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Engineering Design File

Groundwater Pathway Risk Assessment for EBR-II Closure

Idaho Cleanup Project

CH2M ◆ WG Idaho, LLC is the Idaho Cleanup Project contractor for the U.S. Department of Energy

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This Engineering Design File (EDF) was prepared in support of the closure of the EBR-II facility. Three alternative end states were evaluated for radionuclides and chemicals to remain at the facility after closure. The alternatives evaluated are called Alternatives 1, 3, and 4. Alternative 1 is the "no action" alternative. Alternative 3 is similar to Alternative 1 except that the facility will be grouted before closure. Alternative 4 is similar to Alternative 3 except that the EBR-II reactor will be removed before the facility is grouted.

The results of the conservative risk assessment indicate that for Alternative 1 the C-14 predicted maximum aquifer concentrations will be about equal to the maximum contaminant limit in drinking water. The predicted maximum concentrations in the aquifer for all other contaminats of concern are well below the risk, hazard quotients, and MCL concentration standards.

7. Signatures: (See instructions for significance of signatures. Add or delete signatories as needed.)

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N/A	Reviewer	*Nuclear Safety (only if 5(a) is "Yes")

ENGINEERING DESIGN FILE

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Registered Professional Engineer Stamp		
		This Engineering Design File was prepared under the direction of the Registered Professional Engineer as indicated by the stamp and signature provided on this page. The Professional Engineer is registered in the State of Idaho to practice __________ Engineering.

* Not required for commercial level calculations.

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ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
D&D	decontamination and decommissioning
DOE-ID	U.S. Department of Energy Idaho Operations Office
EBR-II	Experimental Breeder Reactor II
EDE	effective dose equivalent
EDF	engineering design file
EE/CA	engineering evaluation/cost analysis
ICDF	Idaho CERCLA Disposal Facility
INEEL	Idaho National Engineering and Environmental Laboratory
INL	Idaho National Laboratory
MCL	maximum contaminant level
NCRP	National Council on Radiation Protection
OU	operable unit
PA	performance assessment
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
SF	screening factor
TBL	technical baseline
TT	Treatment Technique

Groundwater Pathway Risk Assessment for EBR-II Closure

1. INTRODUCTION

The Experimental Breeder Reactor II (EBR-II) and its containment building (referred to as the EBR-II facility) are being evaluated for decontamination and decommissioning (D&D). After closure and D&D of the EBR-II facility, some radionuclides and chemicals will remain. This analysis evaluates the potential of these contaminants to be transported to the Snake River Plain aquifer. This risk assessment estimates the groundwater pathway risk (e.g., ingestion of contaminated drinking water) to potential human receptors. The groundwater performance criteria require that contaminant concentrations in the Snake River Plain Aquifer do not exceed a cumulative carcinogenic risk level of 1E-04, a hazard quotient of 1, or exceed applicable State of Idaho groundwater quality standards in 2095 and beyond. The Analysis Plan for this EDF can be found in Appendix A.

Four alternatives are proposed for evaluation in the *Engineering Evaluation/Cost Analysis (EE/CA) for the Experimental Breeder Reactor II Vessel Disposition and Containment Building End-State*[a]:

- Alternative 1 – No Action – Under the "no action" alternative, no action would be conducted at the EBR-II facility, and there would be no further surveillance and maintenance at the facility.
  - The No Action Alternative offers no reduction in toxicity, mobility, or volume of contaminants. For the purpose of the risk analysis, the No Action Alternative is a hypothetical, conservative, baseline assumption in that the sum of all identified chemical and/or radiological contamination, if not properly contained or controlled, may be released to the environment causing an unacceptable risk to potential receptors. These assumptions are for comparative purposes only and do not reflect the DOE mandate to monitor, maintain, and mitigate potential or actual hazardous or radiological constituent releases to the public or the environment from any facility or site.
  - Under the No Action Alternative, it is assumed that the EBR-II containment building degrades over the next 85 years (until year 2095) to the point were it crumbles to the ground and contamination becomes available for uptake for the hypothetical future resident. It is assumed that all the rubble and contamination from the containment building is mixed with the soil. The groundwater pathway of concern is ingestion of contamination found in groundwater.
- Alternative 2 – No Action with Continued Surveillance and Maintenance – Under Alternative 2, there would be no action except surveillance and maintenance. This alternative also offers no reduction in toxicity or volume of contaminants, but it does provide more protection from mobilization of the contaminants to the environment than Alternative 1. No risk assessment is needed. This alternative assumes that Surveillance and Maintenance keeps contaminants from reaching the environment.

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a. DOE-ID, *Engineering Evaluation/Cost Analysis (EE/CA) for the Experimental Breeder Reactor II Vessel Disposition and Containment Building End-State,* DOE/ID-11398, U.S. Department of Energy Idaho Operations Office, *in preparation.*

- Alternative 3 – Grouting the EBR-II Reactor Vessel in place and demolition of the Containment Building. Alternative 3 would take place after Resource Conservation and Recovery Act (RCRA) closure of the facility (42 USC § 6901 et seq., 1976).

  - Under Alternative 3, most above-grade systems and structures would be demolished. The remaining belowground level systems and structures including the EBR-II reactor vessel would be grouted in place.

  - Void spaces remaining would be grouted as practicable including the interior of the primary coolant tank resulting in encapsulation of the reactor vessel. The concrete monolith will extend approximately 8 ft above grade and will be finished to facilitate drainage away from the site.

  - The end state of EBR-II under Alternative 3 is a concrete monolith that contains the EBR-II primary coolant tank with internal components including the reactor vessel, primary coolant tank cover, rotating plugs, and primary coolant tank support structure.

  - Low-level radioactive waste would be removed from the site and disposed of at the Idaho Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) Disposal Facility (ICDF) (42 USC § 9601 et seq., 1980) in accordance with the *ICDF Complex Waste Acceptance Criteria* (DOE-ID 2009).

  - Residual radioactive materials at EBR-II remaining after decommissioning and demolition activities are completed would stay in place and be managed under the Long-Term Management and Control Program.

- Alternative 4 – Removal of the EBR-II Reactor Vessel and demolition of the Containment Building – Alternative 4 takes place after RCRA closure of the facility and includes removal and disposal of the EBR-II reactor vessel and some primary sodium tank components, including the primary tank cover, large and small rotating plugs, and primary coolant tank support structure.

  - The containment building would be demolished to ground level or below.

  - Low-level radioactive waste, including the reactor vessel and primary sodium tank components, would be removed from the site and disposed of at ICDF in accordance with the ICDF Complex Waste Acceptance Criteria (DOE-ID 2009).

  - Void spaces would be grouted as practicable, including the void left by removal of the EBR-II reactor vessel.

  - Residual radioactive materials at EBR-II after decommissioning and demolition activities are completed would stay in place and be managed under Long-Term Management and Control.

2. BACKGROUND

The EBR-II reactor was an unmoderated, heterogeneous, sodium-cooled, fast breeder reactor. It was completely submerged in a large tank filled with sodium, which served as a heat transfer medium to remove thermal energy from the reactor. Detailed descriptions of the EBR-II components and systems are provided in *EBR-II System Design Description* (ANL 1985), *Experimental Breeder Reactor II, An Integrated Experimental Fast Reactor Nuclear Power Station,* (Koch 2003), and *Extending the Operating Lifetime of EBR-II to 30 Years and Beyond,* (King et al. 1985). Brief descriptions of the systems/components pertinent to the radiological characterization are presented in TBL-194, "EBR-II Pre-Demolition Source Term."

EBR-II was built in the late 1950's and achieved initial "dry" (i.e., without sodium) criticality on September 30, 1961, and "wet" criticality (i.e., with the core submerged in liquid sodium coolant) on November 11, 1963. EBR-II went to power on August 13, 1964. The EBR-II was designed to demonstrate the feasibility of operating a sodium-cooled fast breeder reactor plant with onsite reprocessing of metallic fuel; demonstrations were successfully carried out from 1964 to 1969.

From 1969 on, the emphasis at EBR-II shifted to a fast-neutron irradiation facility that tested fuels and materials in support of the Liquid-Metal Fast Breeder Reactor Program. The EBR-II facility also provided electrical power for ANL-W and INL sites. EBR-II was officially shut down on September 30, 1994. Since then, EBR-II has been prepared for D&D.

The reactor building shell is a steel enclosure that completely envelopes the reactor building volume (see Figure 1). It is cylindrical and has a hemispherical top closure and a semi-ellipsoidal bottom closure. The shell interior diameter is 80 ft and the total height is about 146 ft (of which ~48 ft is below grade). Figure 2 is a drawing of the shell and the EBR-II areas contained within.

The building shell material is 1-in. thick ASTM 201, grade B, carbon steel. A reinforced concrete missile shield, 12 in. thick lines the inside of the building shell between the operating floor and the building crane. Above this elevation, the shell and its hemispherical top are lined with a 6-in. reinforced concrete layer.

Figure 1. Photograph of EBR-II.

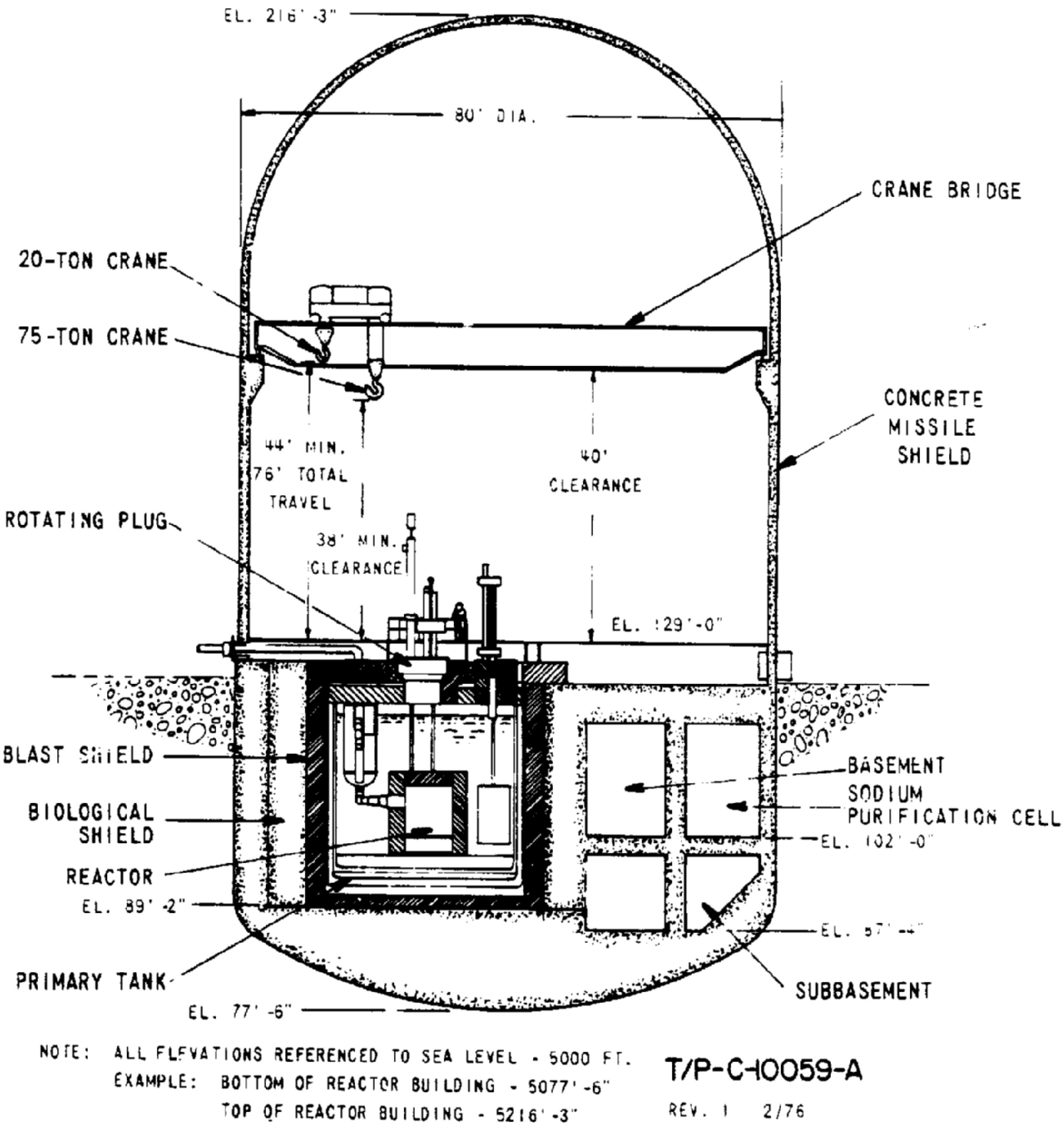

Figure 2. EBR-II Reactor Building Shell.

3. CONTAMINANT INVENTORY FOR THE FUEL REPROCESSING COMPLEX

3.1 Radionuclide Source Term Inventory

Radionuclide inventories in EBR-II were characterized and documented in TBL-194. Table 1 lists the radionuclides and their respective inventories expected to be left in place after the D&D of EBR-II for Alternatives 1, 3, and 4.

- Alternative 1 is defined as the "no action" alternative. The Alternative 1 inventory is defined as the "total EBR-II inventory" shown in Table 1, Column (2).

- For Alternative 3, the reactor is left in place and the aboveground portion of EBR-II is removed. Alternative 3 inventory is defined as "belowgrade inventory" shown in Table 1, Column (4).

- For Alternative 4, the reactor and core are removed. Alternative 4 inventory is defined as the "reactor and blanket removed," shown in Table 1, Column (7).

The primary radionuclide inventory is contained in the reactor. Therefore, the inventory for Alternatives 1 and 3 are basically the same. In Alternative 4, the reactor is removed and the radionuclide inventory left in place is very small relative to Alternative 1 and 3 inventories.

Table 1. Different components of the EBR-II radionuclide inventory and the inventories assumed for Alternatives 1, 3, and 4.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Radionuclide	Total EBR-II Inventory (Alternative 1) (Ci)	Above Grade Inventory (Ci)	Below Grade Inventory (Alternative 3) (Ci)	Core/Blanket Activated Metal Inventory (Ci)	Reactor Vessel Activated Metal Inventory (Ci)	Reactor and Blanket Removed (Alternative 4) (Ci)
Ac-227	2.40E-08		2.40E-08		2.40E-08	0.00E+00
Ag-108m	3.26E-02	4.29E-09	3.26E-02		3.26E-02	0.00E+00
Ag-110m	6.25E-08	2.75E-17	6.25E-08		6.25E-08	0.00E+00
Am-241	1.06E-03		1.06E-03		1.06E-03	0.00E+00
Am-243	1.78E-07		1.78E-07		1.78E-07	0.00E+00
Ba-133	3.23E-01	5.29E-08	3.23E-01		3.23E-01	0.00E+00
Be-10	4.67E-04		4.67E-04		4.67E-04	0.00E+00
C-14	8.38E+00	1.31E-06	8.38E+00	1.87E-01	8.12E+00	7.30E-02
Ca-41	1.46E-03	2.40E-10	1.46E-03		1.46E-03	0.00E+00
Ce-144	4.38E-08		4.38E-08		4.38E-08	0.00E+00
Cl-36	1.72E-01	2.80E-08	1.72E-01	8.72E-05	1.72E-01	0.00E+00
Cm-243	2.45E-07		2.45E-07		2.45E-07	0.00E+00
Cm-244	2.93E-06		2.93E-06		2.93E-06	0.00E+00
Cm-245	1.03E-10		1.03E-10		1.03E-10	0.00E+00
Cm-246	7.30E-12		7.30E-12		7.30E-12	0.00E+00
Cm-247	3.98E-18		3.98E-18		3.98E-18	0.00E+00
Cm-248	1.99E-18		1.99E-18		1.99E-18	0.00E+00

Table 1. (continued).

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Radionuclide	Total EBR-II Inventory (Alternative 1) (Ci)	Above Grade Inventory (Ci)	Below Grade Inventory (Alternative 3) (Ci)	Core/Blanket Activated Metal Inventory (Ci)	Reactor Vessel Activated Metal Inventory (Ci)	Reactor and Blanket Removed (Alternative 4) (Ci)
Co-60	7.43E+03	9.18E-04	7.43E+03	1.23E+03	5.60E+03	6.00E+02
Cs-134	5.92E-02	8.29E-09	5.92E-02		5.92E-02	0.00E+00
Cs-135	9.51E-07	1.56E-13	9.51E-07		9.51E-07	0.00E+00
Cs-137	6.29E-02	3.76E-04	6.25E-02		4.59E-02	1.67E-02
Eu-152	4.36E+00	7.04E-07	4.36E+00		4.36E+00	0.00E+00
Eu-154	6.53E-01	7.15E-08	6.53E-01		6.53E-01	0.00E+00
Eu-155	7.14E-03	1.17E-09	7.14E-03		7.14E-03	0.00E+00
Fe-55	1.46E+03	2.39E-04	1.46E+03		1.46E+03	0.00E+00
H-3	1.74E+01	1.47E-03	1.74E+01		1.73E+01	1.00E-01
Hf-178m	1.05E-01		1.05E-01		1.05E-01	0.00E+00
Ho-166m	3.63E-02	5.95E-09	3.63E-02		3.63E-02	0.00E+00
I-129	1.97E-08	2.20E-15	1.97E-08		1.97E-08	0.00E+00
Mn-53	8.41E-04	1.38E-10	8.41E-04		8.41E-04	0.00E+00
Mn-54	2.38E-02	1.25E-09	2.38E-02		7.60E-03	1.62E-02
Mo-93	1.34E-01	2.19E-08	1.34E-01		1.34E-01	0.00E+00
Na-22	8.14E-05	1.61E-06	7.98E-05			7.98E-05
Nb-92m	2.44E-07	4.00E-14	2.44E-07		2.44E-07	0.00E+00
Nb-94	1.33E-01	1.50E-08	1.33E-01	2.85E-02	9.19E-02	1.26E-02
Ni-59	5.37E+01	8.59E-06	5.37E+01	8.96E-01	5.24E+01	4.04E-01
Ni-63	6.02E+03	9.73E-04	6.02E+03	5.89E+01	5.93E+03	3.11E+01
Np-237	1.44E-08		1.44E-08		1.44E-08	0.00E+00
Pa-231	1.69E-08		1.69E-08		1.69E-08	0.00E+00
Pb-205	4.15E-07	6.80E-14	4.15E-07		4.15E-07	0.00E+00
Pb-210	1.03E-12		1.03E-12		1.03E-12	0.00E+00
Pm-145	2.10E-04	3.44E-11	2.10E-04		2.10E-04	0.00E+00
Pu-238	1.36E-04		1.36E-04		1.36E-04	0.00E+00
Pu-239	1.22E-02	1.17E-08	1.22E-02		1.22E-02	0.00E+00
Pu-240	2.74E-04		2.74E-04		2.74E-04	0.00E+00
Pu-241	1.49E-02		1.49E-02		1.49E-02	0.00E+00
Pu-242	1.23E-07		1.23E-07		1.23E-07	0.00E+00
Pu-244	4.08E-16		4.08E-16		4.08E-16	0.00E+00
Ra-226	1.41E-12		1.41E-12		1.41E-12	0.00E+00
Ru-106	8.96E-07		8.96E-07		8.96E-07	0.00E+00
Sb-125	3.84E-04	1.93E-07	3.84E-04		3.75E-04	9.00E-06
Se-79	1.46E-04	2.40E-11	1.46E-04		1.46E-04	0.00E+00
Sm-146	5.24E-11		5.24E-11		5.24E-11	0.00E+00
Sm-151	6.41E-02	1.05E-08	6.41E-02		6.41E-02	0.00E+00
Sn-121m	1.06E-03		1.06E-03		1.06E-03	0.00E+00

Table 1. (continued).

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Radionuclide	Total EBR-II Inventory (Alternative 1) (Ci)	Above Grade Inventory (Ci)	Below Grade Inventory (Alternative 3) (Ci)	Core/Blanket Activated Metal Inventory (Ci)	Reactor Vessel Activated Metal Inventory (Ci)	Reactor and Blanket Removed (Alternative 4) (Ci)
Sr-90	1.12E+01	2.04E-06	1.12E+01		3.53E-02	1.12E+01
Tb-158	6.45E-04		6.45E-04		6.45E-04	0.00E+00
Tc-99	1.33E-01	4.80E-09	1.33E-01	7.21E-02	2.93E-02	3.16E-02
Th-228	9.37E-04		9.37E-04		9.37E-04	0.00E+00
Th-229	1.82E-08		1.82E-08		1.82E-08	0.00E+00
Th-230	1.16E-10		1.16E-10		1.16E-10	0.00E+00
Th-232	4.31E-09		4.31E-09		4.31E-09	0.00E+00
U-232	7.78E-07		7.78E-07		7.78E-07	0.00E+00
U-233	4.19E-04	6.80E-11	4.19E-04		4.19E-04	0.00E+00
U-234	2.20E-07		2.20E-07		2.20E-07	0.00E+00
U-235	2.96E-05		2.96E-05		4.01E-09	2.96E-05
U-236	1.36E-08		1.36E-08		1.36E-08	0.00E+00
U-238	4.04E-02	1.27E-02	2.77E-02		1.42E-07	2.77E-02
Zn-65	2.10E-05	3.44E-12	2.10E-05		2.10E-05	0.00E+00
Zr-93	1.05E-05	1.72E-12	1.05E-05		1.05E-05	0.00E+00

3.2 Radionuclide Source Term NCRP Screening

A screening method is used to reduce the number of radionuclides by removing insignificant risk contributors so as to focus resources on the more important radionuclides. The radionuclide screening uses screening factors developed by the National Council on Radiation Protection (NCRP) to screen radionuclides (NCRP 1996).

The NCRP provides a series of simple screening factors (SFs) that can be used to demonstrate compliance with environmental standards or other administratively set reference levels for releases of radionuclides to groundwater. The screening factor is essentially a dose conversion factor having units of effective dose equivalent (EDE) per unit of activity (Sv/Bq). These factors incorporate radionuclide fate and transport processes and an assumed exposure scenario to calculate the annual EDE to a hypothetical receptor per unit of activity in the radionuclide inventory. A complete discussion of the assumptions used in the screening dose calculations for ground disposal may be found in NCRP (1996).

The inventory screening limit for each radionuclide is calculated using the following formula:

$$M_i = D_i/(SF_i*CF) \quad (1)$$

Where

M_i = inventory screening limit for radionuclide *i* (Ci),

D_i = screening dose limit for radionuclide *i* (1E-05 Sv)

SF_i = NCRP screening factor for groundwater pathway of ground burial for radionuclide *i* and all progeny for the period of maximum exposure (Sv/Bq) (NCRP 1996)

CF = conversion factor 3.7E+10 Bq/Ci.

Radionuclides with an inventory less than the NCRP screening inventory limit [equates to an NCRP screening dose of 1 mrem (1E-05 Sv)] are removed from further consideration (see Table 2).

In addition to the elimination of radionuclides based on the NCRP screening, some specific radionuclides that do not have NCRP factors were eliminated because either they are a gas or they have an inventory less than 1E-06 Ci, the de minimus curie content for adverse health effects for the groundwater pathway (NCRP 1996). Of the 70 radionuclides presented in Table 1:

- Forty-eight radionuclides were screened using the NCRP screening methodology described above.
- There is no NCRP factor for Nb-92m. The radionuclide has a very short radioactive decay half-life and was eliminated because its inventory is zero after 85 years.
- The following radionuclides were retained even though they were eliminated in the NCRP screening: I-129, Np-237, Pu-238, Pu-241, and U-234. Three nuclides were retained either because they are common contaminants of concern at the D&D sites and explicit evaluation is useful for comparisons with other D&D sites, or they are contained in decay chains for contaminants of concern.

The screening process left 26 radionuclides for the risk assessment.

Table 2. EBR-II Alternative 1 (no action) radionuclide inventory and NCRP groundwater screening results.

Radionuclide	Half-Life (yr)	Total Inventory in 2009 (Ci)	Total Inventory in 2095 (Ci)	NCRP Groundwater Screening Factor (Sv/Bq)	NCRP Inventory Screening Limit for Groundwater Ingestion (Ci)	Total 2095 Inventory < NCRP Inventory Screening Limit?	Other Screening or Retention Reasons	Radionuclides Evaluated in Risk Assessment
Ac-227	2.18E+01	2.40E-08	1.55E-09	8.10E-12	3.34E-05	Yes		
Ag-108m	4.18E+02	3.26E-02	2.83E-02	4.20E-14	6.44E-03			Ag-108m
Ag-110m	6.84E-01	6.25E-08	8.63E-46	5.20E-15	5.20E-02	Yes		
Am-241	4.32E+02	1.06E-03	9.23E-04	5.90E-13	4.58E-04			Am-241
Am-243	7.37E+03	1.78E-07	1.77E-07	6.00E-13	4.50E-04	Yes		
Ba-133	1.05E+01	3.23E-01	1.13E-03	1.80E-14	1.50E-02	Yes		
Be-10	1.51E+06	4.67E-04	4.67E-04	1.40E-14	1.93E-02	Yes		
C-14	5.70E+03	8.38E+00	8.29E+00	1.60E-13	1.69E-03			C-14
Ca-41	1.03E+05	1.46E-03	1.46E-03	5.70E-14	4.74E-03	Yes		
Ce-144	7.80E-01	4.38E-08	2.83E-41	3.60E-15	7.51E-02	Yes		
Cl-36	3.01E+05	1.72E-01	1.72E-01	8.30E-13	3.26E-04			Cl-36
Cm-243	2.91E+01	2.45E-07	3.16E-08	1.50E-13	1.80E-03	Yes		
Cm-244	1.81E+01	2.93E-06	1.09E-07	1.10E-13	2.46E-03	Yes		
Cm-245	8.50E+03	1.03E-10	1.02E-10	5.10E-13	5.30E-04	Yes		
Cm-246	4.76E+03	7.30E-12	7.21E-12	2.90E-13	9.32E-04	Yes		
Cm-247	1.56E+07	3.98E-18	3.98E-18	3.00E-13	9.01E-04	Yes		
Cm-248	3.48E+05	1.99E-18	1.99E-18	1.10E-12	2.46E-04	Yes		
Co-60	5.27E+00	7.43E+03	9.10E-02	5.80E-14	4.66E-03			Co-60
Cs-134	2.07E+00	5.92E-02	1.74E-14	4.20E-15	6.44E-02	Yes		
Cs-135	2.30E+06	9.51E-07	9.51E-07	1.40E-14	1.93E-02	Yes		
Cs-137	3.01E+01	6.29E-02	8.66E-03	7.70E-14	3.51E-03			Cs-137
Eu-152	1.35E+01	4.36E+00	5.30E-02	9.10E-15	2.97E-02			Eu-152
Eu-154	8.59E+00	6.53E-01	6.34E-04	1.10E-14	2.46E-02	Yes		
Eu-155	4.76E+00	7.14E-03	2.61E-08	9.50E-16	2.84E-01	Yes		
Fe-55	2.74E+00	1.46E+03	5.08E-07	9.90E-16	2.73E-01	Yes		
H-3	1.23E+01	1.74E+01	1.38E-01	5.90E-14	4.58E-03			H-3

Table 2. (continued).

Radionuclide	Half-Life (yr)	Total Inventory in 2009 (Ci)	Total Inventory in 2095 (Ci)	NCRP Groundwater Screening Factor (Sv/Bq)	NCRP Inventory Screening Limit for Groundwater Ingestion (Ci)	Total 2095 Inventory < NCRP Inventory Screening Limit?	Other Screening or Retention Reasons	Radionuclides Evaluated in Risk Assessment
Hf-178m	3.10E+01	1.05E-01	1.53E-02	6.30E-12	4.29E-05			Hf-178m
Ho-166m	1.20E+03	3.63E-02	3.45E-02	1.80E-14	1.50E-02			Ho-166m
I-129	1.57E+07	1.97E-08	1.97E-08	1.90E-10	1.42E-06	Yes	Retain - Common COC - Mobile and Long Lived	I-129
Mn-53	3.74E+06	8.41E-04	8.41E-04	1.20E-15	2.25E-01	Yes		
Mn-54	8.55E-01	2.38E-02	1.26E-32	3.80E-15	7.11E-02	Yes		
Mo-93	4.00E+03	1.34E-01	1.32E-01	8.10E-14	3.34E-03			Mo-93
Na-22	2.60E+00	8.14E-05	9.14E-15	4.70E-15	5.75E-02	Yes		
Nb-92m	2.78E-02	2.44E-07	0.00E+00	No Data	No Data	NA	Screen - Half life < 5 years, Inventory < 1E-6 Ci	
Nb-94	2.03E+04	1.33E-01	1.33E-01	2.70E-14	1.00E-02			Nb-94
Ni-59	7.60E+04	5.37E+01	5.37E+01	3.20E-16	8.45E-01			Ni-59
Ni-63	1.00E+02	6.02E+03	3.32E+03	8.60E-16	3.14E-01			Ni-63
Np-237	2.14E+06	1.44E-08	1.44E-08	2.40E-10	1.13E-06	Yes	Retain - Common COC - Part of Am-241 Decay Chain	Np-237
Pa-231	3.28E+04	1.69E-08	1.69E-08	1.50E-11	1.80E-05	Yes		
Pb-205	1.53E+07	4.15E-07	4.15E-07	2.50E-15	1.08E-01	Yes		
Pb-210	2.23E+01	1.03E-12	7.11E-14	5.40E-12	5.01E-05	Yes		
Pm-145	1.77E+01	2.10E-04	7.24E-06	8.10E-16	3.34E-01	Yes		
Pu-238	8.77E+01	1.36E-04	6.89E-05	1.70E-12	1.59E-04	Yes	Retain - Common COC - Decays to U-234	Pu-238
Pu-239	2.41E+04	1.22E-02	1.22E-02	2.00E-12	1.35E-04			Pu-239
Pu-240	6.56E+03	2.74E-04	2.72E-04	2.00E-12	1.35E-04			Pu-240
Pu-241	1.43E+01	1.49E-02	2.30E-04	6.10E-14	4.43E-03	Yes	Retain - Common COC - Decays to Am-241	Pu-241
Pu-242	3.73E+05	1.23E-07	1.23E-07	1.90E-12	1.42E-04	Yes		
Pu-244	8.00E+07	4.08E-16	4.08E-16	2.20E-12	1.23E-04	Yes		

Table 2. (continued).

Radionuclide	Half-Life (yr)	Total Inventory in 2009 (Ci)	Total Inventory in 2095 (Ci)	NCRP Groundwater Screening Factor (Sv/Bq)	NCRP Inventory Screening Limit for Groundwater Ingestion (Ci)	Total 2095 Inventory < NCRP Inventory Screening Limit?	Other Screening or Retention Reasons	Radionuclides Evaluated in Risk Assessment
Ra-226	1.60E+03	1.41E-12	1.36E-12	4.60E-12	5.88E-05	Yes		
Ru-106	1.02E+00	8.96E-07	4.39E-32	6.50E-14	4.16E-03	Yes		
Sb-125	2.76E+00	3.84E-04	1.59E-13	3.60E-15	7.51E-02	Yes		
Se-79	1.10E+06	1.46E-04	1.46E-04	2.20E-14	1.23E-02	Yes		
Sm-146	1.03E+08	5.24E-11	5.24E-11	2.80E-13	9.65E-04	Yes		
Sm-151	9.00E+01	6.41E-02	3.31E-02	1.00E-15	2.70E-01	Yes		
Sn-121m	5.50E+01	1.06E-03	3.59E-04	1.10E-14	2.46E-02	Yes		
Sr-90	2.88E+01	1.12E+01	1.41E+00	3.50E-12	7.72E-05			Sr-90
Tb-158	1.80E+02	6.45E-04	4.63E-04	1.10E-14	2.46E-02	Yes		
Tc-99	2.11E+05	1.33E-01	1.33E-01	3.20E-12	8.45E-05			Tc-99
Th-228	1.91E+00	9.37E-04	2.68E-17	2.10E-15	1.29E-01	Yes		
Th-229	7.34E+03	1.82E-08	1.81E-08	3.60E-13	7.51E-04	Yes		
Th-230	7.54E+04	1.16E-10	1.16E-10	5.20E-13	5.20E-04	Yes		
Th-232	1.41E+10	4.31E-09	4.31E-09	4.80E-13	5.63E-04	Yes		
U-232	6.89E+01	7.78E-07	3.28E-07	3.30E-11	8.19E-06	Yes		
U-233	1.59E+05	4.19E-04	4.19E-04	1.10E-11	2.46E-05			U-233
U-234	2.46E+05	2.20E-07	2.20E-07	4.20E-12	6.44E-05	Yes	Retain - Common COC	U-234
U-235	7.04E+08	2.96E-05	2.96E-05	1.40E-11	1.93E-05			U-235
U-236	2.34E+07	1.36E-08	1.36E-08	3.40E-12	7.95E-05	Yes		
U-238	4.47E+09	4.04E-02	4.04E-02	1.40E-10	1.93E-06			U-238
Zn-65	6.69E-01	2.10E-05	4.09E-44	2.90E-15	9.32E-02	Yes		
Zr-93	1.53E+06	1.05E-05	1.05E-05	1.70E-15	1.59E-01	Yes		

COC contaminant of concern
NA not applicable.
NCRP National Council on Radiation Protection.

3.3 Chemical Source Term Inventory

The chemical contaminant inventory associated with EBR-II was provided by the project and is summarized in Table 3. There are a total of 10 chemical contaminants associated with D&D of the EBR-II facility. There was no screening for the chemical assessment.

Table 3. Summary of the EBR-II remaining chemical contaminant inventory.

	Inventory		
Constituent	Alternative 1 Kg	Alternative 3 Kg	Alternative 4 Kg
Aluminum	6,854	6,455	5,897
Antimony	1	0	1
Boron	408	408	—
Chromium (Cr-III)	54,686	52,131	233
Copper	24,471	15,649	5,693
Lead	14	—	10
Manganese	22,812	15,608	1,093
Nickel	37,836	32,808	689
Uranium	120	83	83
Zinc	1,251	907	593

4. RISK ASSESSMENT

Both the radiological and chemical inventories that are projected to remain after decommissioning of the EBR-II facility were evaluated in this risk assessment. The risk assessment was prepared to assist in the evaluation of end state alternatives for the EBR-II EE/CA (in preparation).

This section describes the methodology and results of the risk assessment for the estimated radionuclide and chemical inventory to be left in place after D&D of the EBR-II facility. As previously discussed, the end state alternatives evaluated are Alternatives 1, 3, and 4. The risk assessment evaluates potential adverse health effects to human receptors via the groundwater pathway. The GWSCREEN model was used to estimate groundwater concentrations in the Snake River Plain Aquifer from the radionuclide contaminants of concern identified in the Section 3.2 screening.

4.1 Alternative 1 (No Action) Risk Assessment

The risk assessment uses the semi-analytical model GWSCREEN Version 2.5 (Rood 2003), to calculate groundwater concentrations for the 26 radionuclides that remain after the NCRP screening and the 10 chemical contaminants of concern. The GWSCREEN model was developed to address CERCLA sites on the INL Site. Risks for the groundwater pathway are computed using risk coefficients published in *Cancer Risk Coefficients for Environmental Exposure to Radionuclides* (EPA 1999). The conceptual model and mathematical model for the source term are discussed in numerous reports (e.g., INEEL 1997, EDF-5186, and DOE-ID 2003).

The GWSCREEN conceptual model is illustrated in Figure 3. The following are primary assumptions in the flow and transport analysis:

- The primary conservative assumption is that all metals have already corroded and the contaminants in the metals are available for transport. In reality, the vast majority of the inventory is contained in stainless steel and carbon steel. The steel will eventually corrode and the contaminants will be slowly released within the EBR-II facility and made available for transport through the subsurface to the aquifer.

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

- All radionuclides present in the EBR-II facility are assumed to be mixed homogeneously with soil and placed in a volume represented by the volume of the EBR-II belowground structure, 25 m × 25 m. Although the contamination is initially focused in the reactor, the contamination must be released from the metal by corrosion, leached into the backfill, and move through the facility, steel, and concrete base. In the process, significant spreading will occur. In addition, after leaving the EBR-II facility, the contamination will spread as it is transported to the aquifer through the vadose zone. The source length and width used in the GWSCREEN model represent both the source area and the final area over which the contaminants are assumed to enter the aquifer. The length and width assumption of the EBR-II facility footprint is a simple but reasonably conservative assumption for this complex process.

- 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 the water and contaminant 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. One-dimensional transport in a 20-m (65.6-ft)-thick unsaturated zone composed of sedimentary interbeds is assumed for the vadose zone model. This thickness of the vadose zone sedimentary interbeds is based on well log evaluations used to define the perched water remedial investigation modeling (INEEL 1997). The total interbed thickness is conservatively assumed relative to the interbed thicknesses presented in the *Comprehensive Remedial Investigation/Feasibility Study for Argonne National Laboratory-West Operable Unit 9-04* (INEEL 1997).

- The receptor well is placed on the downgradient edge of the EBR-II facility. Note that the receptor distance is measured from the center of the source; therefore, the distance to the receptor well is 25 m ÷ 2 = 12.5 m. This receptor is the point where the highest concentrations in the aquifer are estimated.

- For an infiltration rate through the EBR-II facility, the simulations used the Track 2 default infiltration rate of 10 cm/yr (3.9 in./yr) (DOE-ID 1994). This is 10 times larger than the infiltration rate assumed for undisturbed soils at the INL (1 cm/yr).

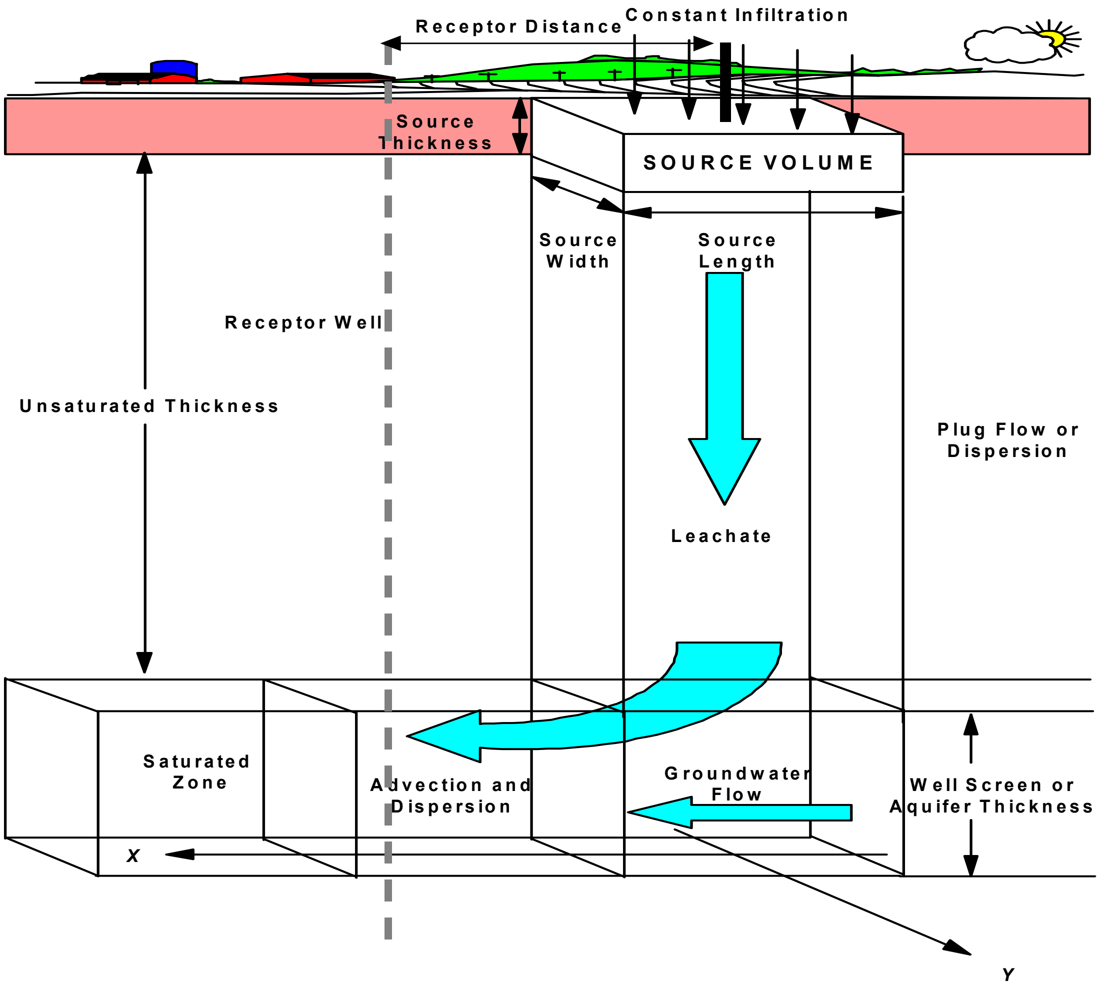

Figure 3. Conceptual model for GWSCREEN groundwater transport model. (For the EBR-II analysis, the receptor is at the edge of the EBR-II facility.)

- The computer code used for the risk assessment simulations (GWSCREEN) assumes one-dimensional flow and transport in the vadose zone; therefore, only longitudinal dispersivity can be included in the vadose zone model. In general, contaminants in the vadose zone would spread both in the direction of flow (longitudinal) and perpendicular to the direction of flow (lateral). With no modeled lateral spreading, the model is conservative relative to lateral dispersivity. Zero dispersion in the vadose zone is a conservative assumption for slow-moving, long-lived radionuclides; however, for radionuclides with relatively short half-lives, the assumption is not conservative. For this analysis, dispersivity in the vadose zone was included. Dispersivity in the vadose zone is a well-known phenomenon, and some effort has been made to quantify the vadose zone longitudinal dispersivity at the INL Site. For purposes of this analysis, since no EBR-II 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 at INTEC for D&D and other environmental studies at the INL (e.g., EDF-8412 and DOE-ID 2003).

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

- Contaminants enter the 76 m (250 ft)-thick aquifer from the vadose zone. The GWSCREEN model estimates the average concentration over a depth defined by a typical well screen of 15 m (49.2 ft).

- The plutonium K_d value used for the Track 2 screening 22 mL/g (DOE 1994) is very conservative and not realistic for this risk assessment. Therefore, the source term K_d used is 140 mL/g, which is consistent with the K_d used in recent analyses of plutonium transport (e.g., EDF-8412, EDF-9247, and DOE-ID 2003). This plutonium K_d is still considered to be a conservative value but less conservative than the Track 2 value used in the screening analysis. In the vadose zone, a K_d of 22 mL/g continued to be used in order to assume a conservative travel time through the vadose zone.

The GWSCREEN model also considers transport of radioactive progeny. In the GWSCREEN code, progeny are assumed to travel at the same rate as their parent. Under most circumstances, this assumption leads to conservative risk 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 under many infiltration scenarios for the 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 risk.

For conservatism, the entire activity of the short-lived immobile parent is converted to the equivalent progeny activity—Equation (1)—by:

$$A_{progeny} = A_{Parent} \frac{SA_{progeny}}{SA_{Parent}} \quad (1)$$

Where

$A_{Progeny}$	=	equivalent activity of the long-lived mobile progeny (Ci)
A_{Parent}	=	original activity of the short-lived immobile parent (Ci)
$SA_{Progeny}$	=	specific activity of the long-lived mobile progeny (Ci/g)
SA_{Parent}	=	specific activity of the short-lived immobile parent (Ci/g).

For radionuclides, the cancer risk was calculated assuming the receptor ingests water at the peak concentration for a duration of 30 years. The radiological risk coefficients are published in *Cancer Risk Coefficients for Environmental Exposure to Radionuclides* (EPA 1999). The calculation was performed using the GWSCREEN model. The groundwater cancer risk was calculated in Equation (2) as:

$$R = C \times I \times \mathrm{EF} \text{ x } ED \times RC \quad (2)$$

Where

R	=	cancer risk
C	=	predicted peak aquifer concentration (pCi/L)
I	=	ingestion rate (2 L/d)

EF = exposure frequency (350 d/yr)

ED = exposure duration (30 years)

RC = risk coefficient (risk/pCi).

Since the mass concentrations for contaminants (radionuclides in particular) in water are generally very low, the simulations generally assumed the solubility in water is infinite. The assumption of complete solubility is overly conservative for some chemicals, in particular, chromium and lead. Therefore, for chromium and lead, the solubility, rather than a simple K_d process, was assumed to simulate the availability of chromium and lead for transport in the environment. The estimated solubility of chromium is 0.052 mg/L, and the estimated solubility of lead is 0.165 mg/L (see Table 4). The chromium and lead solubility are taken from the solubility limits developed for use at the RWMC in buried waste (Dicke 1997). The book, *Chromium in the Natural and Human Environments* (Nriagu and Nieboer 1988), was also reviewed to verify the reliability of the chromium solubility value. The chromium solubility limits are appropriate for solubility in soil.

Table 4. Solubility limits for chromium and lead.

Chemical	Log Solubility (M)[a]	M (Molar Solubility in Water) Mole (solute)/L (solution)	Molecular Weight (g/mole)	Solubility Limited Concentration	
				(g/L)	(mg/L)
Chromium (Cr)	-6	1.00E-06	51.996	5.20E-05	5.20E-02
Lead (Pb)	-6.1	7.94E-07	207.19	1.65E-04	1.65E-01

a. The log solubility is from *Distribution Coefficients and Contaminant Solubilities for the Waste Area Group 7 Baseline Risk Assessment* (Dicke 1997).

Human exposure is expressed in terms of intake and is defined as the amount of a contaminant taken into the body per unit body weight per unit time (mg/kg-day). Intake values were calculated using the standard equation below (EPA 1989):

$$\text{Intake (mg/kg/day)} = (C \times I \times EF \times ED)/(BW \times AT) \quad (3)$$

Where

C = predicted peak aquifer concentration (mg/L)

I = ingestion rate (2L/day)

EF = exposure frequency (350 day/year)

ED = exposure duration (30 years)

BW = body weight (70 kg)

AT = averaging time (days) (10,950 days noncarcinogen; 25,550 days carcinogen).

The hazard potential from toxic effects is computed as the ratio of estimated intake to the reference dose (RfD), and is referred to as the hazard quotient. Hazard quotients less than 1.0 indicate the intake is less than the RfD. The hazard quotient is an index of relative health hazard and does not provide a probabilistic expression of risk. A value less than or equal to 1.0 indicates that it is unlikely for even sensitive subpopulations to experience adverse health effects (EPA 1989). The Integrated Risk Information System database (EPA 2009a) provided information on the toxicity values for the contaminants of concern.

Contaminant-independent parameter values for the subsurface pathway models are provided in Table 5. Contaminant-dependent source term (assumed to be in soil) K_d values are shown in the results subsection. The aquifer K_d values are assumed to be $1/25^{th}$ of the source K_d. With the exception of plutonium, the vadose zone interbed K_d values are assumed to be the same as the source term soil values. As stated above, for plutonium the source term (soil) K_d value is assumed to be 140 mL/g, and the interbed K_d value is assumed to be 22 mL/g. More detail on the parameter values used in the modeling can be found in the GWSCREEN input files included in Appendix B.

4.1.1 Alternative 1 – Radionuclide Risk Assessment Results

The groundwater pathway risk results are shown in Tables 6 and 7 for the radionuclides of concern from the EBR-II facility "No Action" Alternative (Alternative 1). Table 6 presents the inventory, key contaminant-specific parameter values, predicted maximum groundwater concentration, time to maximum, and maximum risk. The risk for each radionuclide is below or within the EPA acceptable target risk range of 1E-06 to 1E-04. The radionuclides predicted to have the largest risks are C-14 (6E-05), Cl-36 (4E-06), Tc-99 (1E-06), and U-238 (1E-06). For all other radionuclides, the predicted risk is below 1E-06. Table 7 compares the predicted peak groundwater concentration to the maximum contaminant level (MCLs). The predicted maximum concentration of C-14 is approximately equal to the C-14 MCL of 2,000 pCi/L. For all other radionuclides, predicted maximum groundwater concentrations are 10% or less than MCLs.

4.1.2 Alternative 1 – Chemical Risk Assessment Results

The groundwater pathway results for the EBR-II facility chemicals of concern are shown in Table 8, along with a comparison of peak groundwater concentrations to the chemical's respective MCL and calculated hazard quotients. All predicted maximum groundwater concentrations are less than the chemical's respective MCL. The predicted maximum copper concentration is 7.4% of the MCL, and is predicted to occur after calendar year 10,000. The predicted maximum uranium concentration is 5.1% of the MCL and is predicted to occur by calendar year 4500. Each of the other chemical contaminants of concern has predicted maximum concentrations that are less than the MCL by more than two orders of magnitude. The chemicals with predicted maximum aquifer concentrations closest to the MCLs are copper and uranium. The hazard quotients are all much less than 1.0, indicating it is unlikely for even sensitive subpopulations to experience adverse health effects.

Table 5. Contaminant-independent parameter values used in the risk assessment.

Parameter	Value	Reference
Source		
Length parallel to groundwater flow	25 m	Contaminant footprint EBR-II and at the water table (assumes no spreading in the vadose zone)
Width perpendicular to groundwater flow	25 m	Contaminant footprint EBR-II and at the water table (assumes no spreading in the vadose zone)
Thickness of source	16.5 m	Based on the facility description
Background percolation rate	0.1 m/yr	Track 2 report (DOE-ID 1994)
Bulk density—source	1.5 g/cm^3	OU 9-04 RI/FS (INEEL1997)
Van Genuchten α in the facility	1.066 m^{-1}	OU 9-04 RI/FS (INEEL 1997)
Van Genuchten η in the facility	1.523	OU 9-04 RI/FS (INEEL 1997)
Saturated hydraulic conductivity	23.9 (m/y)	OU 9-04 RI/FS (INEEL 1997)
Total Porosity	0.487	OU 9-04 RI/FS (INEEL 1997)
Residual moist content	0.142	OU 9-04 RI/FS (INEEL 1997)
Unsaturated (Vadose) Zone		
Cumulative vadose zone interbed thickness	20 m	OU 9-04 RI/FS (INEEL 1997)
Bulk density—unsaturated zone	1.5 g/cm^3	ICDF PA (DOE-ID 2003)
Van Genuchten α in the vadose zone	3.196 m^{-1}	OU 9-04 RI/FS (INEEL 1997)
Van Genuchten η in the vadose zone	2.534	OU 9-04 RI/FS (INEEL 1997)
Saturated hydraulic conductivity	1.26 (m/y)	OU 9-04 RI/FS (INEEL 1997)
Total Porosity	0.48	OU 9-04 RI/FS (INEEL 1997)
Residual moist content	0.083	OU 9-04 RI/FS (INEEL 1997)
Longitudinal dispersivity	2.92 mL/g	ICDF PA (DOE-ID 2003)
Aquifer		
Aquifer thickness	76 m	OU 9-04 RI/FS (INEEL 1997)
Well screen thickness	15 m	OU 9-04 RI/FS (INEEL 1997)
Aquifer porosity	0.1	OU 9-04 RI/FS (INEEL 1997)
Darcy velocity in aquifer	36 m/yr	Calculated base on average linear vel.
Average linear velocity	360 m/yr	OU 9-04 RI/FS (INEEL 1997)
Longitudinal dispersivity	9 m	OU 9-04 RI/FS (INEEL 1997)
Transverse dispersivity	4 m	OU 9-04 RI/FS (INEEL 1997)
Vertical dispersivity	0.4 m	OU 9-04 RI/FS (INEEL 1997)
Bulk density—saturated zone	1.9 g/cm^3	OU 9-04 RI/FS (INEEL 1997)
Receptor Distance from the Center of the Source		
Parallel to groundwater flow direction	12.5 m	Point of maximum, (DOE-ID 1994)
Perpendicular to groundwater flow direction	0 m	Point of maximum, (DOE-ID 1994)

DOE-ID U.S. Department of Energy Idaho Operations Office
EBR-II Experimental Breeder Reactor II
ICDF PA Idaho CERCLA Disposal Facility Performance Assessment
INEEL Idaho National Engineering and Environmental Lahoratory
OU operable unit
RI/FS Remedial Investigation/Feasibility Study

Table 6. Groundwater pathway risk assessment results for the Alternative 1 (No Action) EBR-II radionuclides of concern.

Radionuclide	Progeny	Inventory and Parameters				Simulation Results			
		Inventory (2095) (Ci)	Carcinogenic Risk Slope Factor [a] $(Ci)^{-1}$	K_d Source [b]	K_d Vadose Zone [b]	Peak Time (Calendar Year)	Peak Concentration (pCi/L)	Peak Risk	Total Risk
Ag-108m		2.83E-02	8.14E+00	90	90	7,468	3.58E-09	6.1E-16	6E-16
Am-241(Np-237)		2.17E-07	6.74E+01	8	8	5,390	2.10E-06	3.0E-12	3E-12
	U-233		7.18E+01				3.82E-08	5.8E-14	
	Th-229		5.28E+02				3.89E-10	4.3E-15	
C-14		8.29E+00	1.55E+00	0.1	0.1	2,224	2.00E+03	6.5E-05	6E-05
Cl-36		1.72E-01	3.30E+00	0	0	2,185	6.10E+01	4.2E-06	4E-06
Co-60		9.10E-02	1.57E+01	10	10	19,838	0.00E+00	0.0E+00	0E+00
Cs-137		8.66E-03	3.04E+01	500	500	863,605	0.00E+00	0.0E+00	0E+00
Eu-152		5.30E-02	6.07E+00	340	340	587,615	0.00E+00	0.0E+00	0E+00
H-3		1.38E-01	1.12E-01	0	0	2,137	1.88E+00	3.9E-09	4E-09
Hf-178m		1.53E-02	1.51E+01	450	450	777,695	0.00E+00	0.0E+00	0E+00
Ho-166m		3.45E-02	8.03E+00	250	250	17,257	2.14E-09	3.6E-16	4E-16
I-129		1.97E-08	1.48E+02	0	0	2,185	6.99E-06	2.1E-11	2E-11
Mo-93		1.32E-01	3.35E+00	10	10	5,485	5.41E-01	3.8E-08	4E-08
Nb-94		1.33E-01	7.77E+00	100	100	31,226	3.33E-02	5.4E-09	5E-09
Ni-59		5.37E+01	2.74E-01	100	100	38,220	3.02E+01	1.7E-07	2E-07
Ni-63		3.32E+03	6.70E-01	100	100	176,725	0.00E+00	0.0E+00	0E+00
Np-237		1.44E-08	6.74E+01	8	8	5,390	1.39E-07	2.0E-13	2E-13
	U-233		7.18E+01				2.53E-09	3.8E-15	
	Th-229		5.28E+02				2.58E-11	2.9E-16	
Pu-238(U-234)		4.94E-08	7.07E+01	6	6	4,584	6.28E-07	9.3E-13	9E-13
	Th-230		9.10E+01				1.03E-09	2.0E-15	
	Ra-226		3.86E+02				4.01E-10	3.3E-15	
	Pb-210		1.27E+03				3.93E-10	1.0E-14	
Pu-239		1.22E-02	1.35E+02	140	22	13,373	9.12E-03	2.6E-08	3E-08
	U-235		7.18E+01				3.81E-07	5.7E-13	
	Pa-231		1.73E+02				5.86E-10	2.1E-15	
	Ac-227		4.86E+02				7.13E-10	7.3E-15	

Table 6. (continued).

Radionuclide	Progeny	Inventory and Parameters				Simulation Results			
		Inventory (2095) (Ci)	Carcinogenic Risk Slope Factor [a] $(Ci)^{-1}$	K_d Source [b]	K_d Vadose Zone [b]	Peak Time (Calendar Year)	Peak Concentration (pCi/L)	Peak Risk	Total Risk
Pu-240		2.72E-04	1.35E+02	140	22	10,446	9.73E-05	2.8E-10	3E-10
	U-236		6.70E+01				1.23E-07	1.7E-13	
	Th-232		1.01E+02				2.09E-15	4.4E-21	
	Ra-228		1.04E+03				2.09E-15	4.6E-20	
	Th-228		3.00E+02				2.09E-15	1.3E-20	
Pu-241(Np-237)		1.01E-07	6.74E+01	8	8	5,390	9.78E-07	1.4E-12	1E-12
	U-233		7.18E+01				1.78E-08	2.7E-14	
	Th-229		5.28E+02				1.81E-10	2.0E-15	
Sr-90		1.41E+00	7.40E+01	12	12	23,568	0.00E+00	0.0E+00	0E+00
Tc-99		1.33E-01	2.75E+00	0.2	0.2	2,265	2.50E+01	1.4E-06	1E-06
U-233		4.19E-04	7.18E+01	6	6	4,581	5.31E-03	8.0E-09	9E-09
	Th-229		5.28E+02				8.06E-05	8.9E-10	
U-234		2.20E-07	7.07E+01	6	6	4,584	2.80E-06	4.2E-12	4E-12
	Th-230		9.10E+01				4.59E-09	8.8E-15	
	Ra-226		3.86E+02				1.79E-09	1.4E-14	
	Pb-210		1.27E+03				1.75E-09	4.7E-14	
U-235		2.96E-05	7.18E+01	6	6	4,589	3.79E-04	5.7E-10	6E-10
	Pa-231		1.73E+02				2.58E-07	9.4E-13	
	Ac-227		4.86E+02				3.12E-07	3.2E-12	
U-238		4.04E-02	8.71E+01	6	6	4,589	5.17E-01	9.5E-07	1E-06
	U-234		7.07E+01				3.62E-03	5.4E-09	
	Th-230		9.10E+01				2.98E-06	5.7E-12	
	Ra-226		3.86E+02				8.38E-07	6.8E-12	
	Pb-210		1.27E+03				8.09E-07	2.2E-11	

a. Carcinogenic Risk Slope Factors taken from EPA 1999, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, EPA 402-R-99-001, Federal Guidance Report No. 13, U.S. Environmental Protection Agency.

b. K_d values are primarily consistent with the Track 2 K_d values (DOE-ID 1994). Plutonium is an exception as discussed in the text. Values not included in the Track 2 documentation are taken from the Talley Jenkins letter to Martin Doornbos titled “Kd values for INTEC groundwater modeling” (EM-ER-01-115, July 3, 2001), which surveys groundwater transport models from around the INL and recommends K_d values. The aquifer K_d is $1/25^{th}$ the soil and interbed K_d.

Table 7. Comparison of predicted peak groundwater concentrations for the radionuclides of concern and other selected radionuclides to the Maximum Contaminant Levels.

Radionuclide [a]	MCL [b, c] (pCi/L)	Total Inventory (Ci)	Peak Con (pCi/L)	% of MCL
Ag-108m	NA	2.83E-02	3.58E-09	NA
C-14	2,000	8.29E+00	2.00E+03	100%
Cl-36	700	1.72E-01	6.10E+01	8.7%
Co-60	100	9.10E-02	0.00E+00	0.00%
Cs-137	200	8.66E-03	0.00E+00	0.00%
Eu-152	200	5.30E-02	0.00E+00	0.00%
H-3	20,000	1.38E-01	1.88E+00	0.01%
Hf-178m	NA	1.53E-02	0.00E+00	NA
Ho-166m	NA	3.45E-02	2.14E-09	NA
I-129	1	1.97E-08	6.99E-06	0.00%
Mo-93	NA	1.32E-01	5.41E-01	NA
Nb-94	NA	1.33E-01	3.33E-02	NA
Ni-59	300	5.37E+01	3.02E+01	10.1%
Ni-63	50	3.32E+03	0.00E+00	0.00%
Total Np-237 [d]	Total alpha < 15	3.32E-07	3.22E-06	0.00%
Total Pu [d]	Total alpha < 15	1.25E-02	9.21E-03	0.06%
Sr-90	8	1.41E+00	0.00E+00	0.00%
Tc-99	900	1.33E-01	2.50E+01	2.8%

a. Uraniums are not included in this table. The chemical form of uranium is used for the MCL comparison.

b. EPA 2009b, *Derived Concentrations (pCi/l) of Beta and Photon Emitters in Drinking Water*, http://www.epa.gov/safewater/radionuclides/pdfs/guide_radionuclides_table-betaphotonemitters.pdf , U.S. Environmental Protection Agency, Web page visited October 22, 2009.

c. EPA Maximum Concentration Limits taken from EPA 2009c, *Drinking Water Contaminants*, http://www.epa.gov/safewater/contaminants/index.html#7 , U.S. Environmental Protection Agency, Web page updated September 11, 2009, Web page visited October 22, 2009.

d. Total Np-237 includes the Np-237 from Am-241 and Pu-241. Total Pu includes the concentrations of Pu-239 and Pu-240.

MCL maximum contaminant level
NA not applicable

Table 8. Groundwater pathway results for the EBR-II, No Action (Alternative 1) chemicals of concern.

Chemical	K_d [a] (mL/g)	Inventory (Kg)	Time to Peak (Calendar year)	Comparison of Peak Concentration to MCL: Predicted Peak Conc. (mg/L)	MCL or TT (mg/L)	% MCL	Hazard Quotient for Chemicals with Reference Doses: Chemical Intake (mg/kg/d)	Reference Dose (Oral) [g] (mg/kg/d)	Hazard Quotient
Aluminum	250	6.85E+03	102,375	2.18E-03	No MCL	NA	5.98E-05	1.00E+00	6.0E-05
Antimony	50	1.00E+00	22,222	1.59E-06	6.0E-03	0.03%	4.35E-08	4.00E-04	1.1E-04
Boron	5	4.08E+02	4,188	6.23E-03	No MCL	NA	1.71E-04	2.00E-01	8.5E-04
Chromium III [b, c]	1.2	5.47E+04	NA [f]	1.61E-04	1.0E-01	0.16%	4.41E-06	1.50E+00	2.9E-06
Copper (and compounds)	20	2.45E+04	10,200	9.65E-02	1.3E+00 (TT [e])	7.4%	2.64E-03	4.00E-02	6.6E-02
Lead [b, d]	100	1.40E+01	42,260	1.11E-05	1.5E-02 (TT [e])	0.07%	NA	NA	NA
Manganese (and compounds)	50	2.28E+04	22,222	3.62E-02	No MCL	NA	9.92E-04	2.40E-02	4.1E-02
Nickel	100	3.78E+04	42,260	3.01E-02	No MCL	NA	8.24E-04	2.00E-02	4.1E-02
Uranium	6	1.20E+02	4,589	1.54E-03	3.0E-02	5.1%	4.21E-05	3.00E-03	1.4E-02
Zinc	16	1.25E+03	8,597	6.15E-03	No MCL	NA	1.68E-04	3.00E-01	5.6E-04

a. K_d values are generally consistent with the Track 2 K_d values (DOE-ID 1994). The aluminum value is taken from the Talley Jenkins letter to Marty Doornbos titled "Kd values for INTEC groundwater modeling" (EM-ER-01-115, July 3, 2001), which surveys groundwater flow and transport models from around the INL and recommends K_d values. The aquifer K_d is 1/25th the soil and interbed K_d.
b. Chromium and lead were simulated, including a solubility limit.
c. Chromium III is assumed to be the oxidation state. If the oxidation state was Chromium VI, then the oral reference dose would be 3E-03 and the hazard quotient would be 1.5E-03 (still much less than one).
d. There is no MCL for lead; the value presented is an action level.
e. Lead and copper are regulated by 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, water systems must take additional steps.
f. The chromium concentration reaches its peak in the aquifer within about 300 years, and then stays at that concentration for many thousands of years until all chromium has been transported to the aquifer. Therefore, no time to peak is provided.
g. Reference dose taken from the "Summary Table" on the following website: EPA 2009d, *Mid-Atlantic Risk Assessment*, http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/index.htm , U.S. Environmental Protection Agency, Web page updated June 8, 2009, Web page visited October 29, 2009.

MCL maximum contaminant level.
NA not applicable.
TT Treatment Technique – A required process intended to reduce the level of a contaminant in drinking water.

4.2 Alternatives 3 and 4 Risk Assessments

For Alternative 3, the EBR-II reactor will be grouted in place and for Alternative 4, the reactor will be removed and then the facility will be grouted. The risk assessment analysis differences between the evaluation of Alternative 1 and Alternatives 3 and 4 are in the inventories and the assumptions of contaminant mobility in the subsurface.

- The differences in the Alternative's inventories are shown in Table 1 for radionuclides and in Table 3 for chemicals.

- Contaminant mobility is different for Alternative 1 and Alternatives 3 and 4 because in Alternative 1, the contaminants in the EBR-II facility are assumed to be in soils, and in Alternatives 3 and 4 the contaminants in the EBR-II facility are assumed to be in concrete (a grouted environment). The mobility differences in the source term (within the EBR-II facility after closure) are simulated in the model by applying K_d values for a soil environment in Alternative 1, and K_d values for a grouted environment for Alternatives 3 and 4 (see Table 9).

A grouted closure (such as proposed for Alternatives 3 and 4) will tend to decrease the contaminants' mobility (increase K_d) slowing the contaminants release to the subsurface and decreasing the predicted risk in the aquifer. Therefore, in general, the contaminant risk for Alternatives 3 and 4 will be smaller than the risks for Alternative 1. However, there are two exceptions to this rule: strontium from the radionuclide contaminants of concern, and chromium from the chemical contaminants of concern.

- Strontium in a grouted environment is more mobile than in the natural INL environment. For the Alternative 1 Sr-90 simulations, a K_d of 12 mL/g was used and the resulting predicted concentration was zero. However, for a more mobile form of strontium, the predicted aquifer concentration will not necessarily be zero. The mobility of strontium in grout has been evaluated for a number of projects often related to the High Level Waste EIS (DOE 2005, Portage 2005). The strontium K_d value in a grout environment is estimated at 1 mL/g. Therefore, Sr-90 should be evaluated for Alternatives 3 and 4 using this smaller K_d value in the source area. The decreased K_d for Sr-90 in grout will result in a much higher flux of Sr-90 from the EBR-II facility source area than under Alternative 1.

- Chromium in a grouted environment is more mobile than in the natural INL environment. As the pH increases, the predominant valence state of chromium changes from trivalent (relatively immobile) to hexavalent (relatively mobile) chromium. Therefore, in the grouted source area (high pH), the solubility limit for chromium (hexavalent) would be relatively high and the K_d value would be relatively low. However, as the chromium leaves the vicinity of the EBR-II facility and the grout environment, the predominant valence state will change to the trivalent valence and to a low solubility and relatively high K_d value. For Alternatives 3 and 4, chromium within the EBR-II facility (source term) could be simulated with a zero K_d value. However, since the chromium will change from hexavalent to trivalent during transport through the vadose zone to the aquifer; the chromium solubility limit of 5.2E-02 mg/L will still dominate the deep vadose zone transport concentrations. In other words, increased solubility and mobility in the source (EBR-II facility) will not impact the predicted aquifer concentrations of chromium. There is no need to simulate chromium for Alternatives 3 and 4 since it has been simulated for Alternative 1, and Alternative 3 and 4 simulations will not change the predicted aquifer concentrations.

Table 9. Groundwater pathway risk assessment results for Alternatives 1, 3, and 4.

Contaminant of Interest	MCL		Inventory		K_d (mL/g) Source[a]	K_d (mL/g) Vadose Zone	Simulation Results Peak Time (Calendar Year)	Peak Concentration		Risk	%MCL
Alternative 1 (No Action)											
C-14	2,000	pCi/L	8.29	Ci	0.1	0.1	2224	2004	pCi/L	6.48E-05	100%
Sr-90	8	pCi/L	1.41	Ci	12	12	23,568	0	pCi/L	0.00E+00	0.00%
Copper	1.3	mg/L	24,470	Kg	20	20	10,200	9.65E-02	mg/L	NA	7.4%
Uranium	0.03	mg/L	120	Kg	6	6	4589	1.54E-03	mg/L	NA	5.1%
Alternative 3 (smaller inventory and/or grouted source term)											
C-14	2,000	pCi/L	8.29	Ci	1,000	0.1	2433	1.58	pCi/L	5.14E-08	0.08%
Sr-90	8	pCi/L	1.41	Ci	1	12	2610	9.18E-09	pCi/L	1.42E-14	0.00%
Copper	1.3	mg/L	15,650	Kg	20	20	10,200	6.17E-02	mg/L	NA	4.7%
Uranium	0.03	mg/L	83	Kg	5,000	6	10,852	3.30E-06	mg/L	NA	0.01%
Alternative 4 (smaller inventory and/or grouted source term)											
C-14	2,000	pCi/L	0.072	Ci	1,000	0.1	2433	0.014	pCi/L	4.47E-10	0.00%
Sr-90	8	pCi/L	1.41	Ci	1	12	2610	9.18E-09	pCi/L	1.42E-14	0.00%
Copper	1.3	mg/L	5,693	Kg	20	20	10,200	2.24E-02	mg/L	NA	1.7%
Uranium	0.03	mg/L	83	Kg	5,000	6	10,852	3.30E-06	mg/L	NA	0.01%

a. No reference is available for the copper K_d in a grout environment. Therefore, the copper has been simulated as if the source term is soil for all three scenarios. The C-14, Sr-90, and uranium K_d values are taken from DOE (2005) and Portage (2005).

MCL maximum contaminant level
NA not applicable

The preceding discussion argues that Alternatives 3 and 4 predicted aquifer concentrations will generally be less than Alternative 1 concentrations, estimated risks, and hazard quotients. In order to illustrate the impact of a grouted environment on subsurface transport and decreased inventories for Alternatives 3 and 4, some key contaminants of concern were chosen to evaluate for Alternatives 3 and 4 and were compared with Alternative 1 results. The contaminants chosen for the comparison are the primary risk drivers or the contaminants with predicted maximum aquifer concentrations closest to the MCL. The following contaminants of concern are evaluated:

- C-14 – mobile radionuclide: In the Alternative 1 radionuclide risk assessment, C-14 was predicted to have the largest risk of the contaminants of concern. The C-14 estimated maximum risk for Alternative 1 is 6E-05. In addition, the predicted C-14 maximum aquifer concentration for Alternative 1 is approximately equal to the MCL of 2,000 pCi/L.

- Sr-90 – more mobile in grout than in INL soils; therefore, it is possible the predicted maximum risk could increase significantly.

- Copper and compounds – based on the Alternative 1 chemical simulation results, this is the most significant contributor to future groundwater contamination. The Alternative 1 predicted maximum concentration is 7.4% of the MCL. For the copper, the limit is actually a Treatment Technique limit. If concentrations at the tap are greater than 1.3 mg/L, action is required to reduce the corrosiveness in the water.

- Uranium (the chemical) – based on the Alternative 1 chemical simulation results, this is the second most significant contributor to future groundwater contamination. The Alternative 1 predicted maximum concentration is 5.1% of the MCL.

Table 9 shows a comparison of the C-14, Sr-90, copper, and uranium (chemical) predicted maximum concentrations, risk (for C-14 and Sr-90), and percentage of MCL (for copper and uranium). The table shows that inventories and the K_d values in the source change with the alternative. All other parameters are unchanged. For copper, the K_d in a grouted source term is unknown. Therefore, the source term K_d values for copper are assumed to be the same for Alternatives 1, 3, and 4. As shown in Table 9:

- For Alternative 1, the predicted C-14 maximum aquifer concentration is 2,030 pCi/L, which is approximately the C-14 MCL. The predicted C-14 maximum risk is 6E-05 or 60% of the 1E-04 risk standard. For Alternatives 3 and 4, the EBR-II facility would be grouted, and the K_d value in grout is 1,000 mL/g (instead of 0.1 mL/g). Therefore, C-14 would be very slowly released from the source area, decreasing the predicted maximum aquifer concentration and risk by about three orders of magnitude. The predicted maximum risk for C-14 in Alternatives 3 and 4 are 5E-08 and 4E-10 respectively.

- The predicted maximum risk for Sr-90 in Alternative 1 was zero. For Alternatives 3 and 4, the EBR-II facility would be grouted and the K_d value in grout is 1 mL/g (instead of 12 mL/g). Therefore, Sr-90 would be released more quickly from the source area, increasing the predicted maximum risk. The risk is significantly increased but the resulting maximum risk is still very small for Sr-90 for Alternatives 3 and 4. The predicted maximum risk for Sr-90 in Alternatives 3 and 4 is 1E-14, which is essentially zero.

- The predicted maximum concentration for copper in Alternative 1 was 9.65E-02 mg/L, or 7.4% of the MCL (1.3 mg/L). The K_d in a grouted source term is not known; therefore, the source K_d for Alternatives 3 and 4 was assumed to be the same as the K_d values for Alternative 1. The predicted maximum concentrations for copper in Alternatives 3 and 4 decrease only because the inventory of copper is decreased. For Alternative 3 the predicted maximum concentration is 6E-02 (4.7% of the MCL), and for Alternative 4 the predicted maximum concentration is 2E-02 (1.7% of the MCL).

- The predicted maximum concentration for uranium (the chemical) in Alternative 1 was 1.54E-03 mg/L, or 5.1% of the MCL (0.03 mg/L). In grout the mobility of uranium is much less than the mobility in soils (as simulated in Alternative 1). The predicted maximum concentrations for uranium in Alternatives 3 and 4 are 3E-06 mg/L, or about 0.01% of the uranium MCL.

As previously discussed for all other contaminants of concern, the predicted maximum risk, hazard quotients, and concentrations for Alternatives 3 and 4 will be significantly less than Alternative 1 results, which are less than the groundwater performance criteria. Therefore no analysis is necessary.

Based on this conservative risk assessment, the contamination at the EBR-II facility is not expected to result in groundwater concentrations that exceed the performance criteria for any of the Alternatives.

5. SUMMARY

Four alternatives are proposed for evaluation in the Engineering Evaluation/Cost Analysis (EE/CA) (in preparation) for the Experimental Breeder Reactor II Vessel Disposition and Containment Building End-State: (1) no action, (2) no action with continued surveillance and maintenance, (3) grouting the EBR--II reactor vessel in place and then demolition of the containment building, and (4) removal of the EBR-II reactor vessel and then grouting and demolition of the containment building. This study evaluated the groundwater pathway risk assessment for Alternatives 1, 3, and 4.

The radionuclide inventory to be left in place after D&D of the EBR-II Facility consists of 70 individual radionuclides. A screening method was performed to reduce the list by removing insignificant risk contributors so as to focus the risk assessment on the more important radionuclides. Forty-four of the 70 radionuclides were screened in Section 3.2 of this EDF, leaving twenty-six radionuclides for the risk assessment. There are ten chemicals in the chemical inventory, and there was no screening for the chemicals.

This risk assessment is a conservative analysis. In particular, the analysis assumes that the waste is available for transport when, in fact, the waste is largely in metals that must corrode in order to be released to the environment.

The results of the Alternative 1 radionuclide risk assessment indicate that the maximum cumulative risk is 6E-05 (about 2,000 years into the future) with C-14 accounting for the total radiological risk (see Table 6). This risk is within the EPA's acceptable target risk range of 1E-06 to 1E-04 and meets the CERCLA groundwater performance criteria of 1E-04 risk. The predicted maximum concentration of C-14 is approximately equal to the C-14 MCL of 2,000 pCi/L. All other predicted maximum groundwater concentrations are 10% or less than the MCLs (see Table 7).

The results of the Alternative 1 chemical analysis show the hazard indexes are all much less than 1, indicating it is unlikely for even sensitive subpopulations to experience adverse health effects. When compared to the MCL, all chemical contaminants of concern have predicted maximum aquifer concentrations less than 10% of the MCL. The predicted maximum groundwater concentrations for the chemicals of concern were compared to the State of Idaho MCLs. All predicted maximum groundwater concentrations are less than the chemical's respective MCL.

Alternative 3 assumes that the EBR-II facility is grouted with the reactor in place. Alternative 4 assumes that the reactor is removed and disposed of elsewhere and then the facility is grouted and covered. The impact of reduced inventories and the change of environment from soil to grout were evaluated. The contaminants chosen for the evaluation were C-14, Sr-90, copper, and uranium (chemical). With the exception of Sr-90, the predicted maximum concentrations, risks, and hazard quotients for Alternatives 3 and 4 are significantly smaller than the Alternative 1 results.

This conservative risk assessment demonstrates that for Alternatives 1, 3, and 4, the inventory to be left in place after D&D of the EBR-II facility will meet the CERCLA groundwater performance criteria of contaminant concentrations in the Snake River Plain Aquifer less than or equal to a cumulative carcinogenic risk of 1E-04. For Alternative 1, the predicted maximum concentration of C-14 is approximately equal to the C-14 MCL of 2,000 pCi/L, and all other predicted maximum groundwater concentrations are 10% or less than MCLs. Based on this conservative risk assessment, for Alternatives 3 and 4, the contamination at the EBR-II facility is not expected to result in groundwater concentrations that exceed the performance criteria for any contaminants of concern.

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Appendix A

Analysis Plan

This appendix outlines the work plan for preparation of this Engineering Design File per MCP-2059, "Commercial Analyses and Calculations." Based on HAD-457, "Hazard Assessment Document for the EBR-II Reactor Building (MFC-767)," there are no Safety Class or Safety Significant structures, systems, or components (SSCs) associated with the EBR-II closure.

The objective of this analysis is to calculate the groundwater pathway risk from the residual material to be left in place after the decontamination and decommissioning (D&D) of EBR-II. The calculated risks are used in an engineering evaluation/cost analysis (EE/CA) (in preparation) to support the decision-making process for the D&D of EBR-II.

The subsurface flow and transport analyses will be conducted in accordance with MCP-2059. The GWSCREEN Version 2.5a (01/23/2007) computer code (Enterprise Architecture ID # 121200) will be used to calculate the risk. GWSCREEN has been validated and controlled in accordance with MCP-3039, "Analysis Software Control." The calculations performed are considered commercial level at Quality Level 3.The deliverable for this project is an EDF documenting the calculations and computer files showing the input used in GWSCREEN needed to reproduce the results.

Technical checking will be conducted in accordance with MCP-2059 and will include verification that input data are appropriate, and that input and output documented in the EDF match the associated input and output files for GWSCREEN. The conclusions will be reviewed to ensure they are consistent with the analysis that was presented. The technical checker will also verify that GWSCREEN was appropriate for this use and that the formulas and calculations are correct.

Appendix B

GWSCREEN Risk Calculation Input Files

As explained in the main text, GWSCREEN was used to calculate aquifer concentrations and associated risk for the EBR-II groundwater pathway risk assessment. Below are the input files for the simulation runs.

Radionuclide Risk Calculations

Radionuclide Peak Risk Calculation – Alternative 1
Input File - rad-RA-ebr-ii-alt1-10-20-09.par

```
EBR-II radionuclide risk assessment-Alt 1 - Risk - 10/20/2009 - James McCarthy
$ inventory decayed to 2095
$ Aquifer Kd to 1/25th soil Kd.
$ Pu Kd is 140 in source and 22 in unsaturated zone.
$ Screening Level Evaluation - carcinogenic risk (using ED=30 yr, IR=2 L/d)(<10^-6).
2 3 0 1 1                                 (Card 2)  imode,itype,idisp,kflag,idil
1 1 2 2 2                                 (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                                (Card 4)  jstart jmax eps

$ If imode = 1 and you want to calculate the all-pathways dose
$ Set WI=1000 L/d (1 m3/d), EF=1 d/yr, ED=1 yr when using AllPath DCFs (rem*m3/Ci).
$70. 2.555E+04 1000. 1. 1. 0.025       (Card 5)  bw,at,wi,ef,ed,dlim
$ If imode = 1 and you want to calculate groundwater ingestion dose
$ Set WI=??? (1 m3/d), EF=365 d/yr, ED=1 yr when using EPA GW ingestion (rem*/Ci??).
$ If imode =2 for calculating radiological risk, set ???
  70. 2.555E+04 2.0  350. 30. 1.0E-6       (Card 5) bw,at,wi,ef,ed,dlim
$ if imode =3 for calculating concentration and comparing to MCL set ???
$ put all of the option in.
$ If imode=4 when comparing to MCLs the ed and dlim must both be 1.
$ The other variables are not used.
$70. 2.555E+04 2.0  350.  1. 1.0         (Card 5)  bw,at,wi,ef,ed,dlim (c / MCL of interest)
0.  0.                                  (Card 6) x0,y0
$
25.0 25.0 0.10                            (Card 7)  l,w,perc
16.5 1.5                                  (Card 8b) thicks, rhos, (source term values)
$0.30                                       (Card 8c) thetas (source term mc)
$Table 5-4 OU 9-04 RI/FS W7500-000-ES-02 source term soil parameters
1.066 1.523 23.9 0.487 0.142                (Card 8d) alpha n ksat pors thetar
20.0  1.5    2.92                           (Card 9) depth,rhou,axu
$ NOTE: The values of depth and axu are the ucode calibrated values
$ 0.30                                      (Card 9a) thetau
$Table 5-9 OU 9-04 RI/FS W7500-000-ES-02 VZ soil parameters
3.196 2.534  1.26 0.48 0.083               (Card 9b) alphau nu ksatu porsu thetaru
$ --- use calibrated values for ax and az ay=0.2ax and az=1.16e-3ax as stated in the MEPAS Manual
9. 4. 0.4   76. 15.                     (Card 10) ax,ay,az,b,z(well screen thickness)
$ --- Aquifer density and porosity from EDF-ER-275 60% Design Component Report Table 2-2 and 2-3
$ --- Darcy velocity based on an assumed pore vel of ~ 1 m/d in EDF-ER-275
36. 0.1  1.9                           (Card 11) u,phi,rhoa
1                                         (Card 12a)nrecept
12.5  0.0                                 (Card 12b)xrec yrec
26                                        (Card 14) ncontam
$  ------------------------- Ag-108m --2095------------------ 1
 0  90  90  108  2.83E-02  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-237) --leave for 2095-------- 2
 2  8  8  237  2.17E-07  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Am-241(Np-237)'  2.14E+06  0.32  6.74E+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  5.28E+02                   (card14b) cname thalf kda dcf
$  ------------------------- C-14 ----2095---------------- 3
 0  0.1  0.1  14  8.29E+00  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 ------------------------ 4
 0  0  0  36  1.72E-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
$  ------------------------- Co-60 ---2095----------------- 5
 0  10  10  60  9.10E-02  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 ---2095----------------- 6
 0  500  500  137  8.66E-03  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 ----2095---------------- 7
 0  340  340  152  5.30E-02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Eu-152'  1.35E+01  13.6  6.07E+00                             (card14b) cname thalf kda dcf
$  ------------------------- H-3 ------2095-------------- 8
 0  0  0  3  1.38E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'H-3'  1.23E+01  0  1.12E-01                             (card14b) cname thalf kda dcf
$  ------------------------- Hf-178m ----2095---------------- 9
 0  450  450  178  1.53E-02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Hf-178m'  3.10E+01  18  1.51E+01                             (card14b) cname thalf kda dcf
$  ------------------------- Ho-166m ---2095----------------- 10
 0  250  250  166  3.45E-02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Ho-166m'  1.20E+03  10  8.03E+00                             (card14b) cname thalf kda dcf
$  ------------------------- I-129 ------------------------ 11
 0  0  0  129  1.97E-08  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
$  ------------------------- Mo-93 ----2095---------------- 12
 0  10  10  93  1.32E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Mo-93'  4.00E+03  0.4  3.35E+00                             (card14b) cname thalf kda dcf
$  ------------------------- Nb-94 ------------------------ 13
 0  100  100  94  1.33E-01  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 ------------------------ 14
 0  100  100  59  5.37E+01  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 ----2095---------------- 15
 0  100  100  63  3.32E+03  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 ------------------------ 16
 2  8  8  237  1.44E-08  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Np-237'  2.14E+06  0.32  6.74E+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  5.28E+02                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-238(U-234) --leave for 2095-------- 17
 3  6  6  234  4.94E-08  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Pu-238(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  3.86E+02                   (card14b) cname thalf kda dcf
'Pb-210'  2.23E+01  4  1.27E+03                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-239 ------------------------ 18
 3  140   22  239  1.22E-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  7.18E+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  4.86E+02                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-240 ----2095---------------- 19
 4  140   22  240  2.72E-04  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'  5.75E+00  4  1.04E+03                   (card14b) cname thalf kda dcf
'Th-228'  1.91E+00  4  3.00E+02                   (card14b) cname thalf kda dcf
$  ------------------------- Pu-241(Np-237) ---leave for 2095------- 20
 2  8  8  237  1.01E-07  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
```

```
'Pu-241(Np-237)'  2.14E+06  0.32  6.74E+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  5.28E+02                      (card14b) cname thalf kda dcf
$  ------------------------- Sr-90 ----2095---------------- 21
 0  12  12  90  1.41E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Sr-90'  2.88E+01  0.48  7.40E+01                                 (card14b) cname thalf kda dcf
$  ------------------------- Tc-99 ------------------------ 22
 0  0.2  0.2  99  1.33E-01  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Tc-99'  2.11E+05  0.008  2.75E+00                                (card14b) cname thalf kda dcf
$  ------------------------- U-233 ------------------------ 23
 1  6  6  233  4.19E-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  5.28E+02                      (card14b) cname thalf kda dcf
$  ------------------------- U-234 ------------------------ 24
 3  6  6  234  2.20E-07  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'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  3.86E+02                      (card14b) cname thalf kda dcf
'Pb-210'  2.23E+01  4  1.27E+03                      (card14b) cname thalf kda dcf
$  ------------------------- U-235 ------------------------ 25
 2  6  6  235  2.96E-05  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'U-235'  7.04E+08  0.24  7.18E+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  4.86E+02                      (card14b) cname thalf kda dcf
$  ------------------------- U-238 --includes depleted uran 26
 4  6  6  238  4.04E-02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'U-238'  4.47E+09  0.24  8.71E+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  3.86E+02                      (card14b) cname thalf kda dcf
'Pb-210'  2.23E+01  4  1.27E+03                      (card14b) cname thalf kda dcf
```

Radionuclide Peak Risk Calculation – Alternative 1 – Concrete Source
Input File - rad-RA-ebr-ii-alt1-concrete-10-20-09.par

```
EBR-II radionuclide risk assessment phase - Risk - 10/20/2009 - concrete - James McCarthy
$ inventory decayed to 2095
$ Aquifer Kd to 1/25th soil Kd.
$ Screening Level Evaluation - carcinogenic risk (using ED=30 yr, IR=2 L/d)(<10^-6).
2 3 0 1 1                                  (Card 2)  imode,itype,idisp,kflag,idil
1 1 2 2 2                                  (Card 3)  imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                                 (Card 4)  jstart jmax eps

$ If imode = 1 and you want to calculate the all-pathways dose
$ Set WI=1000 L/d (1 m3/d), EF=1 d/yr, ED=1 yr when using AllPath DCFs (rem*m3/Ci).
$70. 2.555E+04 1000. 1. 1. 0.025       (Card 5)  bw,at,wi,ef,ed,dlim
$ If imode = 1 and you want to calculate groundwater ingestion dose
$ Set WI=??? (1 m3/d), EF=365 d/yr, ED=1 yr when using EPA GW ingestion (rem*/Ci??).
$ If imode =2 for calculating radiological risk, set ???
  70. 2.555E+04 2.0  350. 30. 1.0E-6       (Card 5) bw,at,wi,ef,ed,dlim
$ if imode =3 for calculating concentration and comparing to MCL set ???
$ put all of the option in.
$ If imode=4 when comparing to MCLs the ed and dlim must both be 1.
$ The other variables are not used.
$70. 2.555E+04 2.0  350.  1. 1.0         (Card 5)  bw,at,wi,ef,ed,dlim (c / MCL of interest)
0.  0.                                  (Card 6) x0,y0
$
25.0 25.0 0.10                             (Card 7)  l,w,perc
16.5 1.5                                   (Card 8b) thicks, rhos, (source term values)
$0.30                                        (Card 8c) thetas (source term mc)
$Table 5-4 OU 9-04 RI/FS W7500-000-ES-02 source term soil parameters
1.066 1.523 23.9 0.487 0.142                 (Card 8d) alpha n ksat pors thetar
20.0  1.5    2.92                            (Card 9) depth,rhou,axu
$ NOTE: The values of depth and axu are the ucode calibrated values
$ 0.30                                       (Card 9a) thetau
$Table 5-9 OU 9-04 RI/FS W7500-000-ES-02 VZ soil parameters
3.196 2.534  1.26 0.48 0.083                (Card 9b) alphau nu ksatu porsu thetaru
$ --- use calibrated values for ax and az ay=0.2ax and az=1.16e-3ax as stated in the MEPAS Manual
9. 4. 0.4   76. 15.                     (Card 10) ax,ay,az,b,z(well screen thickness)
$ --- Aquifer density and porosity from EDF-ER-275 60% Design Component Report Table 2-2 and 2-3
$ --- Darcy velocity based on an assumed pore vel of ~ 1 m/d in EDF-ER-275
36. 0.1  1.9                           (Card 11) u,phi,rhoa
1                                          (Card 12a)nrecept
12.5  0.0                                  (Card 12b)xrec yrec
6                                          (Card 14) ncontam
$  ----decayed to 2095------ C-14 -----Alt 1 ------------------- 3
 0  0.1  0.1  14  8.29E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'C-14 Alt1'  5.70E+03  0.004  1.55E+00              (card14b) cname thalf kda dcf
$  ------decayed to 2095---- C-14 concrete Kd 1000 mL/g-----Alt 3--------------- 3
 0  1000. 0.1  14  8.29E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'C-14 Alt3'  5.70E+03  0.004  1.55E+00               (card14b) cname thalf kda dcf
$  ------decayed to 2095---- C-14 concrete Kd 1000 mL/g-----Alt 4--------------- 3
 0  1000. 0.1  14  7.22E-02  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'C-14 Alt4'  5.70E+03  0.004  1.55E+00                 (card14b) cname thalf kda dcf
$  ----decayed to 2095------ Sr-90 ----Alt 1 -------------------- 21
 0  12  12  90  1.41E+00 0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Sr-90 Alt1'  2.88E+01  0.48  7.40E+01                 (card14b) cname thalf kda dcf
$  ----decayed to 2095------ Sr-90 concrete Kd 1 mL/g--Alt 3----------------- 21
 0  1  12  90  1.41E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Sr-90 Alt3'  2.88E+01  0.48  7.40E+01                (card14b) cname thalf kda dcf
$  ----decayed to 2095------ Sr-90 concrete Kd 1 mL/g--Alt 4----------------- 21
 0  1  12  90  1.41E+00  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Sr-90 Alt4'  2.88E+01  0.48  7.40E+01                (card14b) cname thalf kda dcf
```

Chemical GWSCREEN Input Files

Chemical Concentration Calculation – Alternative 1
Input File – RA-EBR-II-nrad-rev1-9-30.par

```
EBR-II nonradionuclide risk assessment - MCL- 9/30/2009
$  comparison is with the MCLs
4 3 0 1 1                                    (Card 2) imode,itype,idisp,kflag,idil
1 1 2 2 2                                    (Card 3) imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                                   (Card 4) jstart jmax eps
$ If imode = 1 and you want to calculate the all-pathways dose
$ Set WI=1000 L/d (1 m3/d), EF=1 d/yr, ED=1 yr when using AllPath DCFs (rem*m3/Ci).
$70. 2.555E+04 1000. 1. 1. 0.025       (Card 5)  bw,at,wi,ef,ed,dlim
$ If imode = 1 and you want to calculate groundwater ingestion dose
$ Set WI=??? (1 m3/d), EF=365 d/yr, ED=1 yr when using EPA GW ingestion (rem*/Ci??).
$ If imode =2 for calculating radiological risk, set ???
$ 70. 2.555E+04 2.0  350. 30. 1.0E-4       (Card 5) bw,at,wi,ef,ed,dlim
$ if imode =3 for calculating concentration and comparing to MCL set ???
$ put all of the option in.
$ If imode=4 when comparing to MCLs the ed and dlim must both be 1.
$ The other variables are not used.
70. 2.555E+04 2.0  350.  1. 1.0         (Card 5)  bw,at,wi,ef,ed,dlim (c / MCL of interest)
0.  0.                                  (Card 6) x0,y0
$
25.0 25.0 0.10                            (Card 7)  l,w,perc
16.5 1.5                                  (Card 8b) thicks, rhos, (source term values)
$0.30                                       (Card 8c) thetas (source term mc)
$Table 5-4 OU 9-04 RI/FS W7500-000-ES-02 source term soil parameters
1.066 1.523 23.9 0.487 0.142                (Card 8d) alpha n ksat pors thetar
20.0  1.5    2.92                           (Card 9) depth,rhou,axu
$ NOTE: The values of depth and axu are the ucode calibrated values
$ 0.30                                      (Card 9a) thetau
$Table 5-9 OU 9-04 RI/FS W7500-000-ES-02 VZ soil parameters
3.196 2.534  1.26 0.48 0.083               (Card 9b) alphau nu ksatu porsu thetaru
$ --- use calibrated values for ax and az ay=0.2ax and az=1.16e-3ax as stated in the MEPAS Manual
9. 4. 0.4   76. 15.                     (Card 10) ax,ay,az,b,z(well screen thickness)
$ --- Aquifer density and porosity from EDF-ER-275 60% Design Component Report Table 2-2 and 2-3
$ --- Darcy velocity based on an assumed pore vel of ~ 1 m/d in EDF-ER-275
36. 0.1  1.9                           (Card 11) u,phi,rhoa
1                                         (Card 12a)nrecept
12.5  0.0                                 (Card 12b)xrec yrec
10                                       (Card 14) ncontam
$  --- Aluminum ---secondary MCL range 50 - 200 mg/m^3 use minimum -------- 1
 0  250  250  26.98  6.854E+09  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Aluminum'  1.00E+12 10. 9.99E+99              (card14b) cname thalf kda dcf
$  ------------------------- Antimony ---MCL------------------ 2
 0  50  50  121.76  1.00E+06  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
$  ------------------------- Boron ---PRG ----------------- 3
 0  5  5  10.81  4.08E+08  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Boron'  1.00E+12  0.2   9.99E+99             (card14b) cname thalf kda dcf
$  ------------------------- Chromium III ---MCL (Total)-------- 4
 0  1.2  1.2  52.00  5.4686E+10  0. 5.20E-02  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'ChromIII'  1.00E+12  0.048   1.00E+02            (card14b) cname thalf kda dcf
$  ------------------------- Copper(andcompounds) ---action level--------- 5
 0  20  20  63.55  2.4471E+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 ---action level--------------------- 6
 0  100  100  207.20  1.4E+07  0. 1.65E-01  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) ----secondary MCL------------- 7
 0  50  50  54.94  2.2812E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Manganese(andcompounds)'  1.00E+12  2  9.99E+99  (card14b) cname thalf kda dcf
$  ------------------------- Nickel ---Remanded MCL--------- 8
 0  100  100  58.69  3.7836E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Nickel'  1.00E+12  4. 9.99E+99                  (card14b) cname thalf kda dcf
```

```
$  ------------------------- Uranium ---MCL------------------ 9
 0  6  6  238.03  1.20E+08  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 ---Secondary MCL-------- 10
 0  16  16  65.39  1.251E+09  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Zinc'  1.00E+12  0.64  9.99E+99               (card14b) cname thalf kda dcf
```

Chemical Calculation – Alternative 1 – Concrete Source

Input File - RA-EBR-II-nrad-ur-cop-concrete-9-30.par

```
EBR-II nonradionuclide risk assessment - MCL- 9/30/2009
$  comparison is with the MCLs
4 3 0 1 1                                    (Card 2) imode,itype,idisp,kflag,idil
1 1 2 2 2                                    (Card 3) imodel,isolve,isolveu,imoist,imoistu
6 12 0.001                                   (Card 4) jstart jmax eps
$ If imode = 1 and you want to calculate the all-pathways dose
$ Set WI=1000 L/d (1 m3/d), EF=1 d/yr, ED=1 yr when using AllPath DCFs (rem*m3/Ci).
$70. 2.555E+04 1000. 1. 1. 0.025       (Card 5)  bw,at,wi,ef,ed,dlim
$ If imode = 1 and you want to calculate groundwater ingestion dose
$ Set WI=??? (1 m3/d), EF=365 d/yr, ED=1 yr when using EPA GW ingestion (rem*/Ci??).
$ If imode =2 for calculating radiological risk, set ???
$ 70. 2.555E+04 2.0  350. 30. 1.0E-4       (Card 5) bw,at,wi,ef,ed,dlim
$ if imode =3 for calculating concentration and comparing to MCL set ???
$ put all of the option in.

$ If imode=4 when comparing to MCLs the ed and dlim must both be 1.
$ The other variables are not used.
70. 2.555E+04 2.0  350.  1. 1.0         (Card 5)  bw,at,wi,ef,ed,dlim (c / MCL of interest)
0.  0.                                  (Card 6) x0,y0
$
25.0 25.0 0.10                            (Card 7)  l,w,perc
16.5 1.5                                  (Card 8b) thicks, rhos, (source term values)
$0.30                                       (Card 8c) thetas (source term mc)
$Table 5-4 OU 9-04 RI/FS W7500-000-ES-02 source term soil parameters
1.066 1.523 23.9 0.487 0.142                (Card 8d) alpha n ksat pors thetar
20.0  1.5    2.92                           (Card 9) depth,rhou,axu
$ NOTE: The values of depth and axu are the ucode calibrated values
$ 0.30                                      (Card 9a) thetau
$Table 5-9 OU 9-04 RI/FS W7500-000-ES-02 VZ soil parameters
3.196 2.534  1.26 0.48 0.083               (Card 9b) alphau nu ksatu porsu thetaru
$ --- use calibrated values for ax and az ay=0.2ax and az=1.16e-3ax as stated in the MEPAS Manual
9. 4. 0.4   76. 15.                     (Card 10) ax,ay,az,b,z(well screen thickness)
$ --- Aquifer density and porosity from EDF-ER-275 60% Design Component Report Table 2-2 and 2-3
$ --- Darcy velocity based on an assumed pore vel of ~ 1 m/d in EDF-ER-275
36. 0.1  1.9                           (Card 11) u,phi,rhoa
1                                         (Card 12a)nrecept
12.5  0.0                                 (Card 12b)xrec yrec
$11                                       (Card 14) ncontam
6                                         (Card 14) ncontam
$  ------------------------- Uranium ---MCL--120 kg for Alt 1 -----------9
 0 6.  6. 238.03  1.20E+08  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Uran A1'  1.00E+12  0.24 3.00E+01           (card14b) cname thalf kda dcf
$  ------------------------- Uranium ---MCL-- 83 kg for Alt 3 and 4 -----9
 0 5000. 6. 238.03  8.30E+07  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Uran A3'  1.00E+12  0.24 3.00E+01           (card14b) cname thalf kda dcf
$  ------------------------- Uranium ---MCL-- 83 kg for Alt 3 and 4 -----9
 0 5000. 6. 238.03  8.30E+07  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Uran A4'  1.00E+12  0.24 3.00E+01           (card14b) cname thalf kda dcf
$  ------------------------- Copper(andcompounds) ---action level--------- 5
 0  20  20  63.55  2.4471E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Copper A1'  1.00E+12  0.8   1.30E+03 (card14b) cname thalf kda dcf
$  ------------------------- Copper(andcompounds) ---action level--------- 5
 0  20  20  63.55  1.5649E+10  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Copper A3'  1.00E+12  0.8   1.30E+03 (card14b) cname thalf kda dcf
$  ------------------------- Copper(andcompounds) ---action level--------- 5
 0  20  20  63.55  5.693E+09  0. 1.00E+06  0.  (card14a) nprog kds kdu zmw qi rmi sl other
'Copper A4'  1.00E+12  0.8   1.30E+03 (card14b) cname thalf kda dc
```