.8E-04**	**Yes**
Ag-110m	6.84E-01	7.40E-11	2.74E+00	5.2E-15	1.4E-14	No
Am-241	**4.32E+02**	**1.82E-01**	**6.74E+09**	**5.9E-13**	**4.0E-03**	**Yes**
Am-243	**7.37E+03**	**2.76E-03**	**1.02E+08**	**6.0E-13**	**6.1E-05**	**Yes**
Be-10	**1.51E+06**	**3.73E-01**	**1.38E+10**	**1.4E-14**	**1.9E-04**	**Yes**
C-14	**5.70E+03**	**1.33E+01**	**4.92E+11**	**1.6E-13**	**7.9E-02**	**Yes**
Ce-144	7.81E-01	2.26E-09	8.36E+01	3.6E-15	3.0E-13	No
Cl-36	**3.01E+05**	**1.26E-01**	**4.66E+09**	**8.3E-13**	**3.9E-03**	**Yes**
Cm-243	2.91E+01	5.04E-04	1.86E+07	1.5E-13	2.8E-06	No
Cm-244	**1.81E+01**	**3.20E-01**	**1.18E+10**	**1.1E-13**	**1.3E-03**	**Yes**
Cm-245	8.50E+03	6.05E-05	2.24E+06	5.1E-13	1.1E-06	No
Cm-246	4.76E+03	6.68E-05	2.47E+06	2.9E-13	7.2E-07	No
Cm-247	1.56E+07	4.71E-10	1.74E+01	3.0E-13	5.2E-12	No
Cm-248	3.48E+05	8.45E-09	3.13E+02	1.1E-12	3.4E-10	No
Co-60	**5.27E+00**	**1.97E+03**	**7.29E+13**	**5.8E-14**	**4.2E+00**	**Yes**
Cs-134	2.07E+00	2.95E-03	1.09E+08	4.2E-15	4.6E-07	No
Cs-137	**3.01E+01**	**2.76E+00**	**1.02E+11**	**7.7E-14**	**7.9E-03**	**Yes**
Eu-152	**1.35E+01**	**1.82E-01**	**6.73E+09**	**9.1E-15**	**6.1E-05**	**Yes**
Eu-154	**8.59E+00**	**1.05E+00**	**3.89E+10**	**1.1E-14**	**4.3E-04**	**Yes**
Fe-55	**2.74E+00**	**5.47E-01**	**2.02E+10**	**9.9E-16**	**2.0E-05**	**Yes**
H-3	**1.23E+01**	**3.29E+04**	**1.22E+15**	**5.9E-14**	**7.2E+01**	**Yes**
I-129	**1.57E+07**	**2.82E-05**	**1.04E+06**	**1.9E-10**	**2.0E-04**	**Yes**
Mn-54	8.56E-01	3.21E-06	1.19E+05	3.8E-15	4.5E-10	No
Nb-94	**2.03E+04**	**4.83E+00**	**1.79E+11**	**2.7E-14**	**4.8E-03**	**Yes**
Ni-59	**7.60E+04**	**1.32E+02**	**4.88E+12**	**3.2E-16**	**1.6E-03**	**Yes**
Ni-63	**1.00E+02**	**2.42E+04**	**8.95E+14**	**8.6E-16**	**7.7E-01**	**Yes**
Np-237	**2.14E+06**	**2.65E-06**	**9.80E+04**	**2.4E-10**	**2.4E-05**	**Yes**
Pa-231	3.28E+04	1.48E-06	5.48E+04	1.5E-11	8.2E-07	No
Pb-210	2.23E+01	6.89E-11	2.55E+00	5.4E-12	1.4E-11	No
Pu-238	**8.77E+01**	**8.38E-02**	**3.10E+09**	**1.7E-12**	**5.3E-03**	**Yes**
Pu-239	**2.41E+04**	**1.85E-02**	**6.84E+08**	**2.0E-12**	**1.4E-03**	**Yes**
Pu-240	**6.56E+03**	**2.23E-02**	**8.25E+08**	**2.0E-12**	**1.7E-03**	**Yes**
Pu-241	**1.43E+01**	**1.82E+00**	**6.74E+10**	**6.1E-14**	**4.1E-03**	**Yes**
Pu-242	**3.73E+05**	**2.84E-04**	**1.05E+07**	**1.9E-12**	**2.0E-05**	**Yes**
Pu-244	8.00E+07	2.67E-10	9.88E+00	2.2E-12	2.2E-11	No
Ra-226	1.60E+03	1.11E-10	4.11E+00	4.6E-12	1.9E-11	No
Ru-106	1.02E+00	3.13E-07	1.16E+04	6.5E-14	7.5E-10	No
Sb-125	2.76E+00	6.60E-03	2.44E+08	3.6E-15	8.8E-07	No
Sr-90	**2.88E+01**	**8.51E-01**	**3.15E+10**	**3.5E-12**	**1.1E-01**	**Yes**

Table 8. (continued).

Radionuclide	Radioactive Half-Life (yr)	ETR Inventory (Ci)	ETR Inventory (Bq)	Groundwater Ingestion NCRP Screening Factor (Sv/Bq)	Screening Dose (Sv)	Is Screening Dose >1 mrem? (>1 × 10^{-5} Sv?)
Tc-99	**2.11E+05**	**6.38E-03**	**2.36E+08**	**3.2E-12**	**7.6E-04**	**Yes**
Th-228	1.91E+00	1.79E-04	6.62E+06	2.1E-15	1.4E-08	No
Th-229	7.34E+03	1.20E-06	4.44E+04	3.6E-13	1.6E-08	No
Th-230	7.54E+04	1.17E-08	4.33E+02	5.2E-13	2.3E-10	No
Th-232	1.41E+10	2.05E-06	7.59E+04	4.8E-13	3.6E-08	No
U-232	**6.89E+01**	**1.73E-04**	**6.40E+06**	**3.3E-11**	**2.1E-04**	**Yes**
U-233	**1.59E+05**	**3.67E-04**	**1.36E+07**	**1.1E-11**	**1.5E-04**	**Yes**
U-234	2.46E+05	3.12E-05	1.15E+06	4.2E-12	4.8E-06	No
U-235	7.04E+08	9.04E-07	3.34E+04	1.4E-11	4.7E-07	No
U-236	2.34E+07	7.23E-07	2.68E+04	3.4E-12	9.1E-08	No
U-238	**4.47E+09**	**1.12E-05**	**4.14E+05**	**1.4E-10**	**5.8E-05**	**Yes**
Zn-65	6.69E-01	1.71E-10	6.33E+00	2.9E-15	1.8E-14	No

a. Radionuclides with a screening dose ≥ 1 mrem are in bold and are highlighted. These nuclides were retained for further analysis.

ETR = Engineering Test Reactor.
NCRP = National Council on Radiation Protection.

3.2 Phase 2 Screening

Phase 2 screening used a conservative implementation of the groundwater-screening model GWSCREEN Version 2.5 (Rood 2003) to calculate groundwater concentrations' ingestion doses and risk for nuclides that were not screened in Phase 1. For the 15 nonradionuclides in the inventory, the peak concentration was calculated for comparison with the MCL or a related limiting value. The GWSCREEN model was developed to address CERCLA sites at the INL Site. The code, coupled with a set of default parameter values identified in the CERCLA Track 2 risk assessment process (DOE-ID 1994), provides conservative estimates of groundwater concentrations and the related ingestion doses and risks at the INL Site. The contaminants are screened based on the predicted peak dose and risk for radionuclides and the predicted peak concentration for nonradionuclides.

The GWSCREEN conceptual model is illustrated in Figure 13. The following are primary assumptions in the flow and transport analysis:

- All radionuclides present in the ETR are assumed to be mixed homogeneously with soil and placed in a volume represented by the volume of the ETR belowground structure, 35 m × 35 m. Although the contamination is initially focused in the reactor, the contamination will have to be released from the metal by corrosion, leached into the backfill in the ETR, and move through the ETR facility and the ETR concrete base. In the process, significant spreading will occur. In addition, after leaving the ETR facility, the contamination will spread as it is transported to the aquifer through the vadose zone. The source length and width used in the GWSREEN model represent both the source area and the final area over which the contaminants will enter the aquifer. The length and width assumption of the ETR footprint is a simple but reasonable assumption for this complex process.

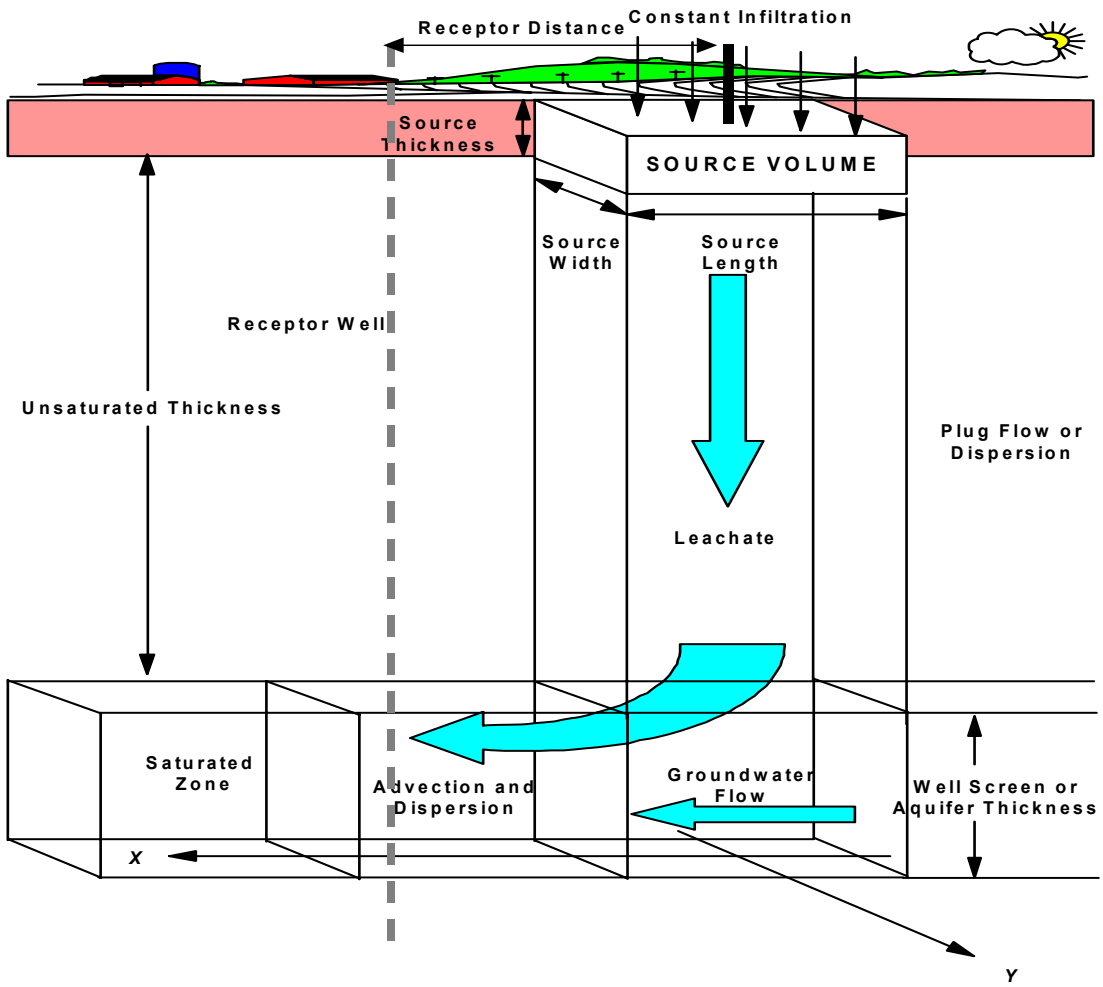

Figure 13. Conceptual model for GWSCREEN groundwater transport model. (For the Engineering Test Reactor analysis, the receptor is at the edge of the source.)

- One-dimensional transport in an 18.3-m (60-ft) -thick unsaturated zone composed of sedimentary interbeds is assumed. This thickness of the vadose zone sedimentary interbeds is based on well log evaluations used to define the perched water remedial investigation (RI) modeling (EGG 1992). The total interbed thickness is conservatively assumed to consist only of the interbed 140 ft below ground surface and neglects the interbed that is 500 ft below ground surface.

- The receptor well is placed on the downgradient edge of the ETR facility. Note that the receptor distance is measured from the center of the source; therefore, the distance to the receptor well is 35 m ÷ 2 = 17.5 m (57.4 ft).

- The conceptual model assumes no containment, engineered barriers, gradual releases to the source via corrosion, or solubility-limited releases. The waste is then assumed to be exposed to infiltrating water, and contaminants are leached from the waste and move into the subsurface.

- The Track 2 default infiltration rate is 10 cm/yr (3.9 in./yr).

- No dispersion in the unsaturated zone is assumed. Generally, this is a conservative assumption. However, if the contaminant's travel time through the vadose zone is much less than the radioactive decay half-life, then it is possible that the assumption is not conservative. The screening results were critically reviewed and this exception has basically no effect on this particular analysis.

- The subsurface environment beneath the INL Site comprises basalt flows separated by sedimentary interbeds. The basalt flows are oftentimes fractured, allowing water to move freely in the vertical direction. The Track 2 methodology (DOE-ID 1994) recognized this feature of the system and assumed that water transport time through the fractured basalt is relatively instantaneous. The overall unsaturated transit time is controlled by the presence of sedimentary interbeds. Therefore, only transport through sedimentary interbeds was considered when computing contaminant transport in the unsaturated zone.

- The aquifer was assumed to be homogeneous isotropic media of infinite lateral extent and finite thickness.

- Contaminants entering the aquifer from the unsaturated zone mix with water in the aquifer over a depth defined by a typical well screen of 15 m (49.2 ft). Concentrations are then evaluated at the downgradient edge of the source. This receptor is the point where the highest concentrations in the aquifer are computed.

The GWSCREEN model also considers transport of radioactive progeny. For simplicity, progeny are assumed to travel at the same rate as their parent. Under most circumstances, this assumption leads to conservative dose estimates at the receptor point. However, when considering the transport of a short-lived immobile parent that has a long-lived mobile progeny, results can be distorted and, in many cases, are not conservative. This situation occurs for the Cm-244⇒Pu-240, Pu-241⇒Am-241⇒Np-237 and Pu-238⇒U-234 decay chains. In general, the short-lived immobile parent nuclide never leaves the waste zone and, instead, decays to its more mobile long-lived progeny. The sorption characteristics of the progeny then determine the overall transit time of the decay chain along with accompanying radiation dose.

For conservatism, the entire activity of the short-lived immobile parent is converted to the equivalent progeny activity—Equation (6)—by:

$$A_{Prog} = A_{Parent} \frac{T_{parent}}{T_{Prog}} \tag{6}$$

where

A_{Prog}	=	equivalent activity of the long-lived mobile progeny (Ci)
A_{Parent}	=	original activity of the short-lived immobile parent (Ci)
T_{Prog}	=	half-life of the long-lived mobile progeny (years)
T_{Parent}	=	half-life of the short-lived immobile parent (years).

The dose-analysis receptor scenario assumes the person drinks 2 L of water per day for 365 days per year. Annual ingestion doses are computed using DCFs published in *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion* (EPA 1988) and include contributions from all progeny.

The annual dose from human consumption of drinking water is calculated in Equation (7) using:

$$D = C_{GW} \times U_W \times DCF \tag{7}$$

where

D	=	dose (cumulative effective dose equivalent) from 1 year's consumption of contaminated media, in this case groundwater (rem/yr)
C_{GW}	=	radionuclide concentration in groundwater (Ci/L)
U_W	=	human consumption rate of water (L/yr)
DCF	=	ingestion dose conversion factor (rem/Ci).

For radionuclides, the cancer risk was calculated assuming the receptor ingests water at the peak concentration for a duration of 30 years. The radiological dose coefficients are published in *Cancer Risk Coefficients for Environmental Exposure to Radionuclides* (EPA 1999). The calculation was done using the GWSCREEN model. The cancer risk was calculated in Equation (8) as:

$$R = C \times I \times ED \times RC \tag{8}$$

where

R	=	cancer risk
C	=	predicted peak aquifer concentration (pCi/L)
I	=	ingestion rate (2 L/d)
ED	=	exposure duration (30 years)
RC	=	risk coefficient (risk/pCi).

The radionuclides are screened from further analysis if the predicted peak dose or the predicted peak risk fails the screening criteria. The radionuclide screening criteria for Phase 2 screening were set at:

- One-tenth of the allowable drinking water dose for beta-gamma emitters of 4 mrem/yr, as stated in 40 CFR 141, "National Primary Drinking Water Regulations" (EDE <0.4 mrem/yr). The EDE is an effective dose equivalent. Although this standard applies only to beta-gamma-emitting nuclides and is calculated using International Commission on Radiological Protection (ICRP) 2 methodology (ICRP 1960), the 0.4-mrem screening criteria, coupled with other conservative assumptions, are believed to be sufficiently stringent to avoid screening any nuclides of importance from the inventory.

- Lifetime cancer incidence risk $<10^{-6}$.

- For nonradionulides, the screening criterion was set at one-tenth the MCL or applicable secondary MCL, action level, MCLG, remanded MCL, or PRG if no MCL has been defined.

A nuclide is defined as a COC if the predicted peak dose (EDE) is greater than 0.4 mrem/yr or the predicted peak risk is greater than 10^{-6}. A nonradionuclide is defined as a COC if the predicted peak concentration is greater than the MCL or a related limiting concentration.

Input data for the GWSCREEN screening simulation (Table 9) were primarily obtained from the *Track 2 Sites: Guidance for Assessing Low Probability Hazard Sites at the INEL* (DOE-ID 1994). The dimension of the waste disposal site, Darcy velocity in the aquifer, and the sedimentary interbed thickness in the unsaturated zone are site-specific values.

3.2.1 Radionuclide Screening

Nuclide-specific parameter data are reported in the results table (Table 10). The primary source of sorption coefficient (K_d) data was from the *Track 2 Sites: Guidance for Assessing Low Probability Hazard Sites at the INEL* (DOE-ID 1994), which provided guidance for screening across the INL Site. If a value for a given nuclide did not exist in the Track 2 report (DOE-ID 1994), then "K_d Values for INTEC Groundwater Modeling"[a] was consulted. The K_d values given in "K_d Values for INTEC Groundwater Modeling" (see footnote a) were developed for the ICDF but are assumed to be applicable for this site. The K_d selected values were assumed to be applicable to sedimentary rocks and materials that make up the surface alluvium and interbeds found in the vicinity of the ETR. Sorption coefficients in fractured basalt, which makes up most of the aquifer, tend to be lower than in sedimentary materials, because surface area of available sorption sites is lacking. The ratio of the aquifer basalt-to-soil K_d value was estimated in the *Comprehensive RI/FS for the Idaho Chemical Processing Plant OU 3-13 at the INEEL—Part A, RI/BRA Report (Final)* (DOE-ID 1997) to be 0.04 and has been commonly used at the INL in later studies. Therefore, it will be used for this ETR evaluation. The ratio was multiplied by all sediment K_d values to obtain the aquifer K_d values used in the GWSCREEN simulation. The infiltration rate is set at 10 cm/yr, which is a factor of 10 times the undisturbed soil infiltration assumed for INL Site soils.

Using the criteria that the predicted peak dose is greater than 0.4 mrem/yr and/or the predicted peak risk is greater than 10^{-6}, C-14, Cl-36, H-3, Ni-59, and Pu-239 were defined as COCs, and the remaining nuclides were eliminated from further consideration (Table 10). Note that this assessment used the Track 2 screening assumptions and K_d values for soils. Any closure action (such as grouting) would tend to decrease the screened contaminants' mobility and further decrease the predicted dose and risk in the aquifer. In addition, any soil cover that decreases the infiltration rate from 10 cm/yr (Track 2 screening value) to 1 cm/yr (undisturbed INL Site sediment estimate) would decrease the predicted peak concentration by an order of magnitude. Note that the high pH environment created by a grout does not necessarily decrease mobility for all contaminants (as discussed in the next section) but it does for the screened constituents.

3.2.2 Nonradionuclide Screening

The chemical-specific parameter data are reported in the results table (Table 11). As with the radionuclide Phase 2 evaluation, the infiltration rate is set at 10 cm/yr, which is a factor of 10 times the undisturbed soil infiltration assumed for INL Site soils.

Using the one-tenth the MCL (or related water concentration) as a screening criteria, about half of the nonradionuclides were screened from further consideration (Table 11). The nonradionuclides remaining after the screen are barium, beryllium, chromium, copper, manganese, and nickel. Of these, only barium, beryllium, and chromium have MCLs assigned. The others have nonenforceable guidelines (copper has an action level, manganese has a secondary MCL, and the nickel MCL has been remanded). The only nonradionuclide with a predicted peak aquifer concentration greater than the MCL is chromium. Note again that this assessment used basically the Track 2 screening assumptions and K_d values for soils. Any closure action such as grouting would tend to decrease the screened contaminants' mobility and further decrease the predicted dose and risk in the aquifer. An example of an exception to this statement

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a. Jenkins, T., DOE Idaho Operations Office, to Marty Doornbos, Idaho National Engineering and Environmental Laboratory, July 3, 2001, "K_d Values for INTEC Groundwater Modeling."

Table 9. Contaminant-independent parameter values for Phase 2 screening of the Engineering Test Reactor inventories.

Parameter	Value	Reference
Source		
Length parallel to groundwater flow	35 m	Assumed contaminant footprint at the ETR and at the water table (assumes no spreading in the vadose zone)
Width perpendicular to groundwater flow	35 m	Assumed contaminant footprint at the ETR and at the water table (assumes no spreading in the vadose zone)
Thickness of source[a]	6 m	Based on the facility description
Background percolation rate	0.1 m/yr	Track 2 report (DOE-ID 1994)
Water-filled porosity—source	0.3	Track 2 report (DOE-ID 1994)
Bulk density—source	1.5 g/cm^3	Track 2 report (DOE-ID 1994)
Unsaturated Zone		
Cumulative vadose zone interbed thickness	18.3 m	TRA perched water RI (EGG 1992)
Water-filled porosity—unsaturated zone	0.3	Track 2 report (DOE-ID 1994)
Bulk density—unsaturated zone	1.5 g/cm^3	Assumed to be sediment-like source
Longitudinal dispersivity	0 m	Generally conservative
Aquifer		
Aquifer thickness	76 m	Track 2 report (DOE-ID 1994)
Well screen thickness[b]	15 m	Track 2 report (DOE-ID 1994)
Aquifer porosity	0.1	Track 2 report (DOE-ID 1994)
Darcy velocity in aquifer	57 m/yr	Track 2 report (DOE-ID 1994)
Average linear velocity	570 m/yr	Darcy velocity divided by porosity
Longitudinal dispersivity	9 m	Track 2 report (DOE-ID 1994)
Transverse dispersivity	4 m	Track 2 report (DOE-ID 1994)
Vertical dispersivity	0.1 m	Conservatively assumed to be small
Bulk density—saturated zone	1.9 g/cm^3	Track 2 report (DOE-ID 1994)
Receptor Distance from the Center of the Source		
Parallel to groundwater flow direction	17.5 m	Point of maximum concentration, based on guidance in the Track 2 report (DOE-ID 1994)
Perpendicular to groundwater flow direction	0 m	Track 2 report (DOE-ID 1994)

Table 9. (continued).

Parameter	Value	Reference
Receptor Scenario		
Water ingestion rates for receptor	2 L/d	Track 2 report (DOE-ID 1994)
Exposure frequency (dose)	365 d/yr	Track 2 report (DOE-ID 1994)
Exposure frequency (carcinogenic risk)	350 d/yr	Track 2 report (DOE-ID 1994)
Exposure duration (dose)	1 yr	Compare to annual dose
Exposure duration (carcinogenic risk)	30 yr	Track 2 report (DOE-ID 1994)

a. The source term thickness is assumed to be basically the height of the reactor portion of the facility. In reality, the facility is significantly deeper and contamination is distributed over that depth. Concentrating the inventory in 6 m is conservative.
b. A vertically averaged solution is used in accordance with the Track 2 guidance (DOE-ID 1994). Thickness of the vertical section is taken to be the well screen thickness.

NCRP = National Council on Radiation Protection.
RI = remedial investigation.
WAG = waste area group.

Table 10. Radionuclide Phase 2 groundwater pathway screening results.[a]

Nuclide	Progeny	Half-Life (yr)	K_d (mL/g)	Peak Time (yr)	Screening Level Predicted Peak Concentration (pCi/L)	Ingestion Dose Conversion Factor (rem/Ci)	Peak Decay Chain Dose (mrem)	Total Dose (mrem)	Morbidity Risk Coefficient (risk/pCi)	Peak Risk	Total Risk
Ag-108m	—	4.18E+02	90	24,777	1.1E-18	7.62E+03	6.0E-21	6.0E-21	8.14E-12	1.7E-25	1.7E-25
Am-241[b] (as Np-237)	—	2.14E+06	8	2,254	1.3E-03	4.44E+06	4.1E-03	4.1E-03	6.18E-11	1.6E-09	1.6E-09
	U-233	1.59E+05	6	—	1.6E-05	2.89E+05	3.3E-06	—	7.18E-11	2.3E-11	—
	Th-229	7.34E+03	100	—	1.1E-07	3.53E+06	2.9E-07	—	2.24E-10	5.2E-13	—
Am-243	—	7.37E+03	340	93,468	3.5E-07	3.62E+06	9.2E-07	2.6E-03	1.03E-10	7.5E-13	2.8E-09
	Pu-239	2.41E+04	22	—	1.0E-03	3.54E+06	2.6E-03	—	1.35E-10	2.8E-09	—
	U-235	7.04E+08	6	—	1.0E-06	2.66E+05	2.0E-07	—	6.96E-11	1.5E-12	—
	Pa-231	3.28E+04	550	—	8.8E-09	1.06E+07	6.8E-08	—	1.73E-10	3.2E-14	—
	Ac-227	2.18E+01	450	—	1.1E-08	1.41E+07	1.1E-07	—	2.01E-10	4.6E-14	—
Be-10	—	1.51E+06	250	68,755	4.1E-01	4.66E+03	1.4E-03	1.4E-03	7.03E-12	6.0E-08	6.0E-08
C-14	—	5.70E+03	0.1	83	1.2E+04	2.09E+03	1.9E+01	1.9E+01	1.55E-12	2.4E-04	2.4E-04
Cl-36	—	3.01E+05	0	55	1.8E+02	3.03E+03	3.9E-01	3.9E-01	3.30E-12	6.0E-06	6.0E-06
Cm-244[b] (as Pu-240)	—	6.56E+03	22	19,944	0.0E+00	3.54E+06	1.5E-02	1.5E-02	1.35E-10	0.0E+00	0.0E+00
	U-236	2.34E+07	6	—	0.0E+00	2.69E+05	9.3E-07	—	6.70E-11	0.0E+00	—
	Th-232	1.41E+10	100	—	0.0E+00	2.73E+06	1.1E-13	—	1.01E-10	0.0E+00	—
	Ra-228	1.60E+03	100	—	0.0E+00	1.44E+06	3.2E-14	—	1.04E-09	0.0E+00	—
	Th-228	1.91E+00	100	—	0.0E+00	3.96E+05	8.7E-15	—	1.07E-10	0.0E+00	—
Co-60	—	5.27E+00	10	9,164	0.0E+00	2.69E+04	0.0E+00	0.0E+00	1.57E-11	0.0E+00	0.0E+00
Cs-137	—	3.01E+01	500	449,370	0.0E+00	5.00E+04	0.0E+00	0.0E+00	3.04E-11	0.0E+00	0.0E+00
Eu-152	—	1.35E+01	240	215,790	0.0E+00	6.48E+03	0.0E+00	0.0E+00	6.07E-12	0.0E+00	0.0E+00
Eu-154	—	8.59E+00	240	215,790	0.0E+00	9.55E+03	0.0E+00	0.0E+00	1.03E-11	0.0E+00	0.0E+00
Fe-55	—	2.74E+00	220	197,820	0.0E+00	6.07E+02	0.0E+00	0.0E+00	8.62E-13	0.0E+00	0.0E+00
H-3	—	1.23E+01	0	55	2.0E+06	6.40E+01	9.6E+01	9.6E+01	5.07E-14	6.5E-04	6.5E-04
I-129	—	1.57E+07	0	55	3.9E-02	2.76E+05	7.9E-03	7.9E-03	1.48E-10	6.1E-08	6.1E-08
Nb-94	—	2.03E+04	100	27,534	5.3E+00	7.14E+03	2.8E-02	2.8E-02	7.77E-12	8.6E-07	8.6E-07
Ni-59	—	7.60E+04	100	27,535	2.9E+02	2.10E+02	4.4E-02	4.4E-02	2.74E-13	1.7E-06	1.7E-06

Table 10. (continued).

Nuclide	Progeny	Half-Life (yr)	K_d (mL/g)	Peak Time (yr)	Screening Level Predicted Peak Concentration (pCi/L)	Ingestion Dose Conversion Factor (rem/Ci)	Peak Decay Chain Dose (mrem)	Total Dose (mrem)	Morbidity Risk Coefficient (risk/pCi)	Peak Risk	Total Risk
Ni-63	—	1.00E+02	100	90,018	0.0E+00	5.77E+02	0.0E+00	0.0E+00	6.70E-13	0.0E+00	0.0E+00
Np-237	—	2.14E+06	8	2,254	9.1E-05	4.44E+06	3.0E-04	3.0E-04	6.18E-11	1.1E-10	1.2E-10
	U-233	1.59E+05	6	—	1.1E-06	2.89E+05	2.4E-07	—	7.18E-11	1.7E-12	—
	Th-229	7.34E+03	100	—	8.1E-09	3.53E+06	2.1E-08	—	2.24E-10	3.8E-14	—
Pu-238[b] (as U-234)	—	2.46E+05	6	1,704	1.4E-03	2.83E+05	2.8E-04	2.8E-04	7.07E-11	1.9E-09	2.0E-09
	Th-230	7.54E+04	100	—	1.5E-06	5.48E+05	6.1E-07	—	9.10E-11	2.8E-12	—
	Ra-226	1.60E+03	100	—	4.5E-07	1.32E+06	4.3E-07	—	3.85E-10	3.6E-12	—
	Pb-210	2.23E+01	100	—	4.3E-07	5.37E+06	1.7E-06	—	8.81E-10	7.9E-12	—
Pu-239	—	2.41E+04	22	6,101	2.0E-01	3.54E+06	5.1E-01	5.1E-01	1.35E-10	5.4E-07	5.4E-07
	U-235	7.04E+08	6	—	4.1E-06	2.66E+05	8.0E-07	—	6.96E-11	5.8E-12	—
	Pa-231	3.28E+04	550	—	3.5E-09	1.06E+07	2.7E-08	—	1.73E-10	1.2E-14	—
	Ac-227	2.18E+01	450	—	4.2E-09	1.41E+07	4.3E-08	—	2.01E-10	1.7E-14	—
Pu-240	—	6.56E+03	22	6,101	1.5E-01	3.54E+06	3.8E-01	3.8E-01	1.35E-10	4.1E-07	4.1E-07
	U-236	2.34E+07	6	—	1.2E-04	2.69E+05	2.4E-05	—	6.70E-11	1.6E-10	—
	Th-232	1.41E+10	100	—	1.4E-12	2.73E+06	2.9E-12	—	1.01E-10	3.0E-18	—
	Ra-228	1.60E+03	100	—	7.6E-13	1.44E+06	8.0E-13	—	1.04E-09	1.6E-17	—
	Th-228	1.91E+00	100	—	7.6E-13	3.96E+05	2.2E-13	—	1.07E-10	1.7E-18	—
Pu-241[b] (as Np-237)	—	2.14E+06	8	2,254	4.2E-04	4.44E+06	1.3E-03	1.3E-03	6.18E-11	5.2E-10	5.3E-10
	U-233	1.59E+05	6	—	5.2E-06	2.89E+05	1.1E-06	—	7.18E-11	7.6E-12	
	Th-229	7.34E+03	100	—	3.7E-08	3.53E+06	9.6E-08	—	2.24E-10	1.7E-13	
Pu-242	—	3.73E+05	22	6,101	3.6E-03	3.36E+06	8.7E-03	8.7E-03	1.28E-10	9.3E-09	9.3E-09
	U-238	4.47E+09	6	—	1.1E-08	2.55E+05	2.0E-09	—	6.40E-11	1.4E-14	—
	U-234	2.46E+05	6	—	9.3E-11	2.83E+05	1.9E-11	—	7.07E-11	1.3E-16	—
	Th-230	7.54E+04	100	—	1.2E-13	5.48E+05	4.9E-14	—	9.10E-11	2.3E-19	—
	Ra-226	1.60E+03	100	—	5.2E-14	1.32E+06	5.0E-14	—	3.85E-10	4.1E-19	—
	Pb-210	2.23E+01	100	—	5.1E-14	5.37E+06	2.0E-13	—	8.81E-10	9.2E-19	—

Table 10. (continued).

Nuclide	Progeny	Half-Life (yr)	K_d (mL/g)	Peak Time (yr)	Screening Level Predicted Peak Concentration (pCi/L)	Ingestion Dose Conversion Factor (rem/Ci)	Peak Decay Chain Dose (mrem)	Total Dose (mrem)	Morbidity Risk Coefficient (risk/pCi)	Peak Risk	Total Risk
Sr-90	—	2.88E+01	12	3,351	1.8E-34	1.42E+05	1.9E-35	1.9E-35	5.59E-11	1.6E-40	1.6E-40
Tc-99	—	2.11E+05	0	55	8.9E+00	1.46E+03	9.5E-03	9.5E-03	2.75E-12	2.5E-07	2.5E-07
U-232	—	6.89E+01	6	1,704	2.8E-10	1.31E+06	2.7E-10	2.8E-10	2.92E-10	1.5E-15	1.5E-15
	Th-228	1.91E+00	100	—	2.1E-11	3.96E+05	6.1E-12	—	1.07E-10	4.0E-17	—
U-233	—	1.59E+05	6	1,704	1.7E-02	2.89E+05	3.5E-03	4.0E-03	7.18E-11	2.4E-08	2.5E-08
	Th-229	7.34E+03	100	—	1.8E-04	3.53E+06	4.6E-04	—	2.24E-10	8.2E-10	—
U-238	—	4.47E+09	6	1,704	5.1E-04	2.55E+05	9.5E-05	9.5E-05	6.40E-11	6.6E-10	6.7E-10
	U-234	2.46E+05	6	—	2.4E-06	2.83E+05	5.0E-07	—	7.07E-11	3.5E-12	—
	Th-230	7.54E+04	100	—	1.4E-09	5.48E+05	5.5E-10	—	9.10E-11	2.6E-15	—
	Ra-226	1.60E+03	100	—	2.8E-10	1.32E+06	2.7E-10	—	3.85E-10	2.3E-15	—
	Pb-210	2.23E+01	100	—	2.7E-10	5.37E+06	1.1E-09	—	8.81E-10	4.9E-15	—

a. Highlighting indicates these nuclides were retained for further evaluation.
b. Nuclides followed by a progeny in parentheses are assumed to decay instantaneously to the progeny and the progeny is simulated for this evaluation.

Table 11. Nonradionuclide Phase 2 groundwater pathway screening results using Track 2 (DOE-ID 1994) assumptions.[a]

Contaminant	K_d (mL/g)	MCL or Related Concentration Limit (mg/L)	Concentration Limit Description	Screening Level Predicted Peak Concentration (mg/L)	Years to Peak Concentration	Screening Peak >One-tenth MCL?
Aluminum	250	0.05	Secondary MCL	3.8E-03	6.88E+04	No
Antimony	50	0.006	MCL	3.4E-06	1.38E+04	No
Barium	50	2	MCL	5.7E-01	1.38E+04	Yes
Beryllium	250	0.004	MCL	7.9E-04	6.88E+04	Yes
Boron	5	0.6	MCLG	2.7E-05	1.43E+03	No
Chromium[b]	**1.2**	**0.1**	**MCL (total)**	**7.1E+00**	**3.85E+02**	**Yes**
Copper	20	1.3	Action level	5.1E-01	5.55E+03	Yes
Lead	100	0.015	Action level	1.1E-04	2.75E+04	No
Manganese	50	0.05	Secondary MCL	4.3E-02	1.38E+04	Yes
Nickel	100	0.1	Remanded MCL	5.5E-02	2.75E+04	Yes
Silver	90	0.1	Secondary MCL	1.3E-04	2.48E+04	No
Tin	130	22	PRG	1.7E-04	3.58E+04	No
Uranium	6	0.03	MCL	1.5E-06	1.70E+03	No
Zinc	16	5	Secondary MCL	1.3E-02	4.45E+03	No

a. Highlighting indicates nonradionuclide COCs.
b. Bold indicates a predicted peak aquifer concentration greater than the MCL.

MCL = maximum contaminant level as set by the EPA.
Secondary MCL = as set by the EPA—nonenforceable guidelines. Regulate contaminants that may cause cosmetic or esthetic effects.
Action level = Lead is regulated by a treatment technique that requires systems to control the corrosiveness of their water.
MCLG = MCL goal as set by the EPA—nonenforceable guideline. This is protective of adverse human health effects and allows an adequate margin of safety.
PRG = preliminary remediation goal as defined by EPA's Region 9 office. Nonenforceable, generic standard for evaluating and cleaning up contaminated sites.
Remanded MCL = The MCL and MCLG for nickel were remanded on February 9, 1995. This means that there is currently no EPA legal limit on the amount of nickel in drinking water. The remanded MCL was 0.1 mg/L; therefore, that value was used for this screening.
EPA = Environmental Protection Agency.

would be chromium. As the pH increases, the predominant valence state of chromium changes from trivalent (relatively immobile) to hexavalent (relatively mobile) chromium. For this analysis, a relatively mobile form of chromium is assumed for the source, vadose zone, and aquifer, so the fact that chromium does not necessarily become less mobile when grouted does not affect the solution or conclusions. In addition, any soil cover that decreases the infiltration rate from 10 cm/yr (Track 2 screening value) to 1 cm/yr (undisturbed INL Site sediment estimate) would decrease the predicted peak concentration by an order of magnitude.

4. ENGINEERING TEST REACTOR CONTAMINANT OF CONCERN RISK ASSESSMENT APPROACH AND RESULTS

4.1 Engineering Test Reactor Risk Assessment Approach

After screening, the five radionuclides and six nonradionuclides that require further analysis are defined as the COCs. The COCs are C-14, Cl-36, H-3, Ni-59, Pu-239, barium, beryllium, chromium, copper, manganese, and nickel. A more detailed and site-specific risk analysis was conducted for the COCs. The risk assessment approach for the COCs is presented in this section. For this risk assessment, many of the conservative assumptions made in the screening are retained. However, some specific assumptions are relaxed, because they are overly conservative for the ETR analysis. Changing these parameters allows the simulations to more accurately represent the ETR source term and flow and transport system. In this section, the changes to the model parameters are discussed and the results are presented. Parameters not discussed will remain the same as the Phase 2 screening parameters. These results are still conservative, because many conservative screening-level parameter values are still used in the analysis. The parameter changes are related to the infiltration rates, unsaturated zone dispersivity, and the release of contaminants via corrosion to the subsurface as explained in the following subsections.

4.1.1 Infiltration Rate

The Track 2 screening methodology used in the Phase 2 screening is based on an infiltration rate of 10 cm/yr. This rate is assumed to be conservative, because the estimated infiltration rate at the INL Site for undisturbed soil is about 1 cm/yr. The undisturbed soil infiltration rate of 1 cm/yr has been used in many INL studies, for example, EDF-4488, “Streamlined Risk Assessment for the CPP-603 EE/CA,” and the *Performance Assessment for the INEEL CERCLA Disposal Facility Landfill* (DOE-ID 2003). This assessment assumes that, after closure, the facilities will have at least a soil layer that limits the infiltration through the ETR facilities to undisturbed background levels. All of the COCs were evaluated based on the 1-cm/yr infiltration rate for this risk assessment. Contaminants are primarily contained in metals that must corrode before the contaminants are available for transport. Significant fractions of the contaminants will not be available until long after the ETR is closed and the soil cover is established. Therefore, a steady-state infiltration assumption is reasonable for this analysis.

4.1.2 Dispersion in the Vadose Zone

The Track 2 screening methodology used in the Phase 2 screening assumed no unsaturated zone dispersivity. In the risk assessment for the COC constituents, dispersion in the vadose zone was included.

In general, zero dispersion in the vadose zone is a conservative assumption; however, for radionuclides with relatively short half-lives, the assumption may not be conservative. Note that, in general, contaminants in the unsaturated zone would spread both in the direction of flow (longitudinal) and perpendicular to the direction of flow (lateral). The computer code used for the risk assessment

simulations (GWSCREEN) assumes one-dimensional flow and transport in the unsaturated zone; therefore, only longitudinal dispersivity can be included in the model.

Dispersivity in the unsaturated zone is a well-known phenomenon, and some effort has been made to quantify the longitudinal dispersivity at the INL Site. For purposes of this analysis, since no site-specific values are available, a value of 2.92 m (9.5 ft) is chosen for the unsaturated dispersivity. This value is consistent with the value used for the *Performance Assessment for the INEEL CERCLA Disposal Facility Landfill* (DOE-ID 2003).

4.1.3 Corrosion Source Term

A primary assumption of the Phase 2 screening was that the contaminants are in the soil and are immediately available for leaching to the subsurface. At the ETR, the inventory for the radionuclide COCs is currently in metal and not available for leaching to the subsurface. The radionuclides are contained in both beryllium and stainless steel. The nonradionuclides are contained in a variety of metals, but primarily in beryllium, stainless steel, steel, and copper. For COCs that are part of the metal, corrosion of the metal is required before the contaminants are available for subsurface transport. The corrosion mechanism delays the contaminants' availability for leaching from the ETR to the subsurface.

INL has done extensive research on the corrosion rates of beryllium and stainless steel; therefore, site-specific estimates of the corrosion rates of these metals are available. Site-specific corrosion rates for other metals have not been identified. The beryllium and stainless-steel corrosion rates used in this study are from INEEL (2000). The beryllium corrosion rate used is 2.54×10^{-2} mm/yr (39.4 yr/mm) and the stainless-steel corrosion rate used is 2.2×10^{-4} mm/yr (4,500 yr/mm). A corrosion study at the INL is ongoing in order to verify that the corrosion rates used in the performance assessment are conservative (Adler-Flitton et al. 2004). At this time, 1-year, 3-year, and 5-year corrosion rates have been measured. The maximum measured corrosion rate for beryllium is 9.1×10^{-3} mm/yr (110 yr/mm) or one-third the beryllium corrosion rate used for this modeling study. Therefore, the beryllium corrosion rate used is conservative. The stainless-steel corrosion rate is so small it is not reportable. The stainless-steel corrosion rate appears to be very conservative.

Appendix A contains radionuclide inventory estimates for each of the major components in the ETR reactor. In addition, for the radionuclide COCs (H-3, C-14, Cl-36, Ni-59, and Pu-239), the percent contribution is presented for each of the ETR reactor components. As can be seen in Table A-2, the ETR reactor components that contribute more than 10% to the inventory are the beryllium reflector block, grid plate, inner tank, and the gray rod poison (only for Ni-59). A total of less than 15% of the radionuclide inventory is contained in the combined in-pile tubes and rod poisons.

For the nonradionuclide COCs, the individual COC is generally contained within one specific metal. For example, the chromium, manganese, and nickel are almost exclusively contained in the stainless steel, while the copper is contained in copper piping, vessels, wiring, and bronze components.

Corrosion rates and the calculation of the time for beryllium and stainless steel to corrode ETR reactor components are shown in Table 12. As can be seen, the beryllium reflector is expected to last for 1,377 years with this conservative corrosion model. The stainless-steel components are expected to corrode much more slowly.

Table 12. ETR corrosion estimates from beryllium and stainless steel.

Component	Material	Metal Thickness[a] (mm [in.])	Inverse Metal Corrosion Rate[b] (yr/mm)	Time to Corrode [c] (yr)
Be reflector	Beryllium	69.9 [2.75]	39.4	1,377
Average of all stainless steel	Stainless steel	25.4 [d] [1]	4,500	57,150
Grid plate	Stainless steel	12.7 [e] [0.5]	4,500	28,575
F-10 inpile tube	Stainless steel	12.7 [f] [0.5]	4,500	28,575
Inner tank	Stainless steel	12.7 [0.5]	4,500	28,575
Black rod poison and shock assays	Stainless steel	2.54 [0.1]	4,500	5,715
Gray rod poison and shock assays	Stainless steel	2.54 [0.1]	4,500	5,715

a. From EDF-6060, "Engineering Test Reactor Vessel and Internal Components' Volumes and Weights," unless noted otherwise.
b. From INEEL (2000).
c. Nuclides are released when the metal corrodes. The release rates are calculated as the nuclide inventory divided by the number of years to corrode 50% through the metal. Since the corrosion is from both sides, this is the time until the metal is gone. The cumulative release rates are the sum of the rates from all the source terms for the periods of time that each source term contributes to the source.
d. Personal communication, July 2004, Harry Heidkamp (CH2M-WG Idaho, LLC [CWI]) estimated the average metal thickness. Notice that much of the stainless steel has very little nuclide inventory; therefore, those components are not listed in this table. However, any nonradionuclide inventory from the stainless steel will come from all of the stainless-steel components.
e. The grid plate is 9.5 in. thick, although it is full of holes. Therefore, the approximate thickness between holes (0.5 in.) was used for the corrosion rate calculations. This is a very conservative estimate of the corrosion time.
f. Personal communications, July 2004. Glen Longhurst (Battelle Energy Alliance, LLC) estimated the metal thickness.

The COC release rate from the corrosion of stainless steel or beryllium was calculated as the inventory divided by the number of years to corrode 50% of the thickness of the metal. Since the corrosion is assumed to be from both sides, this is the time until the metal is completely corroded and the contaminants are completely released from the metal for transport in infiltrating water. This is an accurate corrosion model but it does not incorporate radionuclide decay. Therefore, the corrosion model is conservative for radionuclides and very conservative for radionuclides with a short decay half-life relative to the total corrosion time. For example, this is not an accurate model for H-3 because it has a 12.3-yr decay half-life, which is much smaller than the corrosion time of any of the metal components. Since this is not an accurate model for all of the COCs, it is only used for COCs for which the model is appropriate and that can significantly contribute to the cumulative risk or MCL if assumed to be immediately available for transport in infiltrating water.

As will be shown in Section 4.2, C-14 and chromium were both predicted to be significant contributors to the cumulative groundwater risk or the MCL, if the corrosion mechanism was excluded from the source term model. Therefore, the peak concentrations and risks for each of these were recalculated including the corrosion model.

The chromium inventory is in the stainless steel and was simulated as being uniformly released to the ETR facility over a period of 57,150 years. This release estimate is based on an assumed average thickness of stainless steel of 25.4 mm (1 in.) as shown in Table 12. Based on a total chromium inventory of 35,420 kg and a release timeframe of 57,150 yr, the chromium release rate is 6.20×10^5 mg/yr.

The C-14 inventory is divided between the beryllium reflector blocks and various stainless-steel components of the ETR reactor (listed in Table 12). The C-14 was simulated using three different constant release rates based on the waste form of each portion of the C-14 inventory. The ETR component-specific inventory for C-14 is shown in Appendix A, Table A-2. The inventory and release rates are as follows;

- 22.4% (or 2.97 Ci) of the C-14 is contained in the beryllium reflector. Based on a 1,377-yr corrosion period (Table 12), the C-14 is assumed to be released at a rate of 2.2×10^{-3} Ci/yr.

- 67.59% (or 8.97 Ci) of the C-14 is contained in stainless steel making up the grid plate, in-pile tubes, and the inner tank. Based on a 28,575-yr corrosion period (Table 12), the C-14 is assumed to be released at a rate of 3.1×10^{-4} Ci/yr.

- 10.03% (or 1.33 Ci) of the C-14 make up the remainder of the C-14 inventory. This is primarily in the black rod poison. Therefore, the 1.33 Ci remaining is assumed to be released based on a 5,715-yr corrosion period (Table 12). The C-14 is assumed to be released at a rate of 2.3×10^{-4} Ci/yr.

The corrosion source term was simulated in the GWSCREEN model (Rood 2003) using the pond model. The pond model allows for a constant flux of a contaminant and of water to the source volume. The contaminant is leached to the vadose zone by both the pond water source and the water included as infiltration. By choosing the constant pond water flux to be zero, the only water source leaching a contaminant from the source volume is the infiltration water. This mathematical model is an accurate representation of the corrosion conceptual model where the metal is assumed to corrode at a constant rate, introducing a constant flux of a contaminant into the ETR source volume, which is then leached to the vadose zone at an infiltration rate of 1 cm/yr (as discussed in Section 4.1.1).

4.1.4 Summary of the Contaminant of Concern Risk Assessment Parameters

As previously explained, some of the conservative assumptions used for Phase 2 screening were relaxed for this risk assessment. In particular, the infiltration rate was decreased from 10 cm/yr to 1 cm/yr (to simulate the reduction in infiltration expected after a soil cover is placed over the ETR), and the vadose zone dispersivity is included in the simulation model. A plug flow model was assumed for the screening and a longitudinal dispersivity of 2.92 m was assumed for the risk assessment. In both the screening and risk assessment, the transverse dispersivity in the vadose zone is assumed to be zero. In addition, since the plutonium K_d value used for the screening (Track 2 value of 22 mL/g) is very conservative, the K_d was increased to 140 mL/g, which is consistent with the K_d used in the *Performance Assessment for the INEEL CERCLA Disposal Facility Landfill* (DOE-ID 2003). This plutonium K_d is considered to still be a conservative value but less conservative than the Track 2 value used in the screening analysis.

The risk assessment results were calculated in two stages. The first stage ignores the fact that the contaminants are largely a part of the beryllium and stainless steel within the ETR. For all COCs that have a predicted risk that is not a significant contributor to the cumulative groundwater risk or MCL, no further calculations were performed. For COCs that are significant contributors to cumulative risk or the MCL, the peak aquifer concentrations and risks were recalculated including corrosion in the source release model.

4.2 Engineering Test Reactor Risk Assessment Results

The contaminants that did not pass the Phase 2 screening were evaluated with more realistic simulation parameters, as explained in the last subsections. The predicted peak groundwater risk was calculated at a location in the aquifer beneath the downgradient edge of the ETR facility. The results are presented in this section.

The radionuclide results are summarized in Table 13. Results are shown for both with and without the corrosion model (for C-14). If the COCs are assumed to be mixed in the backfilled soils in the ETR facility rather than contained in the stainless steel and beryllium and no corrosion is considered, the predicted peak risk ranged from 8.1×10^{-6} for C-14 to 5.1×10^{-12} for Pu-239. A risk of $> 1\times10^{-6}$ was used

to define a potentially significant cumulative risk contributor. Only C-14 was predicted to have a total groundwater pathway risk of greater than 1×10^{-6}. Therefore, the C-14 was resimulated including corrosion in the release model. The predicted peak C-14 risk is 1.6×10^{-6} when corrosion is included, which is about five time less than the C-14 risk calculated without including the corrosion mechanism and about 62 times smaller than the 1×10^{-4} risk standard. The predicted risk in the aquifer from each of the radionuclides is shown in Figures 14 and 15. The risk for C-14 plotted in Figure 14 does not include the corrosion mechanism and the C-14 plotted in Figure 15 does include the corrosion mechanism. As seen in Table 13 and Figures 14 and 15, the predicted peak risk for all radionuclides is well below the 1×10^{-4} standard. The maximum cumulative risk is 8.2×10^{-6} if corrosion is not considered and 1.6×10^{-6} if corrosion is considered for the C-14 release model. During the early time, the risk is dominated by C-14. Later in time, the risk is dominated by Ni-59.

The nonradionuclide results are summarized in Table 14. Results are shown for both with and without the corrosion model (for chromium). When no corrosion is considered, the predicted peak fraction of the MCL ranged from 1.57 for chromium to 0.0043 for beryllium. Only the peak predicted chromium concentration is greater than its MCL. The next largest fraction of the MCL is 0.019 (or 1.9%) for manganese. Chromium is the only nonradionuclide COC that would significantly contribute to the cumulative MCL. The chromium was resimulated including the corrosion mechanism. Based on the corrosion model, the predicted peak chromium concentration was 0.0158 mg/L (the MCL is 0.1 mg/L) and the fraction of the chromium peak concentration to the MCL is 0.158 (or 16%). The predicted fraction to the MCLs is shown in Figures 16 and 17. The maximum cumulative fraction of the COC concentrations to their MCLs is 1.57 if corrosion is not considered and 0.169 if corrosion is considered. The chromium dominates the fraction of the MCLs for the first 20,000 years when no corrosion is included and dominates for the first 70,000 years when corrosion was included. Manganese is the primary contributor to the cumulative fraction of the MCLs in the later time but the fraction is well below a level that would be a significant contribution to the MCL.

Table 13. ETR radionuclide groundwater risk assessment assuming the contaminants are immediately available for release.

		Without Corrosion Model				With Corrosion Model	
Nuclide	Progeny	Date of Peak Time (yr)	Peak Concentration (pCi/L)	Peak Decay Chain Groundwater Pathway Risk	Total Groundwater Pathway Risk by Nuclide	Peak Concentration (pCi/L)	Total Groundwater Pathway Risk by Nuclide
C-14	—	2,853	2.48E+02	8.1E-06	8.1E-06	5.06E+01	1.6E-06
Cl-36	—	2,587	3.91E+00	2.7E-07	2.7E-07	NA[a]	NA
H-3	—	2,135	7.84E+00	8.1E-09	8.1E-09	NA	NA
Ni-59	—	185,130	1.05E+00	6.1E-09	6.1E-09	NA	NA
Pu-239	—	145,260	1.75E-06	5.0E-12	5.1E-12	NA	NA
	U-235	b	6.99E-08	1.0E-13	—[c]	NA	NA
	Pa-231	b	8.13E-10	3.0E-15	—	NA	NA
	Ac-227	b	9.94E-10	4.2E-15	—	NA	NA
			Maximum Cumulative Risk		8.2E-06		1.6E-06 [d]

a. NA = Corrosion model is not applicable.
b. Progeny are assumed to travel with the parent.
c. Risk included with parent nuclide.
d. The cumulative risk with corrosion is the C-14 risk with corrosion plus the risk from Cl-36, H-3, Ni-59, and Pu-239 without corrosion.

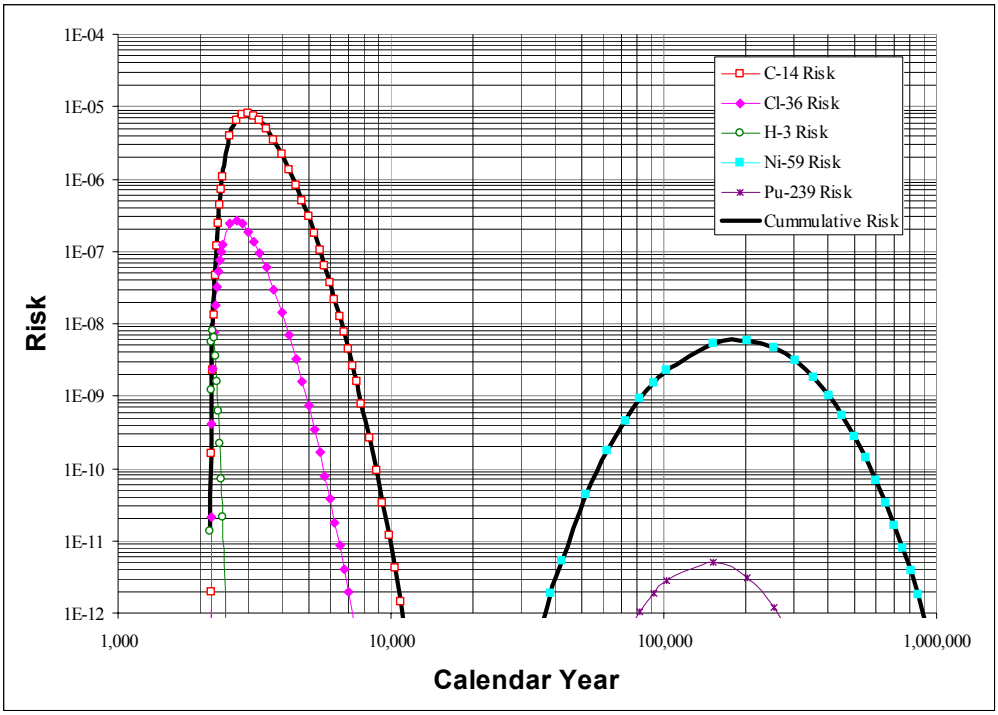

Figure 14. ETR nuclide risk contributors and the total calculated risk for the next 1,000,000 years. Corrosion was not considered.

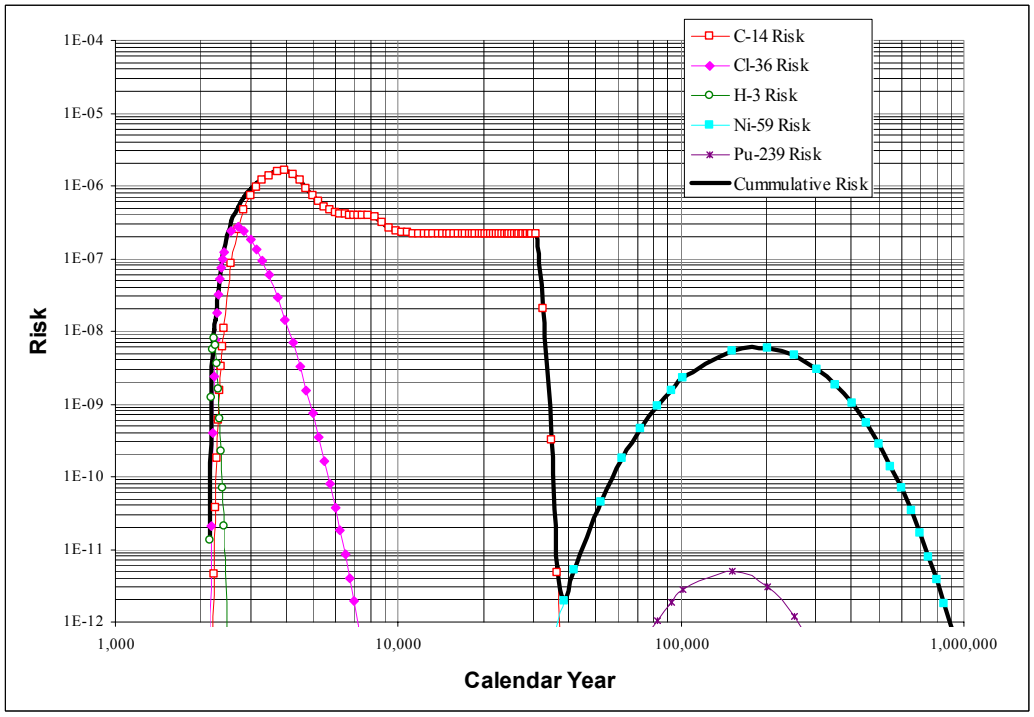

Figure 15. ETR nuclide risk contributors and the total calculated risk for the next 1,000,000 years. Corrosion was considered for C-14.

Table 14. ETR nonradionuclide groundwater risk assessment assuming the contaminants are immediately available for release.

Contaminant	K_d (mL/g)	MCL or Related Concentration Limit (mg/L)	Year of Peak Concentration	Without Corrosion Model		With Corrosion Model [a]	
				Predicted Peak Concentration (mg/L)	Fraction – Peak Concentration to the MCL (mg/L)	Predicted Peak Concentration (mg/L)	Fraction – Peak Concentration to the MCL (mg/L)
Barium (MCL)	50	2	146,990	1.3E-02	0.0063	NA[b]	NA
Beryllium (MCL)	250	0.004	724,610	1.7E-05	0.0043	NA	NA
Chromium (MCL total chromium)	1.2	0.1	6,053	1.57E-01	1.57	1.58E-02	0.158
Copper (action level)	20	1.3	60,349	1.1E-02	0.0087	NA	NA
Manganese (secondary MCL)	50	0.05	146,990	9.5E-04	0.019	NA	NA
Nickel (remanded MCL)	100	0.1	291,400	1.2E-03	0.012	NA	NA
Maximum Cumulative Fraction to the MCL					1.57	NA	0.169 [c]

a. With the corrosion model, the constant chromium flux results in basically a constant flux to the aquifer and concentration in the aquifer from time 10,000 years to 60,000 years.
b. NA = Corrosion model is not applicable.
c. The cumulative fraction with corrosion is the chromium fraction with corrosion plus the fraction of the other metals without corrosion.

Action level = Lead is regulated by a treatment technique that requires systems to control the corrosiveness of their water.
EPA = Environmental Protection Agency.
MCL = maximum contaminant level as set by the EPA.
MCLG = MCL goal as set by the EPA—nonenforceable guideline. This is protective of adverse human health effects and allows an adequate margin of safety.
PRG = preliminary remediation goal as defined by EPA's Region 9 office. Nonenforceable, generic standard for evaluating and cleaning up contaminated sites.
Remanded MCL = The MCL and MCLG for nickel were remanded on February 9, 1995. This means that there is currently no EPA legal limit on the amount of nickel in drinking water. The remanded MCL was 0.1 mg/L; therefore, that value was used for this screening.
Secondary MCL = as set by the EPA—nonenforceable guidelines. Regulate contaminants that may cause cosmetic or esthetic effects.

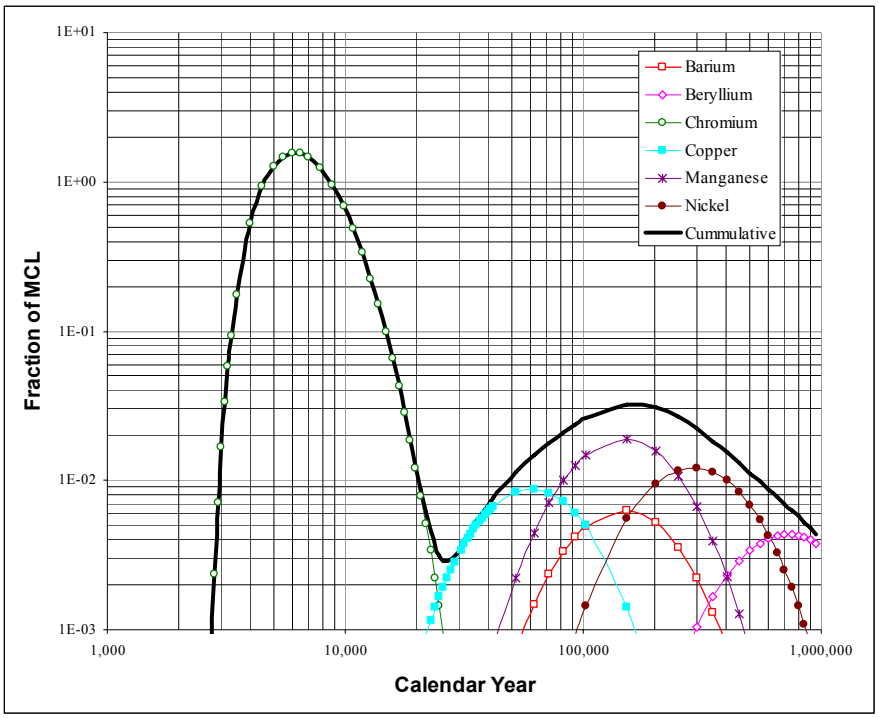

Figure 16. Nonradionuclide predicted COC fractions of the MCL and total sum of fractions for the ETR. Corrosion was not considered.

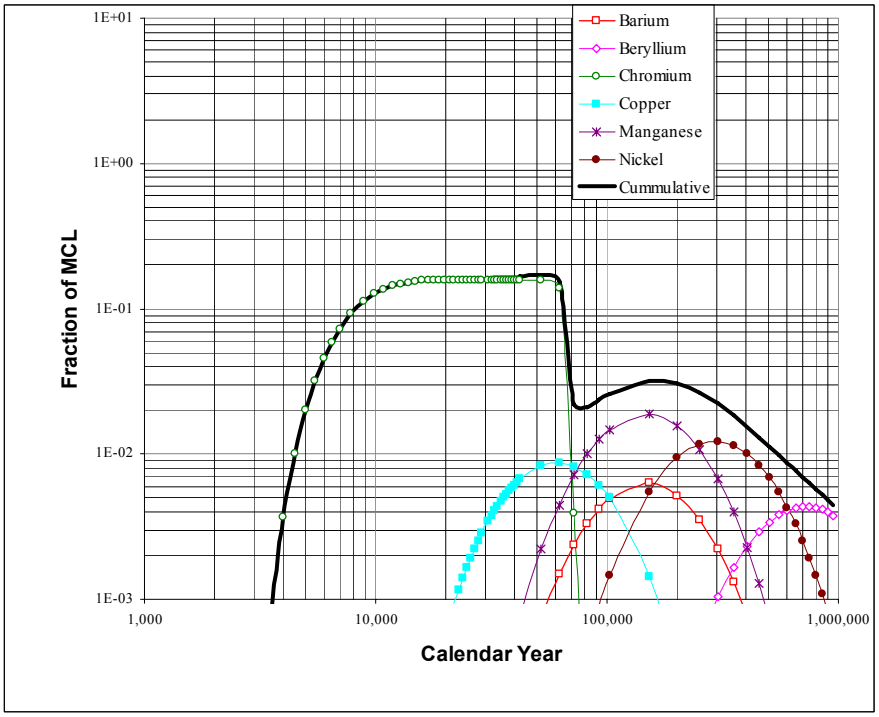

Figure 17. Nonradionuclide predicted COC fractions of the MCL and total sum of fractions for the ETR. Corrosion was considered for chromium.

4.3 Soil Contamination under the Engineering Test Reactor Facility

As described above in this document, the cumulative radionuclide carcinogenic risk for the ETR Complex is estimated to be 1.6×10^{-6}. This risk is attributed almost entirely to C-14. The cumulative fraction of the MCL for the ETR Complex is estimated to be 0.17. This fraction is attributed almost entirely to chromium. Significant contaminant releases would be needed to sufficiently increase this risk and fraction of MCL to a level of concern.

The potential and documented releases and release locations within the ETR Complex are summarized in EDF-6224, "Potential and Documented Release Locations within the Engineering Test Reactor Complex." Releases include both chemical and radiological contaminants, which might have entered the environment as a result of past operations. No known significant contaminant releases were reported in EDF-6224 for the ETR Complex (TRA-642, TRA-643, TRA-644, TRA-648, TRA-704, TRA-705, and TRA-706). Releases—for purposes of this EDF—were defined in accordance with the definition in Management Control Procedure (MCP) -3480, "Environmental Instructions for Facilities, Processes, Materials, and Equipment," as "any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing of any chemical…."

Based on records reviewed, potential release sites below the ETR are suggested by certain conditions rather than by an actual release being documented or investigated. These potential release sites include locations where past releases of waste constituents—primarily radionuclides—are possible, because the concrete structure is built directly on basalt bedrock and contained a sump, which was used to receive, accumulate, and/or store radioactive waste. These include the hot waste pit, warm waste pit (and warm waste sump), and rod drive access room sump, all located within the ETR building.

Based on the available information and risk assessment analysis, there is no reason to believe that sufficient releases have occurred under the facility to result in a significant risk or fraction of the MCL.

5. SUMMARY

The contaminant screening and risk assessment presented in this report are based on the assumption that the contaminant inventory at the ETR is left in place and the facilities are stabilized with INL Site native soils. Based on this streamlined risk assessment, the predicted groundwater concentrations meet the required performance criteria. For groundwater, the performance criteria are to prevent migration of contaminants from the ETR facility that would cause the SRPA to exceed a cumulative carcinogenic risk level of 1×10^{-4} or applicable State of Idaho groundwater quality standards in 2095 and beyond. The maximum predicted cumulative risk is 1.6×10^{-6} or one sixty-second of the performance criteria. The maximum cumulative fraction of nonradionuclide concentration to the MCL is 0.17 or one-sixth the performance criteria of 1. The radionuclide risk is dominated by C-14 and the nonradionuclide concentration fraction of the MCL is dominated by chromium.

A number of conservative assumptions were used to calculate peak aquifer concentrations and risks. The following is a list of the primary assumptions and their impact on the predicted contaminant concentrations in the aquifer.

1. The assumption that native soils are used to fill both the reactor and ETR basement was used to simulate the release of contaminants within the ETR. In general, contaminants are less mobile in a high-pH environment (such as grout) than they are in soils. Therefore, simulating the contaminant release from native soils results in faster release from the ETR to the subsurface than if the transport was simulated using grout K_ds. This results in higher predicted concentrations in the

aquifer than would be expected with a grouted source. As explained in Section 3.2.2, chromium could be an exception to the rule that contaminants are less mobile in a grouted source because as the pH increases, the predominant valence state of chromium changes from trivalent (relatively immobile) to hexavalent (relatively mobile) chromium. Therefore, in order to be conservative, a relatively mobile form of chromium is assumed for the entire analysis.

2. For the risk assessment, the hydraulic effects of grouting the ETR vessel were ignored. If the facility is grouted, the grouting will isolate the vast majority of the contaminants (reactor vessel) from water for a very long time. A common assumption at the INL is that the grout will remain intact for 500 years and then fail, allowing water to infiltrate, contact contaminants, and leach them to the vadose zone. Any time delay provided by the grout would delay the predicted peak aquifer concentrations and reduce the concentrations by radioactive decay.

3. Water and contaminants are assumed to move straight down through the vadose zone sediments. The contaminant velocity through the sediments depends on the contaminant-specific sediment K_d. There is no retardation effect from the basalt in the vadose zone, and there is no horizontal spreading simulated in the vadose zone. The result of these assumptions is to predict a contaminant travel time from ETR to the aquifer that is shorter than would be expected with horizontal spreading and sorption in the basalt.

4. Track 2 default values are, in general, more conservative than the parameter values used for detailed RTC modeling.

5. For screening, the receptor was assumed to be at the edge of the ETR facility. This is the location of the peak concentration in the aquifer. Any change of the receptor location will result in decreased predictions of peak concentration.

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Appendix A

Distribution of Radionuclides at ETR

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Appendix A

Distribution of Radionuclides in the ETR Reactor

The following information was received from Craig Nesshoefer (CWI). Table A-1 contains the inventory of each nuclide by component in the ETR reactor. The inventory is based on the inventory analysis done for the EDF-6958. Table A-2 contains the inventory for the radionuclide contaminants of concern and the fractional contribution from each of the components. As can be seen in Table A-2, the ETR reactor components that contribute more than 10% to the inventory are the beryllium reflector block, grid plate, inner tank, and the gray rod poison.

Table A-1. ETR reactor estimated radionuclide inventory.

Isotope	Be Reflector (Be) (Ci)	Grid Plate (304-SS) (Ci)	I-Beams (all 6, 304-SS) (Ci)	C-7 In-Pile Tube (304-SS) (Ci)	F-10 In-Pile Tube (304-SS) (Ci)	M-13 In-Pile Tube (304-SS) (Ci)	N-14 In-Pile Tube (304-SS) (Ci)	Upper Support Frame (304-SS) (Ci)	Inner Tank (304-SS, Steel) (Ci)	Internal Thermal Shields (304-SS) (Ci)	External Thermal Shield (304-SS, Pb) (Ci)	External Tank (304-SS, Steel) (Ci)	Black Rod Poison (Cd) (Ci)	Gray Rod Poison (Ni) (Ci)	Total Inventory
H-3	32944.18	4.75E+00	1.57E-06	1.47E-01	1.12E-01	1.12E-01	9.03E-02	3.83E-07	3.20E+00	9.50E-02	8.24E-04	1.91E-03	1.19E-01	1.40E-04	3.30E+04
Be-10	3.73E-01	8.57E-07	2.73E-13	3.02E-08	8.40E-08	3.79E-08	1.94E-08	6.68E-14	5.84E-07	1.65E-08	1.82E-10	4.20E-10	1.95E-07	1.25E-06	3.73E-01
C-14	2.97E+00	4.71E+00	1.31E-06	1.77E-01	5.42E-01	2.40E-01	1.17E-01	3.20E-07	3.18E+00	7.94E-02	7.19E-05	2.09E-04	1.25E+00	3.99E-04	1.33E+01
Cl-36	3.63E-02	4.83E-02	1.04E-08	1.39E-03	3.91E-03	1.82E-03	9.12E-04	2.54E-09	2.51E-02	6.30E-04	1.62E-07	7.40E-07	7.94E-03	1.34E-05	1.26E-01
Mn-54	9.16E-09	1.63E-06	3.11E-13	4.83E-08	1.64E-07	1.45E-07	6.30E-08	7.61E-14	7.56E-07	1.88E-08	1.03E-10	2.43E-10	3.74E-07	6.05E-09	3.21E-06
Ni-59	2.69E-02	5.55E+00	7.31E-06	9.03E-01	1.74E+00	1.04E+00	5.76E-01	1.79E-06	1.70E+01	4.45E-01	1.14E-04	5.21E-04	2.17E+00	1.03E+02	1.32E+02
Co-60	1.11E+00	5.50E+02	2.07E-04	2.98E+01	8.11E+01	5.80E+01	2.82E+01	5.08E-05	4.96E+02	1.26E+01	5.71E-03	2.04E-02	1.39E+02	5.76E+02	1.97E+03
Ni-63	3.88E+00	6.35E+02	7.73E-04	1.03E+02	2.76E+02	1.37E+02	6.93E+01	1.90E-04	1.86E+03	4.71E+01	1.26E-02	5.55E-02	5.08E+02	2.05E+04	2.42E+04
Zn-65	4.29E-11	3.84E-11	7.69E-18	1.31E-12	6.68E-12	4.62E-12	1.77E-12	1.87E-18	1.95E-11	4.66E-13	2.77E-15	1.38E-15	2.36E-11	3.22E-11	1.71E-10
Sr-90	7.52E-01	4.87E-02	3.43E-09	1.36E-03	6.22E-03	2.71E-03	1.09E-03	8.40E-10	1.78E-02	2.11E-04	8.36E-07	2.01E-06	1.30E-02	3.27E-06	8.43E-01
Nb-94	8.19E-03	4.75E+00	1.78E-08	2.35E-03	6.35E-03	3.05E-03	1.54E-03	4.33E-09	4.29E-02	1.08E-03	1.58E-06	4.20E-06	1.21E-02	3.24E-06	4.83E+00
Tc-99	5.50E-04	3.21E-03	7.06E-10	9.03E-05	2.25E-04	1.13E-04	5.88E-05	1.72E-10	1.65E-03	4.24E-05	1.13E-08	5.08E-08	3.80E-04	1.07E-07	6.33E-03
Ru-103	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru-106	3.07E-07	3.85E-09	1.74E-17	1.21E-10	4.62E-10	4.62E-10	1.80E-10	4.24E-18	1.28E-09	1.44E-12	4.13E-15	9.96E-15	7.44E-10	1.67E-13	3.14E-07
Ag-108m	3.50E-02	6.51E-02	1.42E-08	1.89E-03	5.17E-03	2.51E-03	1.26E-03	3.46E-09	3.41E-02	8.57E-04	4.20E-03	8.03E-06	9.24E-02	2.64E-06	2.43E-01
Ag-110m	2.61E-11	1.23E-11	3.51E-18	4.18E-13	3.26E-13	7.65E-13	4.87E-13	8.57E-19	7.52E-12	2.13E-13	1.05E-12	1.99E-15	2.47E-11	3.91E-17	7.38E-11
Sb-125	6.89E-04	2.85E-03	6.05E-10	9.33E-05	3.28E-04	2.48E-04	1.08E-04	1.48E-10	1.47E-03	3.67E-05	1.36E-07	4.33E-08	7.86E-04	1.51E-07	6.61E-03
I-129	4.09E-06	9.50E-08	2.17E-15	2.57E-09	1.19E-08	5.04E-09	1.99E-09	5.34E-16	3.03E-08	1.38E-10	5.17E-13	1.24E-12	2.21E-08	6.09E-12	4.26E-06
Cs-134	2.33E-03	3.27E-04	7.56E-11	1.08E-05	2.49E-05	2.55E-05	1.27E-05	1.84E-11	1.76E-04	4.58E-06	1.17E-09	5.38E-09	3.23E-05	8.32E-09	2.95E-03
Cs-137	2.52E+00	1.01E-01	3.73E-09	2.79E-03	1.36E-02	5.92E-03	2.30E-03	9.12E-10	3.35E-02	2.32E-04	9.03E-07	2.17E-06	2.79E-02	7.06E-06	2.70E+00
Ce-144	2.20E-09	3.71E-11	1.42E-18	1.18E-12	4.37E-12	4.33E-12	1.71E-12	3.47E-19	1.36E-11	8.91E-14	3.47E-16	8.32E-16	7.35E-12	1.63E-15	2.27E-09
Eu-152	1.53E-02	3.74E-02	2.75E-07	1.57E-03	6.77E-06	9.45E-05	5.63E-04	6.72E-08	1.08E-01	1.64E-02	6.14E-04	1.39E-03	5.29E-06	1.76E-09	1.82E-01
Eu-154	8.99E-01	9.03E-02	1.57E-08	2.75E-03	2.09E-03	3.18E-03	2.13E-03	3.84E-09	4.41E-02	9.54E-04	3.49E-05	7.94E-05	9.87E-04	3.69E-07	1.05E+00

Table A-1. (continued).

Isotope	Be Reflector (Be) (Ci)	Grid Plate (304-SS) (Ci)	I-Beams (all 6, 304-SS) (Ci)	C-7 In-Pile Tube (304-SS) (Ci)	F-10 In-Pile Tube (304-SS) (Ci)	M-13 In-Pile Tube (304-SS) (Ci)	N-14 In-Pile Tube (304-SS) (Ci)	Upper Support Frame (304-SS) (Ci)	Inner Tank (304-SS, Steel) (Ci)	Internal Thermal Shields (304-SS) (Ci)	External Thermal Shield (304-SS, Pb) (Ci)	External Tank (304-SS, Steel) (Ci)	Black Rod Poison (Cd) (Ci)	Gray Rod Poison (Ni) (Ci)	Total Inventory
Pb-210	1.61E-11	1.66E-11	4.37E-14	4.13E-13	4.54E-12	9.29E-13	2.62E-13	8.82E-14	5.84E-12	3.37E-12	1.11E-12	2.22E-12	1.74E-11	3.78E-15	6.89E-11
Ra-226	2.24E-11	4.08E-11	1.26E-13	1.04E-12	3.92E-12	1.41E-12	6.01E-13	2.56E-13	1.56E-11	9.71E-12	3.22E-12	6.43E-12	6.05E-12	2.01E-15	1.12E-10
Ac-227	1.26E-07	5.08E-07	7.90E-13	1.48E-08	1.59E-08	1.27E-08	8.53E-09	1.35E-12	3.04E-07	8.53E-09	1.43E-10	3.24E-10	1.24E-08	4.62E-12	1.01E-06
Th-228	6.30E-05	6.35E-05	4.96E-09	1.66E-06	1.15E-05	4.54E-06	1.47E-06	1.00E-08	1.60E-05	3.81E-07	4.79E-07	9.12E-07	1.61E-05	5.08E-09	1.80E-04
Th-229	1.05E-07	6.09E-07	2.29E-13	1.79E-08	1.26E-08	1.14E-08	9.12E-09	5.59E-14	4.12E-07	1.28E-08	2.05E-10	4.71E-10	1.07E-08	3.90E-12	1.20E-06
Th-230	3.27E-09	3.79E-09	1.27E-11	9.87E-11	3.83E-10	1.63E-10	6.56E-11	2.58E-11	1.40E-09	9.75E-10	3.25E-10	6.47E-10	5.50E-10	1.76E-13	1.17E-08
Th-232	1.30E-08	1.02E-07	5.00E-09	3.31E-09	1.33E-09	1.47E-09	1.53E-09	1.01E-08	1.26E-07	3.80E-07	4.83E-07	9.20E-07	1.00E-09	3.66E-13	2.05E-06
Pa-231	2.02E-07	7.35E-07	1.57E-12	2.17E-08	2.40E-08	1.98E-08	1.31E-08	2.82E-12	4.37E-07	1.23E-08	2.17E-10	4.87E-10	1.94E-08	7.02E-12	1.48E-06
U-232	6.14E-05	6.14E-05	2.50E-16	1.62E-06	1.12E-05	4.41E-06	1.42E-06	4.50E-17	1.54E-05	3.58E-09	6.60E-13	1.82E-12	1.57E-05	4.96E-09	1.73E-04
U-233	3.49E-05	1.69E-04	6.39E-11	5.13E-06	3.53E-06	3.63E-06	2.90E-06	1.56E-11	1.15E-04	3.58E-06	5.76E-08	1.32E-07	2.79E-06	9.96E-10	3.41E-04
U-234	1.37E-05	7.19E-06	3.08E-08	1.94E-07	7.77E-07	4.24E-07	1.59E-07	6.26E-08	2.48E-06	2.34E-06	7.86E-07	1.57E-06	9.50E-07	2.88E-10	3.07E-05
U-235	3.82E-09	1.01E-08	1.40E-09	3.67E-10	6.09E-11	5.04E-11	1.18E-10	2.84E-09	2.26E-08	1.06E-07	3.57E-08	7.10E-08	8.49E-11	2.48E-14	2.54E-07
U-236	5.50E-07	9.41E-08	3.32E-14	2.85E-09	2.25E-09	1.91E-09	1.58E-09	8.11E-15	6.47E-08	2.01E-09	7.86E-12	1.89E-11	3.78E-09	9.75E-13	7.24E-07
U-238	2.40E-06	6.01E-07	3.04E-08	1.95E-08	6.64E-09	8.19E-09	8.91E-09	6.18E-08	7.56E-07	2.32E-06	7.77E-07	1.55E-06	3.79E-09	1.56E-12	8.54E-06
Np-237	1.89E-06	1.79E-07	6.05E-15	4.75E-09	7.10E-09	5.76E-09	3.31E-09	1.48E-15	5.17E-08	3.62E-10	1.43E-12	3.43E-12	8.61E-09	2.49E-12	2.15E-06
Pu-238	7.77E-02	4.33E-03	1.20E-16	9.29E-05	3.49E-04	2.05E-04	6.64E-05	3.55E-18	4.14E-04	5.55E-09	2.62E-13	7.61E-13	2.31E-04	8.70E-08	8.34E-02
Pu-239	1.26E-02	2.79E-03	1.61E-09	8.78E-05	3.51E-05	4.29E-05	4.37E-05	3.95E-10	2.42E-03	9.54E-05	3.81E-07	9.16E-07	2.01E-05	8.28E-09	1.82E-02
Pu-240	1.81E-02	2.61E-03	9.71E-15	7.61E-05	6.60E-05	5.67E-05	4.62E-05	2.86E-16	1.20E-03	4.58E-07	2.12E-11	6.14E-11	8.32E-05	2.63E-08	2.22E-02
Pu-241	1.64E+00	1.29E-01	2.79E-18	3.52E-03	4.45E-03	4.83E-03	2.91E-03	9.92E-21	2.95E-02	1.05E-07	5.63E-14	1.97E-13	3.58E-03	1.24E-06	1.82E+00
Pu-242	2.76E-04	4.96E-06	3.63E-28	1.16E-07	1.30E-06	5.92E-07	1.41E-07	1.55E-31	4.13E-07	1.09E-14	6.77E-23	2.86E-22	1.21E-06	4.50E-10	2.85E-04
Pu-244	2.54E-10	9.45E-14	0.00E+00	1.83E-15	1.63E-12	1.87E-13	7.61E-15	0.00E+00	1.25E-15	2.09E-27	1.76E-39	1.08E-38	1.11E-11	1.74E-15	2.67E-10
Am-241	1.59E-01	1.65E-02	3.58E-19	4.37E-04	4.71E-04	5.13E-04	3.24E-04	1.27E-21	3.80E-03	1.35E-08	7.23E-15	2.53E-14	3.27E-04	1.22E-07	1.82E-01
Am-243	2.71E-03	1.52E-05	4.79E-33	3.10E-07	1.70E-05	4.50E-06	5.38E-07	2.45E-37	5.25E-07	1.14E-16	8.24E-27	4.20E-26	1.91E-05	6.89E-09	2.76E-03
Cm-243	4.83E-04	1.42E-05	6.01E-33	2.98E-07	3.45E-06	1.68E-06	3.44E-07	3.10E-37	5.88E-07	1.43E-16	1.04E-26	5.29E-26	1.56E-06	7.73E-10	5.05E-04
Cm-244	3.05E-01	3.27E-04	3.91E-37	5.88E-06	3.43E-03	3.29E-04	1.62E-05	0.00E+00	4.41E-06	7.44E-18	6.26E-30	3.86E-29	1.06E-02	2.73E-06	3.20E-01
Cm-245	5.71E-05	3.47E-08	0.00E+00	5.71E-10	8.03E-07	5.76E-08	1.92E-09	0.00E+00	2.32E-10	3.71E-24	3.64E-38	2.70E-37	2.58E-06	6.81E-10	6.06E-05
Cm-246	4.79E-05	5.59E-09	0.00E+00	7.98E-11	1.36E-06	3.11E-08	4.16E-10	0.00E+00	1.44E-11	1.79E-27	4.50E-44	1.56E-42	1.77E-05	2.87E-09	6.70E-05
Cm-247	2.15E-10	6.51E-15	0.00E+00	8.19E-17	9.92E-12	9.96E-14	6.18E-16	0.00E+00	6.85E-18	6.89E-36	0.00E+00	0.00E+00	2.44E-10	3.35E-14	4.69E-10
Cm-248	1.00E-09	7.10E-15	0.00E+00	7.82E-17	8.99E-11	3.19E-13	8.66E-16	0.00E+00	2.98E-18	2.40E-38	0.00E+00	0.00E+00	7.35E-09	6.77E-13	8.45E-09

Table A-2. ETR inventory for the radionuclide contaminants of concern and the fractional contribution from each component.

Isotope	Be Reflector (Be) (Ci)	Grid Plate (304-SS) (Ci)	I-Beams (all 6, 304-SS) (Ci)	C-7 In-Pile Tube (304-SS) (Ci)	F-10 In-Pile Tube (304-SS) (Ci)	M-13 In-Pile Tube (304-SS) (Ci)	N-14 In-Pile Tube (304-SS) (Ci)	Upper Support Frame (304-SS) (Ci)	Inner Tank (304-SS, Steel) (Ci)	Internal Thermal Shields (304-SS) (Ci)	External Thermal Shield (304-SS, Pb) (Ci)	External Tank (304-SS, Steel) (Ci)	Black Rod Poison (Ci)	Gray Rod Poison (Ni) (Ci)
H-3	32944.18	4.75E+00	1.57E-06	1.47E-01	1.12E-01	1.12E-01	9.03E-02	3.83E-07	3.20E+00	9.50E-02	8.24E-04	1.91E-03	1.19E-01	1.40E-04
C-14	2.97E+00	4.71E+00	1.31E-06	1.77E-01	5.42E-01	2.40E-01	1.17E-01	3.20E-07	3.18E+00	7.94E-02	7.19E-05	2.09E-04	1.25E+00	3.99E-04
Cl-36	3.63E-02	4.83E-02	1.04E-08	1.39E-03	3.91E-03	1.82E-03	9.12E-04	2.54E-09	2.51E-02	6.30E-04	1.62E-07	7.40E-07	7.94E-03	1.34E-05
Ni-59	2.69E-02	5.55E+00	7.31E-06	9.03E-01	1.74E+00	1.04E+00	5.76E-01	1.79E-06	1.70E+01	4.45E-01	1.14E-04	5.21E-04	2.17E+00	1.03E+02
Pu-239	1.26E-02	2.79E-03	1.61E-09	8.78E-05	3.51E-05	4.29E-05	4.37E-05	3.95E-10	2.42E-03	9.54E-05	3.81E-07	9.16E-07	2.01E-05	8.28E-09
Percent contribution to the total inventory of each COC by component in the ETR														
H-3	99.97%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
C-14	22.37%	35.49%	0.00%	1.33%	4.09%	1.81%	0.88%	0.00%	23.99%	0.60%	0.00%	0.00%	9.44%	0.00%
Cl-36	28.71%	38.26%	0.00%	1.10%	3.10%	1.44%	0.72%	0.00%	19.86%	0.50%	0.00%	0.00%	6.29%	0.01%
Ni-59	0.02%	4.19%	0.00%	0.68%	1.32%	0.78%	0.43%	0.00%	12.85%	0.34%	0.00%	0.00%	1.64%	77.74%
Pu-239	69.57%	15.35%	0.00%	0.48%	0.19%	0.24%	0.24%	0.00%	13.29%	0.52%	0.00%	0.01%	0.11%	0.00%

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Appendix B

GWSCREEN Input Files

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Appendix B

GWSCREEN Input Files

As explained in the main text, GWSCREEN was used to calculate aquifer concentrations and associated dose or risk. All input and output files and the GWSCREEN executable file are available on the attached CD-ROM.

For the radionuclide risk assessment of the Engineering Test Reactor (ETR) Complex, there are four different corrosion source terms. Three corrosion source terms were used for the C-14 simulations because C-14 is contained in beryllium and a number or stainless-steel components that can be separated into two categories based on the thickness of the stainless steel and the consequent time for total corrosion of the components. Therefore, three different simulations were run and the results of each were added to create the nuclide transport results from corrosion of beryllium and stainless steel. Chromium is simulated using a corrosion mechanism and the average thickness of all the stainless steel is used to calculate the time for corrosion for the chromium source term. Below are the inputs for all of the simulation runs.

Phase 2 Screening ETR Complex – Radionuclide Dose Calculation – Input

ETRRNPIIdose_r1.par

```
ETR Radionuclide Screening Phase II
$ Phase 2 of screening based on Track 2 screening aproach (track 2 defaults used, DOE-ID 1994).
$ Assumed no dispersion in v.z. and contaminants immediately available for leaching from source.
$ RNs screened based on predicted peak dose (<0.4 mrem) and carcinogenic risk (using ED=30 yr,
IR=2 L/d)(<10^-6).
1 1 0 1 1                                (Card 2)  imode,itype,idisp,kflag,idil
1 1 1 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                               (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  365. 1. 0.004        (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.10                            (Card 7)  l,w,perc
6.0  1.5                                 (Card 8b) thicks, rhos, (source term values)
0.30                                     (Card 8c) thetas (source term mc)
18.3  1.5  0.                           (Card 9)  depth,rhou,axu
0.30                                     (Card 9a) thetau
9.0 4.0  0.10  76. 15.                  (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                          (Card 11) u,phi,rhoa
1                                        (Card 12a)nrecept
17.5  0.0                                (Card 12b)xrec yrec
28                                       (Card 14) ncontam
$  ------------------------- Ag-108m ------------------------ 1
 0  90  90  108  2.42E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Ag-108m'  4.18E+02  3.6  7.62E+03            (card14b) cname thalf kda dcf
$  ------------------------- Am-241(Np) ------------------------ 2
 2  8  8  237  3.67E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Am-241(Np)'  2.14E+06  0.32  4.44E+06     (card14b) cname thalf kda dcf
'U-233'  1.59E+05  0.24  2.89E+05                  (card14b) cname thalf kda dcf
'Th-229'  7.34E+03  4  3.53E+06                  (card14b) cname thalf kda dcf
$  ------------------------- Am-243 ------------------------ 3
 4  340  340  243  2.76E-03  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Am-243'  7.37E+03  13.6  3.62E+06                                (card14b) cname thalf kda dcf
'Pu-239'  2.41E+04  0.88  3.54E+06                  (card14b) cname thalf kda dcf
'U-235'  7.04E+08  0.24  2.66E+05                  (card14b) cname thalf kda dcf
'Pa-231'  3.28E+04  22  1.06E+07                  (card14b) cname thalf kda dcf
'Ac-227'  2.18E+01  18  1.41E+07                  (card14b) cname thalf kda dcf
$  ------------------------- Be-10 ------------------------ 4
 0  250  250  10  3.73E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Be-10'  1.51E+06  10  4.66E+03                                (card14b) cname thalf kda dcf
$  ------------------------- C-14 ------------------------ 5
 0  0.1  0.1  14  1.33E+01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'C-14'  5.70E+03  0.004  2.09E+03                                (card14b) cname thalf kda dcf
$  ------------------------- Cl-36 ------------------------ 6
 0  0  0  36  1.26E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
```

```
'Cl-36'  3.01E+05  0  3.03E+03                                (card14b) cname thalf kda dcf
$  ------------------------- Cm-244(Pu240) ------------------------- 7
 4  22  22  240  8.82E-04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Cm-244(Pu240)'  6.56E+03  0.88  3.54E+06         (card14b) cname thalf kda dcf
'U-236'  2.34E+07  0.24  2.69E+05                   (card14b) cname thalf kda dcf
'Th-232'  1.41E+10  4  2.73E+06                   (card14b) cname thalf kda dcf
'Ra-228'  1.60E+03  4  1.44E+06                   (card14b) cname thalf kda dcf
'Th-228'  1.91E+00  4  3.96E+05                   (card14b) cname thalf kda dcf
$  ------------------------- Co-60 ------------------------- 8
 0  10  10  60  1.97E+03  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Co-60'  5.27E+00  0.4  2.69E+04                                (card14b) cname thalf kda dcf
$  ------------------------- Cs-137 ------------------------- 9
 0  500  500  137  2.76E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Cs-137'  3.01E+01  20  5.00E+04                                (card14b) cname thalf kda dcf
$  ------------------------- Eu-152 ------------------------- 10
 0  240  240  152  1.82E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Eu-152'  1.35E+01  9.6  6.48E+03                                (card14b) cname thalf kda dcf
$  ------------------------- Eu-154 ------------------------- 11
 0  240  240  154  1.05E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Eu-154'  8.59E+00  9.6  9.55E+03                                (card14b) cname thalf kda dcf
$  ------------------------- Fe-55 ------------------------- 12
 0  220  220  55  5.47E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Fe-55'  2.74E+00  8.8  6.07E+02                                (card14b) cname thalf kda dcf
$  ------------------------- H-3 ------------------------- 13
 0  0  0  3  3.29E+04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'H-3'  1.23E+01  0  6.40E+01                                (card14b) cname thalf kda dcf
$  ------------------------- I-129 ------------------------- 14
 0  0  0  129  2.82E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'I-129'  1.57E+07  0  2.76E+05                                (card14b) cname thalf kda dcf
$  ------------------------- Nb-94 ------------------------- 15
 0  100  100  94  4.83E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Nb-94'  2.03E+04  4  7.14E+03                                (card14b) cname thalf kda dcf
$  ------------------------- Ni-59 ------------------------- 16
 0  100  100  59  1.32E+02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Ni-59'  7.60E+04  4  2.10E+02                                (card14b) cname thalf kda dcf
$  ------------------------- Ni-63 ------------------------- 17
 0  100  100  63  2.42E+04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Ni-63'  1.00E+02  4  5.77E+02                                (card14b) cname thalf kda dcf
$  ------------------------- Np-237 ------------------------- 18
 2  8  8  237  2.65E-06  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Np-237'  2.14E+06  0.32  4.44E+06                                (card14b) cname thalf kda dcf
'U-233'  1.59E+05  0.24  2.89E+05                   (card14b) cname thalf kda dcf
'Th-229'  7.34E+03  4  3.53E+06                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-238(U234) ------------------------- 19
 3  6  6  234  2.99E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-238(U234)'  2.46E+05  0.24  2.83E+05       (card14b) cname thalf kda dcf
'Th-230'  7.54E+04  4  5.48E+05                   (card14b) cname thalf kda dcf
'Ra-226'  1.60E+03  4  1.32E+06                   (card14b) cname thalf kda dcf
'Pb-210'  2.23E+01  4  5.37E+06                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-239 ------------------------- 20
 3  22  22  239  1.85E-02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-239'  2.41E+04  0.88  3.54E+06                                (card14b) cname thalf kda dcf
'U-235'  7.04E+08  0.24  2.66E+05                   (card14b) cname thalf kda dcf
'Pa-231'  3.28E+04  22  1.06E+07                   (card14b) cname thalf kda dcf
'Ac-227'  2.18E+01  18  1.41E+07                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-240 ------------------------- 21
 4  22  22  240  2.23E-02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-240'  6.56E+03  0.88  3.54E+06                                (card14b) cname thalf kda dcf
'U-236'  2.34E+07  0.24  2.69E+05                   (card14b) cname thalf kda dcf
'Th-232'  1.41E+10  4  2.73E+06                   (card14b) cname thalf kda dcf
'Ra-228'  1.60E+03  4  1.44E+06                   (card14b) cname thalf kda dcf
'Th-228'  1.91E+00  4  3.96E+05                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-241(Np) ------------------------- 22
 2  8  8  237  1.21E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-241(Np)'  2.14E+06  0.32  4.44E+06      (card14b) cname thalf kda dcf
'U-233'  1.59E+05  0.24  2.89E+05                   (card14b) cname thalf kda dcf
'Th-229'  7.34E+03  4  3.53E+06                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-242 ------------------------- 23
 5  22  22  242  2.84E-04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-242'  3.73E+05  0.88  3.36E+06                                (card14b) cname thalf kda dcf
'U-238'  4.47E+09  0.24  2.55E+05                   (card14b) cname thalf kda dcf
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'U-234'  2.46E+05  0.24  2.83E+05                  (card14b) cname thalf kda dcf
'Th-230'  7.54E+04  4  5.48E+05                  (card14b) cname thalf kda dcf
'Ra-226'  1.60E+03  4  1.32E+06                  (card14b) cname thalf kda dcf
'Pb-210'  2.23E+01  4  5.37E+06                  (card14b) cname thalf kda dcf
$  ------------------------- Sr-90 ------------------------- 24
 0  12  12  90  8.51E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Sr-90'  2.88E+01  0.48  1.42E+05                                (card14b) cname thalf kda dcf
$  ------------------------- Tc-99 ------------------------- 25
 0  0.0  0.0  99  6.38E-03  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Tc-99'  2.11E+05  0.0    1.46E+03                                 (card14b) cname thalf kda dcf
$  ------------------------- U-232 ------------------------- 26
 1  6  6  232  1.73E-04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'U-232'  6.89E+01  0.24  1.31E+06                                (card14b) cname thalf kda dcf
'Th-228'  1.91E+00  4  3.96E+05                  (card14b) cname thalf kda dcf
$  ------------------------- U-233 ------------------------- 27
 1  6  6  233  3.67E-04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'U-233'  1.59E+05  0.24  2.89E+05                                (card14b) cname thalf kda dcf
'Th-229'  7.34E+03  4  3.53E+06                  (card14b) cname thalf kda dcf
$  ------------------------- U-238 ------------------------- 28
 4  6  6  238  1.12E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'U-238'  4.47E+09  0.24  2.55E+05                                (card14b) cname thalf kda dcf
'U-234'  2.46E+05  0.24  2.83E+05                  (card14b) cname thalf kda dcf
'Th-230'  7.54E+04  4  5.48E+05                  (card14b) cname thalf kda dcf
'Ra-226'  1.60E+03  4  1.32E+06                  (card14b) cname thalf kda dcf
'Pb-210'  2.23E+01  4  5.37E+06                  (card14b) cname thalf kda dcf
```

Phase 2 Screening ETR Complex – Radionuclide Risk Calculation – Input

ETRRNPIIRisk_r1.par

```
ETR Radionuclide Screening Phase II - Risk
$ Phase 2 of screening based on Track 2 screening aproach (track 2 defaults used, DOE-ID 1994).
$ Assumed no dispersion in V.Z. and contaminants immediately available for leaching from source.
$ RNs screened based on predicted peak dose (<0.4 mrem) and carcinogenic risk (using ED=30 yr,
IR=2 L/d)(<10^-6).
2 1 0 1 1                                (Card 2)  imode,itype,idisp,kflag,idil
1 1 1 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                               (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  350. 30. 1.0E-06     (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.10                            (Card 7)  l,w,perc
6.0  1.5                                 (Card 8b) thicks, rhos, (source term values)
0.30                                     (Card 8c) thetas (source term mc)
18.3  1.5  0.                           (Card 9)  depth,rhou,axu
0.30                                     (Card 9a) thetau
9.0 4.0  0.10  76. 15.                  (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                          (Card 11) u,phi,rhoa
1                                        (Card 12a)nrecept
17.5  0.0                                (Card 12b)xrec yrec
28                                       (Card 14) ncontam
$  ------------------------- Ag-108m ------------------------- 1
 0  90  90  108  2.42E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Ag-108m'  4.18E+02  3.6  8.14E+00                                (card14b) cname thalf kda dcf
$  ------------------------- Am-241(Np) ------------------------- 2
 2  8  8  237  3.67E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Am-241(Np)'  2.14E+06  0.32  6.18E+01                      (card14b) cname thalf kda dcf
'U-233'  1.59E+05  0.24  7.18E+01                  (card14b) cname thalf kda dcf
'Th-229'  7.34E+03  4  2.24E+02                  (card14b) cname thalf kda dcf
$  ------------------------- Am-243 ------------------------- 3
 4  340  340  243  2.76E-03  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Am-243'  7.37E+03  13.6  1.03E+02                                (card14b) cname thalf kda dcf
'Pu-239'  2.41E+04  0.88  1.35E+02                  (card14b) cname thalf kda dcf
'U-235'  7.04E+08  0.24  6.96E+01                  (card14b) cname thalf kda dcf
'Pa-231'  3.28E+04  22  1.73E+02                  (card14b) cname thalf kda dcf
'Ac-227'  2.18E+01  18  2.01E+02                  (card14b) cname thalf kda dcf
$  ------------------------- Be-10 ------------------------- 4
 0  250  250  10  3.73E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Be-10'  1.51E+06  10  7.03E+00                                (card14b) cname thalf kda dcf
$  ------------------------- C-14 ------------------------- 5
 0  0.1  0.1  14  1.33E+01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'C-14'  5.70E+03  0.004  1.55E+00                                (card14b) cname thalf kda dcf
$  ------------------------- Cl-36 ------------------------- 6
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 0  0  0  36  1.26E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Cl-36'  3.01E+05  0  3.30E+00                                  (card14b) cname thalf kda dcf
$  ------------------------- Cm-244(Pu240) ------------------------ 7
 4  22  22  240  0.00E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Cm-244(Pu240)'  6.56E+03  0.88  1.35E+02          (card14b) cname thalf kda dcf
'U-236'  2.34E+07  0.24  6.70E+01                   (card14b) cname thalf kda dcf
'Th-232'  1.41E+10  4  1.01E+02                   (card14b) cname thalf kda dcf
'Ra-228'  1.60E+03  4  1.04E+03                   (card14b) cname thalf kda dcf
'Th-228'  1.91E+00  4  1.07E+02                   (card14b) cname thalf kda dcf
$  ------------------------- Co-60 ------------------------ 8
 0  10  10  60  1.97E+03  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Co-60'  5.27E+00  0.4  1.57E+01                                  (card14b) cname thalf kda dcf
$  ------------------------- Cs-137 ------------------------ 9
 0  500  500  137  2.76E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Cs-137'  3.01E+01  20  3.04E+01                                  (card14b) cname thalf kda dcf
$  ------------------------- Eu-152 ------------------------ 10
 0  240  240  152  1.82E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Eu-152'  1.35E+01  9.6  6.07E+00                                  (card14b) cname thalf kda dcf
$  ------------------------- Eu-154 ------------------------ 11
 0  240  240  154  1.05E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Eu-154'  8.59E+00  9.6  1.03E+01                                  (card14b) cname thalf kda dcf
$  ------------------------- Fe-55 ------------------------ 12
 0  220  220  55  5.47E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Fe-55'  2.74E+00  8.8  8.62E-01                                  (card14b) cname thalf kda dcf
$  ------------------------- H-3 ------------------------ 13
 0  0  0  3  3.29E+04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'H-3'  1.23E+01  0  5.07E-02                                  (card14b) cname thalf kda dcf
$  ------------------------- I-129 ------------------------ 14
 0  0  0  129  2.82E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'I-129'  1.57E+07  0  1.48E+02                                  (card14b) cname thalf kda dcf
$  ------------------------- Nb-94 ------------------------ 15
 0  100  100  94  4.83E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Nb-94'  2.03E+04  4  7.77E+00                                  (card14b) cname thalf kda dcf
$  ------------------------- Ni-59 ------------------------ 16
 0  100  100  59  1.32E+02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Ni-59'  7.60E+04  4  2.74E-01                                  (card14b) cname thalf kda dcf
$  ------------------------- Ni-63 ------------------------ 17
 0  100  100  63  2.42E+04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Ni-63'  1.00E+02  4  6.70E-01                                  (card14b) cname thalf kda dcf
$  ------------------------- Np-237 ------------------------ 18
 2  8  8  237  2.65E-06  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Np-237'  2.14E+06  0.32  6.18E+01                                  (card14b) cname thalf kda dcf
'U-233'  1.59E+05  0.24  7.18E+01                   (card14b) cname thalf kda dcf
'Th-229'  7.34E+03  4  2.24E+02                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-238(U234) ------------------------ 19
 3  6  6  234  2.99E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-238(U234)'  2.46E+05  0.24  7.07E+01              (card14b) cname thalf kda dcf
'Th-230'  7.54E+04  4  9.10E+01                   (card14b) cname thalf kda dcf
'Ra-226'  1.60E+03  4  3.85E+02                   (card14b) cname thalf kda dcf
'Pb-210'  2.23E+01  4  8.81E+02                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-239 ------------------------ 20
 3  22  22  239  1.85E-02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-239'  2.41E+04  0.88  1.35E+02                                  (card14b) cname thalf kda dcf
'U-235'  7.04E+08  0.24  6.96E+01                   (card14b) cname thalf kda dcf
'Pa-231'  3.28E+04  22  1.73E+02                   (card14b) cname thalf kda dcf
'Ac-227'  2.18E+01  18  2.01E+02                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-240 ------------------------ 21
 4  22  22  240  2.23E-02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-240'  6.56E+03  0.88  1.35E+02                                  (card14b) cname thalf kda dcf
'U-236'  2.34E+07  0.24  6.70E+01                   (card14b) cname thalf kda dcf
'Th-232'  1.41E+10  4  1.01E+02                   (card14b) cname thalf kda dcf
'Ra-228'  1.60E+03  4  1.04E+03                   (card14b) cname thalf kda dcf
'Th-228'  1.91E+00  4  1.07E+02                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-241(Np) ------------------------ 22
 2  8  8  237  1.21E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-241(Np)'  2.14E+06  0.32  6.18E+01               (card14b) cname thalf kda dcf
'U-233'  1.59E+05  0.24  7.18E+01                   (card14b) cname thalf kda dcf
'Th-229'  7.34E+03  4  2.24E+02                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-242 ------------------------ 23
 5  22  22  242  2.84E-04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-242'  3.73E+05  0.88  1.28E+02                                  (card14b) cname thalf kda dcf
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'U-238'  4.47E+09  0.24  6.40E+01                  (card14b) cname thalf kda dcf
'U-234'  2.46E+05  0.24  7.07E+01                  (card14b) cname thalf kda dcf
'Th-230'  7.54E+04  4  9.10E+01                  (card14b) cname thalf kda dcf
'Ra-226'  1.60E+03  4  3.85E+02                  (card14b) cname thalf kda dcf
'Pb-210'  2.23E+01  4  8.81E+02                  (card14b) cname thalf kda dcf
$  ------------------------- Sr-90 ------------------------ 24
 0  12  12  90  8.51E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Sr-90'  2.88E+01  0.48  5.59E+01                                (card14b) cname thalf kda dcf
$  ------------------------- Tc-99 ------------------------ 25
 0  0.0  0.0  99  6.38E-03  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Tc-99'  2.11E+05  0.0    2.75E+00                                 (card14b) cname thalf kda dcf
$  ------------------------- U-232 ------------------------ 26
 1  6  6  232  1.73E-04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'U-232'  6.89E+01  0.24  2.92E+02                                (card14b) cname thalf kda dcf
'Th-228'  1.91E+00  4  1.07E+02                  (card14b) cname thalf kda dcf
$  ------------------------- U-233 ------------------------ 27
 1  6  6  233  3.67E-04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'U-233'  1.59E+05  0.24  7.18E+01                                (card14b) cname thalf kda dcf
'Th-229'  7.34E+03  4  2.24E+02                  (card14b) cname thalf kda dcf
$  ------------------------- U-238 ------------------------ 28
 4  6  6  238  1.12E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'U-238'  4.47E+09  0.24  6.40E+01                                (card14b) cname thalf kda dcf
'U-234'  2.46E+05  0.24  7.07E+01                  (card14b) cname thalf kda dcf
'Th-230'  7.54E+04  4  9.10E+01                  (card14b) cname thalf kda dcf
'Ra-226'  1.60E+03  4  3.85E+02                  (card14b) cname thalf kda dcf
'Pb-210'  2.23E+01  4  8.81E+02                  (card14b) cname thalf kda dcf
```

Phase 2 Screening ETR Complex - Nonradionuclides – Input

ETRNonRNPII-r1.par

```
ETR Non-Radionuclide Screening Phase II
$ Phase 2 of screening based on Track 2 screening aproach (track 2 defaults used, DOE-ID 1994).
$ Assumed no dispersion in V.Z. and contaminants immediately available for leaching from source.
$ Non-RNs screened based on predicted peak concentration (vs MCL or alternative).
4 1 0 1 1                                (Card 2)  imode,itype,idisp,kflag,idil
1 1 1 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                               (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  365. 30. 1.0         (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.10                            (Card 7)  l,w,perc
6.0  1.5                                 (Card 8b) thicks, rhos, (source term values)
0.30                                     (Card 8c) thetas (source term mc)
18.3  1.5  0.                           (Card 9)  depth,rhou,axu
0.30                                     (Card 9a) thetau
9.0 4.0  0.1   76. 15.                  (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                          (Card 11) u,phi,rhoa
1                                        (Card 12a)nrecept
17.5  0.0                                (Card 12b)xrec yrec
14                                      (Card 14) ncontam
$  ------------------------- Aluminum ------------------------ 1
 0  250  250  26.98  3.34E+09  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Aluminum'  1.00E+12  10  5.00E+01                                (card14b) cname thalf kda dcf
$  ------------------------- Antimony ------------------------ 2
 0  50  50  121.76  6.00E+05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Antimony'  1.00E+12  2  6.00E+00                                (card14b) cname thalf kda dcf
$  ------------------------- Barium(andcompounds) ------------------------ 3
 0  50  50  137.33  1.0181E+11  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Barium(andcompounds)'  1.00E+12  2  2.00E+03         (card14b) cname thalf kda dcf
$  ------------------------- Beryllium(andcompounds) ------------------------ 4
 0  250  250  9.01  7.00E+08  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Beryllium(andcompounds)'  1.00E+12  10  4.00E+00             (card14b) cname thalf kda dcf
$  ------------------------- Boron ------------------------ 5
 0  5  5  10.81  5.00E+05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Boron'  1.00E+12  0.2  6.00E+02                                (card14b) cname thalf kda dcf
$  ------------------------- Chromium ------------------------ 7
 0  1.2  1.2  52.00  3.542E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Chromium'  1.00E+12  0.048  1.00E+02                  (card14b) cname thalf kda dcf
$  ------------------------- Copper(andcompounds) ------------------------ 8
 0  20  20  63.55  3.684E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Copper(andcompounds)'  1.00E+12  0.8  1.30E+03             (card14b) cname thalf kda dcf
$  ------------------------- Lead ------------------------ 9
```

```
 0  100  100  207.20  4.00E+07  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Lead'  1.00E+12  4  1.50E+01                                (card14b) cname thalf kda dcf
$  ------------------------- Manganese(andcompounds) ------------------------ 10
 0  50  50  54.94  7.67E+09  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Manganese(andcompounds)'  1.00E+12  2  5.00E+01              (card14b) cname thalf kda dcf
$  ------------------------- Nickel ------------------------ 11
 0  100  100  58.69  1.961E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Nickel'  1.00E+12  4  1.00E+02                                (card14b) cname thalf kda dcf
$  ------------------------- Silver(andcompounds) ------------------------ 12
 0  90  90  107.87  4.00E+07  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Silver(andcompounds)'  1.00E+12  3.6  1.00E+02           (card14b) cname thalf kda dcf
$  ------------------------- Tin ------------------------ 13
 0  130  130  118.69  8.00E+07  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Tin'  1.00E+12  5.2  2.20E+04                                (card14b) cname thalf kda dcf
$  ------------------------- Uranium ------------------------ 14
 0  6  6  238.03  3.38E+04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Uranium'  1.00E+12  0.24  3.00E+01                                (card14b) cname thalf kda dcf
$  ------------------------- Zinc ------------------------ 15
 0  16  16  65.39  7.40E+08  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Zinc'  1.00E+12  0.64  5.00E+03                                (card14b) cname thalf kda dcf
```

COC Radionuclide Risk Assessment – Risk Calculation - Input

Input File, with no corrosion
rad-risk-final.par

```
ETR Radionuclide Risk Assessment for rad COCs - Risk - ignore corrosion
2 1 0 1 1                                (Card 2)  imode,itype,idisp,kflag,idil
1 1 2 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                               (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  350. 30. 0.0001      (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.01                            (Card 7)  l,w,perc
6.0  1.5                                 (Card 8b) thicks, rhos, (source term values)
0.30                                     (Card 8c) thetas (source term mc)
18.3  1.5  2.92                          (Card 9)  depth,rhou,axu
0.30                                     (Card 9a) thetau
9.0 4.0  0.10  76. 15.                  (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                          (Card 11) u,phi,rhoa
1                                        (Card 12a)nrecept
17.5  0.0                                (Card 12b)xrec yrec
5                                        (Card 14) ncontam
$  ------------------------- C-14 ------------------------ 5
 0  0.1  0.1  14  1.33E+01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'C-14'  5.70E+03  0.004  1.55E+00        (card14b) cname thalf kda dcf
$  ------------------------- Cl-36 ------------------------ 6
 0  0  0  36  1.26E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Cl-36'  3.01E+05  0  3.30E+00           (card14b) cname thalf kda dcf
$  ------------------------- H-3 ------------------------ 13
 0  0  0  3  3.29E+04  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'H-3'  1.23E+01  0  5.07E-02             (card14b) cname thalf kda dcf
$  ------------------------- Ni-59 ------------------------ 16
 0  100  100  59  1.32E+02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Ni-59'  7.60E+04  4  2.74E-01           (card14b) cname thalf kda dcf
$  ------------------------- Pu-239 ------------------------ 20
 3 140 140  239  1.85E-02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-239'  2.41E+04  5.6   1.35E+02        (card14b) cname thalf kda dcf
'U-235'  7.04E+08  0.24  6.96E+01          (card14b) cname thalf kda dcf
'Pa-231'  3.28E+04  22  1.73E+02           (card14b) cname thalf kda dcf
'Ac-227'  2.18E+01  18  2.01E+02           (card14b) cname thalf kda dcf
```

Input File, with no corrosion – Risk vs Time
rad-risk-final-time-depb.par

```
ETR Radionuclide Risk Assessment for rad COCs - Risk - ignore corrosion
2 1 0 2 1                                (Card 2)  imode,itype,idisp,kflag,idil
1 1 2 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.0001                              (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  350. 30. 0.0001      (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.01                            (Card 7)  l,w,perc
6.0  1.5                                 (Card 8b) thicks, rhos, (source term values)
0.30                                     (Card 8c) thetas (source term mc)
18.3  1.5  2.92                          (Card 9)  depth,rhou,axu
0.30                                     (Card 9a) thetau
```

```
9.0 4.0  0.10  76. 15.                 (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                          (Card 11) u,phi,rhoa
1                                        (Card 12a)nrecept
17.5  0.0                                (Card 12b)xrec yrec
9                                        (Card 13a)ntimes
$ t=0 is time = 0.
0  300  25                               (Card 13b)t1(i),t2(i),tp(i)
301  1377 150                           (Card 13b)t1(i),t2(i),tp(i)
1377  5715 250                          (Card 13b)t1(i),t2(i),tp(i)
5715  28575  500                        (Card 13b)t1(i),t2(i),tp(i)
28575  40000 2000                       (Card 13b)t1(i),t2(i),tp(i)
40000  100000  10000                    (Card 13b)t1(i),t2(i),tp(i)
100000  1000001  50000                  (Card 13b)t1(i),t2(i),tp(i)
1000000  10000001  500000               (Card 13b)t1(i),t2(i),tp(i)
10000000  100000001  5000000            (Card 13b)t1(i),t2(i),tp(i)
5                                        (Card 14) ncontam
$  ------------------------- C-14 ------------------------ 5
 0  0.1  0.1  14  1.33E+01  0. 1.00E+06  0. (card14a) nprog kds kdu zmw qi rmi sl other
'C-14'  5.70E+03  0.004  1.55E+00           (card14b) cname thalf kda dcf
$  ------------------------- Cl-36 ------------------------ 6
 0  0  0  36  1.26E-01  0. 1.00E+06  0.    (card14a) nprog kds kdu zmw qi rmi sl other
'Cl-36'  3.01E+05  0  3.30E+00              (card14b) cname thalf kda dcf
$  ------------------------- H-3 ------------------------ 13
 0  0  0  3  3.29E+04  0. 1.00E+06  0.     (card14a) nprog kds kdu zmw qi rmi sl other
'H-3'  1.23E+01  0  5.07E-02                (card14b) cname thalf kda dcf
$  ------------------------- Ni-59 ------------------------ 16
 0  100  100  59  1.32E+02  0. 1.00E+06  0. (card14a) nprog kds kdu zmw qi rmi sl other
'Ni-59'  7.60E+04  4  2.74E-01              (card14b) cname thalf kda dcf
$  ------------------------- Pu-239 ------------------------ 20
 3 140 140  239  1.85E-02  0. 1.00E+06  0. (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-239'  2.41E+04  5.6   1.35E+02          (card14b) cname thalf kda dcf
'U-235'  7.04E+08  0.24  6.96E+01           (card14b) cname thalf kda dcf
'Pa-231'  3.28E+04  22  1.73E+02            (card14b) cname thalf kda dcf
'Ac-227'  2.18E+01  18  2.01E+02            (card14b) cname thalf kda dcf
```

Corrosion related C-14 input files

The C-14 is in beryllium and in stainless steel. The configuration of the stainless steel is such that it was modeled with two different release rates. So there are three corrosion simulations and the results shown in the report are based on the sum of these three simulation results.

Input File, Nuclide Corrosion – Beryllium

c-14-beryl.par

```
ETR Radionuclide Risk Assessment with Corrosion from Beryllium into soil
$ Infiltration rate is 1 cm/yr (INL soils)
$ Unsaturated dispersivity set at 2.92 m (same as ICDF)
$ Soil Kds are used.
$ C-14 is contained in beryllium (Be) and released by corrosion for this simulation.
$ Estimated metal corrosion rate was used to calculate # of years before all metal is gone.
$ Contaminants released at a constant rate over that period of time (1,377 years)
$ Using the pond model to simulate a flux to the source from corrosion.
$ The pond flux is set at 0 and allows the percolation flux to leach the nuclides.
2 1 0 2 1                                (Card 2)  imode,itype,idisp,kflag,idil
2 1 2 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.0001                              (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  350. 30. 1.0E-04     (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.01                            (Card 7)  l,w,perc
$ Infiltration is assumed to be 1 cm/yr (pond flux = 35x35xI=1225xI m^3/yr)
$ Art Rood upgraded GWSCREEN so we can set the pond flux to zero and leach with precipitation.
$ This allows us to add dry source term at a constant rate.
1377  0. 0. 0.3                          (Card 8a) toper,pndflx,evap,thetap
6.0  1.5                                 (Card 8b) thicks, rhos, (source term values)
0.30                                     (Card 8c) thetas (source term mc)
18.3  1.5  2.92                          (Card 9)  depth,rhou,axu
0.30                                     (Card 9a) thetau
9.0 4.0  0.10  76. 15.                  (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                          (Card 11) u,phi,rhoa
1                                        (Card 12a)nrecept
```

```
17.5  0.0                                (Card 12b)xrec yrec
9                                        (Card 13a)ntimes
$ t=0 is time = 0.
0  300  25                   (Card 13b)t1(i),t2(i),tp(i)
301  1377 150                (Card 13b)t1(i),t2(i),tp(i)
1377  5715 250               (Card 13b)t1(i),t2(i),tp(i)
5715  28575  500             (Card 13b)t1(i),t2(i),tp(i)
28575  40000 2000            (Card 13b)t1(i),t2(i),tp(i)
40000  100000  10000         (Card 13b)t1(i),t2(i),tp(i)
100000  1000001  50000       (Card 13b)t1(i),t2(i),tp(i)
1000000  10000001  500000    (Card 13b)t1(i),t2(i),tp(i)
10000000  100000001  5000000 (Card 13b)t1(i),t2(i),tp(i)
1                            (Card 14) ncontam
$  ------------------------- C-14 ------------------------ 1
 0 0.1 0.1  14  0.00E+00  2.2E-03 1.00E+06  0. (card14a) nprog kds kdu zmw qi rmi sl other
'C-14'  5.70E+03  0.004  1.6E+00               (card14b) cname thalf kda dcf
```

Input File, Nuclide Corrosion – Stainless-steel #1

c-14-ss1.par

```
ETR Radionuclide Risk Assessment with Corrosion from 1st set of SS components into soil
$ Infiltration rate is 1 cm/yr (INL soils)
$ Unsaturated dispersivity set at 2.92 m (same as ICDF)
$ Soil Kds are used.
$ C-14 is contained in stainless steel and released by corrosion for this simulation.
$ Assumes corrosion from the first set of stainless steel components.
$ Estimated metal corrosion rate was used to calculate # of years before all metal is gone.
$ Contaminants released at a constant rate over that period of time (28,575 years).
$ Using the pond model to simulate a flux to the source from corrosion.
$ The pond flux is set at 0 and allows the percolation flux to leach the nuclides.
2 1 0 2 1                                (Card 2)  imode,itype,idisp,kflag,idil
2 1 2 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.0001                              (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  350. 30. 1.0E-04     (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.01                            (Card 7)  l,w,perc
$ Infiltration is assumed to be 1 cm/yr (pond flux = 35x35xI=1225xI m^3/yr)
$ Art Rood upgraded GWSCREEN so we can set the pond flux to zero and leach with precipitation.
$ This allows us to add dry source term at a constant rate.
28575. 0. 0. 0.3                         (Card 8a) toper,pndflx,evap,thetap
6.0  1.5                                 (Card 8b) thicks, rhos, (source term values)
0.30                                     (Card 8c) thetas (source term mc)
18.3  1.5  2.92                          (Card 9)  depth,rhou,axu
0.30                                     (Card 9a) thetau
9.0 4.0  0.10  76. 15.                  (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                          (Card 11) u,phi,rhoa
1                                        (Card 12a)nrecept
17.5  0.0                                (Card 12b)xrec yrec
9                                        (Card 13a)ntimes
$ t=0 is time = 0.
0  300  25                     (Card 13b)t1(i),t2(i),tp(i)
301  1377 150                  (Card 13b)t1(i),t2(i),tp(i)
1377  5715 250                 (Card 13b)t1(i),t2(i),tp(i)
5715  28575  500               (Card 13b)t1(i),t2(i),tp(i)
28575  40000 2000              (Card 13b)t1(i),t2(i),tp(i)
40000  100000  10000           (Card 13b)t1(i),t2(i),tp(i)
100000  1000001  50000         (Card 13b)t1(i),t2(i),tp(i)
1000000  10000001  500000      (Card 13b)t1(i),t2(i),tp(i)
10000000  100000001  5000000   (Card 13b)t1(i),t2(i),tp(i)
1                              (Card 14) ncontam
$  ------------------------- C-14 ------------------------ 1
 0 0.1  0.1  14  0.00E+00  3.1E-04 1.00E+06  0. (card14a) nprog kds kdu zmw qi rmi sl other
'C-14'  5.70E+03  0.004  1.6E+00                (card14b) cname thalf kda dcf
```

Input File, Nuclide Corrosion – Stainless Steel #2

c-14-ss2.par

```
ETR Radionuclide Risk Assessment with Corrosion from 2nd set of SS components into soil
$ Infiltration rate is 1 cm/yr (INL soils)
$ Unsaturated dispersivity set at 2.92 m (same as ICDF)
$ Soil Kds are used.
$ C-14 is contained in stainless steel and released by corrosion for this simulation.
$ Assumes corrosion from the second set of stainless steel components.
$ Estimated metal corrosion rate was used to calculate # of years before all metal is gone.
$ Contaminants released at a constant rate over that period of time (5,715 years).
```

```
$ Using the pond model to simulate a flux to the source from corrosion.
$ The pond flux is set at 0 and allows the percolation flux to leach the nuclides.
2 1 0 2 1                                (Card 2)  imode,itype,idisp,kflag,idil
2 1 2 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.0001                              (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  350. 30. 1.0E-04     (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.01                            (Card 7)  l,w,perc
$ Infiltration is assumed to be 1 cm/yr (pond flux = 35x35xI=1225xI m^3/yr)
$ Art Rood upgraded GWSCREEN so we can set the pond flux to zero and leach with precipitation.
$ This allows us to add dry source term at a constant rate.
5715. 0. 0. 0.3                          (Card 8a) toper,pndflx,evap,thetap
6.0  1.5                                 (Card 8b) thicks, rhos, (source term values)
0.30                                     (Card 8c) thetas (source term mc)
18.3  1.5  2.92                          (Card 9)  depth,rhou,axu
0.30                                     (Card 9a) thetau
9.0 4.0  0.10  76. 15.                  (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                          (Card 11) u,phi,rhoa
1                                        (Card 12a)nrecept
17.5  0.0                                (Card 12b)xrec yrec
9                                        (Card 13a)ntimes
$ t=0 is time = 0.
0  300  25                     (Card 13b)t1(i),t2(i),tp(i)
301  1377 150                  (Card 13b)t1(i),t2(i),tp(i)
1377  5715 250                 (Card 13b)t1(i),t2(i),tp(i)
5715  28575  500               (Card 13b)t1(i),t2(i),tp(i)
28575  40000 2000              (Card 13b)t1(i),t2(i),tp(i)
40000  100000  10000           (Card 13b)t1(i),t2(i),tp(i)
100000  1000001  50000         (Card 13b)t1(i),t2(i),tp(i)
1000000  10000001  500000      (Card 13b)t1(i),t2(i),tp(i)
10000000  100000001  5000000   (Card 13b)t1(i),t2(i),tp(i)
1                              (Card 14) ncontam
$  ------------------------- C-14 ------------------------ 1
 0 0.1 0.1  14  0.00E+00  2.3E-04 1.00E+06  0. (card14a) nprog kds kdu zmw qi rmi sl other
'C-14'  5.70E+03  0.004  1.6E+00               (card14b) cname thalf kda dcf
```

COC Nonradionuclide Risk Assessment – Concentration Calculation - Input

Input File, with no corrosion

nonrad-ra-final.par

```
ETR Non-Radionuclide Risk Assessment assuming no corrosion and no solubility limit
$ Infiltration rate changed to 1 cm/yr (INL soils), vadose zone dispersion included.
$ Unsaturated dispersivity set at 2.92 m (same as ICDF)
$ Non-RNs risk assessment based on predicted peak concentration (vs MCL or alternative).
4 1 0 1 1                                (Card 2)  imode,itype,idisp,kflag,idil
1 1 2 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                               (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  365. 30. 1.0         (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.01                            (Card 7)  l,w,perc
6.0  1.5                                 (Card 8b) thicks, rhos, (source term values)
0.30                                     (Card 8c) thetas (source term mc)
18.3  1.5  2.92                          (Card 9)  depth,rhou,axu
0.30                                     (Card 9a) thetau
9.0 4.0  0.1   76. 15.                  (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                          (Card 11) u,phi,rhoa
1                                        (Card 12a)nrecept
17.5  0.0                                (Card 12b)xrec yrec
6                                        (Card 14) ncontam
$  ------------------------- Barium(andcompounds) ------------------------ 3
 0  50  50  137.33  1.0181E+11  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Barium(andcompounds)'  1.00E+12  2  2.00E+03              (card14b) cname thalf kda dcf
$  ------------------------- Beryllium(andcompounds) ------------------------ 4
 0  250  250  9.01  7.00E+08  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Beryllium(andcompounds)'  1.00E+12  10  4.00E+00             (card14b) cname thalf kda dcf
$  ------------------------- Chromium ------------------------ 7
 0  1.2  1.2  52.00  3.542E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Chromium'  1.00E+12  0.048  1.00E+02                (card14b) cname thalf kda dcf
$  ------------------------- Copper(andcompounds) ------------------------ 8
 0  20  20  63.55  3.684E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Copper(andcompounds)'  1.00E+12  0.8  1.30E+03             (card14b) cname thalf kda dcf
$  ------------------------- Manganese(andcompounds) ------------------------ 10
 0  50  50  54.94  7.67E+09  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Manganese(andcompounds)'  1.00E+12  2  5.00E+01            (card14b) cname thalf kda dcf
$  ------------------------- Nickel ------------------------ 11
 0  100  100  58.69  1.961E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Nickel'  1.00E+12  4  1.00E+02                                (card14b) cname thalf kda dcf
```

Input File, with no corrosion – Risk vs Time

nonrad-ra-final-time-dep.par

```
ETR Non-Radionuclide Risk Assessment assuming no corrosion and no solubility limit
$ Infiltration rate changed to 1 cm/yr (INL soils), vadose zone dispersion included.
$ Unsaturated dispersivity set at 2.92 m (same as ICDF)
$ Non-RNs risk assessment based on predicted peak concentration (vs MCL or alternative).
4 1 0 2 1                                (Card 2)  imode,itype,idisp,kflag,idil
1 1 2 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                               (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  365. 30. 1.0         (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.01                            (Card 7)  l,w,perc
6.0  1.5                                 (Card 8b) thicks, rhos, (source term values)
0.30                                     (Card 8c) thetas (source term mc)
18.3  1.5  2.92                          (Card 9)  depth,rhou,axu
0.30                                     (Card 9a) thetau
9.0 4.0  0.1   76. 15.                  (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                          (Card 11) u,phi,rhoa
1                                        (Card 12a)nrecept
17.5  0.0                                (Card 12b)xrec yrec
6                                        (Card 13a)ntimes
$ t=0 is time = 0.
0. 1377. 100.                           (Card 13b)t1(i),t2(i),tp(i)
1377. 5715. 500.                        (Card 13b)t1(i),t2(i),tp(i)
5715. 28575. 1000.                      (Card 13b)t1(i),t2(i),tp(i)
28575. 40000. 1000.                     (Card 13b)t1(i),t2(i),tp(i)
40000. 100000. 10000.                  (Card 13b) t1(i), t2(i), t3(i)
100000. 1000000. 50000.                 (Card 13b) t1(i), t2(i), t3(i)
$1000000. 10000000. 500000.             (Card 13b) t1(i), t2(i), t3(i)
$10000000. 1000000001. 5000000.         (Card 13b) t1(i), t2(i), t3(i)
6                                        (Card 14) ncontam
$  ------------------------- Barium(andcompounds) ------------------------ 3
 0  50  50  137.33  1.0181E+11  0. 1.E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Barium(andcompounds)'  1.E+12  2  2.0E+03      (card14b) cname thalf kda dcf
$  ------------------------- Beryllium(andcompounds) ------------------------ 4
 0  250  250  9.01  7.00E+08  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Beryllium(andcompounds)'  1.E+12  10  4.0E+00  (card14b) cname thalf kda dcf
$  ------------------------- Chromium ------------------------ 7
 0  1.2  1.2  52.00  3.542E+10  0. 1.00E+06  0. (card14a) nprog kds kdu zmw qi rmi sl other
'Chromium'  1.00E+12  0.048  1.00E+02           (card14b) cname thalf kda dcf
$  ------------------------- Copper(andcompounds) ------------------------ 8
 0  20  20  63.55  3.684E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Copper(andcompounds)'  1.00E+12  0.8  1.30E+03 (card14b) cname thalf kda dcf
$  ------------------------- Manganese(andcompounds) ------------------------ 10
 0  50  50  54.94  7.67E+09  0. 1.00E+06  0.   (card14a) nprog kds kdu zmw qi rmi sl other
'Manganese(andcompounds)'  1.00E+12  2  5.0E+01 (card14b) cname thalf kda dcf
$  ------------------------- Nickel ------------------------ 11
 0  100  100  58.69  1.961E+10  0. 1.00E+06  0. (card14a) nprog kds kdu zmw qi rmi sl other
'Nickel'  1.00E+12  4  1.00E+02                 (card14b) cname thalf kda dcf
```

Input File, Chromium Corrosion – Stainless Steel

cr-ss.par

```
ETR Non-Radionuclide Risk Assessment with Corrosion
$ Infiltration rate is 1 cm/yr (INL soils)
$ Unsaturated dispersivity set at 2.92 m (same as ICDF)
$ Soil Kds are used.
$ C-14 is contained in stainless steel and released by corrosion for this simulation.
$ Assumes corrosion from the overall average thickness of the stainless steel components.
$ Estimated metal corrosion rate was used to calculate # of years before all metal is gone.
$ Contaminants released at a constant rate over that period of time (57,150 years).
$ Using the pond model to simulate a flux to the source from corrosion.
$ The pond flux is set at 0 and allows the percolation flux to leach the nuclides.
4 1 0 2 1                                (Card 2)  imode,itype,idisp,kflag,idil
2 1 2 1 1                                (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                               (Card 4)  jstart jmax eps
70. 2.555E+04 2.0  365. 30. 1.         (Card 5)  bw,at,wi,ef,ed,dlim
0.  0.                                  (Card 6)  x0,y0
35. 35. 0.01                            (Card 7)  l,w,perc
$ Infiltration is assumed to be 1 cm/yr (pond flux = 35x35xI=1225xI m^3/yr)
```

```
$ Art Rood upgraded GWSCREEN so we can set the pond flux to zero and leach with precipitation.
$ This allows us to add dry source term at a constant rate.
57150. 0. 0. 0.3                          (Card 8a) toper,pndflx,evap,thetap
6.0  1.5                                  (Card 8b) thicks, rhos, (source term values)
0.30                                      (Card 8c) thetas (source term mc)
18.3  1.5  2.92                           (Card 9)  depth,rhou,axu
0.30                                      (Card 9a) thetau
9.0 4.0  0.10  76. 15.                  (Card 10) ax,ay,az,b,z(well screen thickness)
57.0  0.10  1.9                           (Card 11) u,phi,rhoa
1                                         (Card 12a)nrecept
17.5  0.0                                 (Card 12b)xrec yrec
6                                         (Card 13a)ntimes
$ t=0 is time = 0.
0. 1377. 25.                  (Card 13b)t1(i),t2(i),tp(i)
1377. 5715. 25.               (Card 13b)t1(i),t2(i),tp(i)
5715. 28575. 25.              (Card 13b)t1(i),t2(i),tp(i)
28575. 40000. 25.             (Card 13b)t1(i),t2(i),tp(i)
40000. 100000. 500.           (Card 13b) t1(i), t2(i), t3(i)
100000. 1000000. 5000.         (Card 13b) t1(i), t2(i), t3(i)
$1000000. 10000000. 50000.     (Card 13b) t1(i), t2(i), t3(i)
$10000000. 1000000001. 500000. (Card 13b) t1(i), t2(i), t3(i)
1                                         (Card 14) ncontam
$  ------------------------- Chromium ------------------------ 1
 0  1.2  1.2  51.996  0.00E+00  6.20E5 1.00E+06  0. (card14a) nprog kds kdu zmw qi rmi sl other
'Chromium'  1.00E+12  0.048  100                    (card14b) cname thalf kda dcf
```