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## Engineering Design File

# EBR-II Proposed Removal Action: Human and Ecological Risk Assessment

Idaho Cleanup Project

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

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Human and ecological risks were assessed for three alternatives for the EBR-II removal action. Radiological risks to a hypothetical future (human) resident on the EBR-II site from Alternatives 3 and 4 would be within acceptable levels, i.e., below a 1E-04 cancer risk. Radiological risks to a future resident from the No Action alternative, however, would be greater than 1E-04. Nonradiological risks to a human receptor would be within acceptable levels (hazard index less than 1) for Alternatives 3 and 4, but greater than 1 for the No Action alternative.

Radiological risks to ecological receptors are below screening levels. The risks from nonradionuclides (metals) to ecological receptors are calculated to be above 10 for five metals in Alternative 1, and for three metals in Alternative 3. However, the extremely conservative assumption that 100% of metal masses are available to ecological receptors makes it highly unlikely that these metals pose an ecological risk.

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* Not required for commercial level calculations.

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# ACRONYMS

| | |
|---|---|
| CERCLA | Comprehensive Environmental Response, Compensation and Liability Act |
| D&D | decommissioning and demolition |
| DOE | U.S. Department of Energy |
| EBR-II | Experimental Breeder Reactor II |
| EDF | engineering design file |
| EPA | U.S. Environmental Protection Agency |
| HI | hazard index |
| HQ | hazard quotient |
| ICDF | Idaho CERCLA Disposal Facility |
| INL | Idaho National Laboratory |
| RCRA | Resource Conservation and Recovery Act |

# EBR-II Proposed Removal Action: Human and Ecological Risk Assessment

## 1. INTRODUCTION

This engineering design file (EDF) documents the human health and ecological risk assessments for the Experimental Breeder Reactor II (EBR-II) proposed removal action. EBR-II will be undergoing decommissioning and demolition (D&D) under the Comprehensive Environmental Response and Liability Act (CERCLA) non-time critical removal action process.

EBR-II was a sodium-cooled fast breeder reactor that operated from 1964 until 1994. The reactor vessel and the primary coolant system were contained in the primary coolant tank. This tank is approximately 26 feet high and 26 feet in diameter. The tank is double-walled stainless steel and is topped by a welded tank cover. The tank and cover alone weigh 190 tons, and with the internals installed is estimated to be over 700 tons

## 2. PROPOSED ALTERNATIVES FOR EBR-II

Four alternatives are evaluated in the *Engineering Evaluation/Cost Analysis (EE/CA) for the Experimental Breeder Reactor II Vessel Disposition and Containment Building End-State.*[a] Although Alternatives 1 and 2 are described in the following subsection, neither of these alternatives brings EBR-II to a final end state and, therefore, are not viable alternatives.

### 2.1 Alternative 1—No Action

Under the "No Action" alternative, no removal action and no further surveillance and maintenance would be conducted at EBR-II. The No Action alternative offers no reduction in toxicity, mobility, or volume of contaminants.

The No Action alternative is a hypothetical, conservative, baseline assumption, in that the sum of all identified chemical or radiological contamination or both, 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 Department of Energy (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. In addition, this alternative does not meet the DOE goal of reducing the "risk footprint" by consolidating wastes in the Idaho CERCLA Disposal Facility (ICDF) and reducing surveillance and maintenance costs on legacy buildings and structures.

Under the No Action alternative, it is assumed that the EBR-II containment building degrades over the next 85 years to the point where it crumbles to the ground and contamination becomes available for uptake by the hypothetical future resident and ecological receptors. It is assumed that all the rubble and contamination from the containment building is mixed with the soil in the top 10-foot interval below ground surface. The human health risk assessment includes an assessment of inhalation of particles from

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a. DOE-ID, 2009, *Engineering Evaluation/Cost Analysis (EE/CA) for the Experimental Breeder Reactor II Vessel Disposition and Containment Building End-State,* DOE/ID-11398, Draft, U.S. Department of Energy Idaho Operations Office.

fugitive dust, direct exposure to the contaminated media, and ingestion of contaminated fruits and vegetables grown at the site. The groundwater pathway of concern is ingestion of contaminated groundwater; risks from groundwater are covered in a separate risk assessment.

## 2.2 Alternative 2—No Action: Continued Surveillance and Maintenance

Under Alternative 2, there would be no action except surveillance and maintenance until the year 2095 when it is assumed that DOE will no longer be operating the Idaho National Laboratory (INL). 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.

Maintenance includes maintaining MFC-767 EBR-II containment building and ancillary support systems that provide power and ventilation to the containment building. Surveillance includes periodic facility inspections to ensure building integrity and systems operability to prevent release of radiological or chemical constituents to the environment causing an unacceptable risk to potential receptors.

## 2.3 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, which includes treatment of residual sodium and sodium potassium (NaK). Under Alternative 3, most above-ground-level systems and structures would be demolished, and the remaining below–ground-level systems and structures, including the EBR-II reactor vessel, would be grouted in place. 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, and support structure. 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 would extend approximately 8 feet above grade and would be finished to facilitate drainage away from the site. Residual radioactive materials remaining after D&D are completed would stay in place and be managed under the Sitewide Institutional Control Program.

## 2.4 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. To allow removal of the reactor vessel, the primary coolant tank, the primary coolant tank cover, tank support structure, heat exchanger, coolant pumps and much of the coolant lines would have to be removed. The containment building would be demolished to ground level or below. 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 waste acceptance criteria (DOE-ID 2009). Void spaces would be grouted as practicable, including the void left by removal of the primary coolant tank. Residual radioactive materials remaining after D&D are completed would stay in place and be managed under the Sitewide Institutional Control Program.

# 3. SCOPE AND APPROACH OF RISK ASSESSMENT

Only Alternatives 1, 3, and 4 are quantitatively evaluated for risk in this EDF. It is assumed that, in Alternative 2, DOE would continue to control access to the facility; therefore, there would be no onsite risk to the public. The continued maintenance of the building would also limit access to ecological receptors.

Under the three alternatives evaluated, it is assumed that the grout and portions of EBR-II remaining degrade over the next 85 years to the point where they crumble and contamination becomes available for uptake by a hypothetical future resident. It is assumed that all the rubble and contamination are mixed in a volume equal to the diameter of the EBR-II footprint to a depth of 10 feet.

The human health scenario assumes someone will immediately build a house on the contaminated rubble and will live at the site for 30 years, including 6 years of childhood, while being exposed to external radiation and to contamination through soil ingestion and inhalation of fugitive dust and volatiles. The human health risk assessment is presented in Sections 4 and 5.

The area is assumed to be habitat in which ecological receptors would have immediate and complete access. The ecological risk assessment is presented in Section 6.

Radiological and nonradiological inventories for the three evaluated alternatives were provided by D&D Programs. For both radiological and nonradiological inventories, the entire source term is assumed spread throughout a volume of soil 10 feet (3.0 m) thick by the area of the EBR-II containment (5,030 $ft^2$ [467 $m^2$]); that volume is 5.03E+04 $ft^3$ (1.42E+03 $m^3$). Assumed soil density is 1.5 g/cc, resulting in a total of 2.13E+06 kg of soil.

# 4. HUMAN HEALTH SCREENING PROCESS

The human health risk assessment is a two-step process. The first step is screening the soil contamination source term against soil screening levels. Normally, for radionuclides, Environmental Protection Agency's (EPA's) soil screening level calculator (EPA 2009a) would be used. Radiological soil screening levels are based on a 1E-06 carcinogenic risk, i.e., for a given radionuclide, a soil concentration at or below its soil screening level indicates risk from that radionuclide is less than one-in-a-million (1E-06). The National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR 300) considers a risk less than 1E-04 (one excess cancer risk in 10,000 people) to be within the acceptable carcinogenic risk range; a 1E-06 risk threshold for screening ensures an adequate margin for retaining potentially significant risk contributors. In the case of EBR-II alternatives, calculated soil concentrations were quite low, and screening was based on a 1E-03-pCi/g screening level (see discussion in Section 4.1.1).

For nonradiological contaminants, in this case metals, EPA's regional screening levels (EPA 2009b) were used for screening purposes. Regional screening levels were developed by EPA by back-calculating from target risk levels. For the inhalation pathway and for the combined direct ingestion/dermal absorption pathway, target risk levels for soil exposures are a one-in-a-million (1E-06) excess lifetime cancer risk for carcinogens and a hazard quotient (HQ) of 1 for noncarcinogens.

The second step of the risk assessment is to perform risk calculations on those radionuclides and nonradionuclides not screened out in the first step.

## 4.1 Source Term and Screening for Human Health

### 4.1.1 Radiological Source Term

The 2095 radionuclide source term, and daughter radionuclides expected in the source term in 2095, was provided by the D&D Program and is presented in Table 1. The decayed source term was generated from the predemolition source term documented in TBL-194 (2009). Only Alternative 1 would include the above-ground inventory.

Calculated soil concentrations are quite low for many radionuclides. Previous experience with soil screening levels has shown that minimum soil screening levels for the soil ingestion, inhalation, and external exposure pathways are no less than 1E-01 pCi/g. To be conservative, soil concentrations were filtered so that all radionuclides with soil concentrations greater than 1E-03 pCi/g were retained for the risk assessment.

### 4.1.2 Nonradiological Source Term

The nonradiological source term was provided by D&D Programs (see Table 2). As for radionuclides, nonradiological contaminants were assumed mixed throughout the 5.03E+04-$ft^3$ (1.42E+03-$m^3$) soil volume; soil concentrations were screened against EPA's regional screening levels (EPA 2009b). Table 3 presents the screening results.

Table 1. EBR-II alternatives: radionuclide inventories decayed to 2095 and soil concentrations.

| | Alternative 1 | | Alternative 3 | | Alternative 4 | |
|---|---|---|---|---|---|---|
| Radionuclide | Combined Above- & Belowgrade Source Term (Ci) | Soil Concentration @ 85 yr (pCi/g) | Source Term (Below Grade) (Ci) | Soil Concentration @ 85 yr (pCi/g) | Source Term (Below Grade) (Ci) | Soil Concentration @ 85 yr (pCi/g) |
| H-3 | 5.53E-05 | 2.59E-02 | 2.16E-05 | 1.01E-02 | 1.37E-06 | 6.42E-04 |
| C-14 | 1.30E-06 | 6.08E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Cl-36 | 2.80E-08 | 1.31E-05 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ca-41 | 2.40E-10 | 1.12E-07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Mn-53 | 1.38E-10 | 6.47E-08 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ni-59 | 8.58E-06 | 4.02E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Co-60 | 1.28E-08 | 6.02E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ni-63 | 5.40E-04 | 2.53E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Se-79 | 2.40E-11 | 1.12E-08 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Sr-90 | 1.41E+00 | 6.62E+02 | 7.06E-01 | 3.31E+02 | 2.93E-08 | 1.37E-05 |
| Zr-93 | 1.72E-12 | 8.06E-10 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Mo-93 | 2.15E-08 | 1.01E-05 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |

Table 1. (continued).

| Radionuclide | Alternative 1 | | Alternative 3 | | Alternative 4 | |
|---|---|---|---|---|---|---|
| | Combined Above- & Belowgrade Source Term (Ci) | Soil Concentration @ 85 yr (pCi/g) | Source Term (Below Grade) (Ci) | Soil Concentration @ 85 yr (pCi/g) | Source Term (Below Grade) (Ci) | Soil Concentration @ 85 yr (pCi/g) |
| Nb-94 | 1.50E-08 | 7.01E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Tc-99 | 4.80E-09 | 2.25E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ag-108m | 2.70E-09 | 1.26E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ba-133 | 1.93E-10 | 9.07E-08 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Cs-137 | 1.02E-04 | 4.76E-02 | 2.41E-05 | 1.13E-02 | 6.03E-06 | 2.83E-03 |
| Pm-145 | 1.23E-12 | 5.78E-10 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Sm-151 | 5.46E-09 | 2.56E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Eu-152 | 9.25E-09 | 4.34E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Eu-154 | 8.84E-11 | 4.14E-08 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ho-166m | 5.66E-09 | 2.65E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Bi-210 | 1.64E-11 | 7.71E-09 | 5.23E-12 | 2.45E-09 | 5.23E-12 | 2.45E-09 |
| Pb-210 | 1.65E-11 | 7.72E-09 | 5.24E-12 | 2.45E-09 | 5.24E-12 | 2.45E-09 |
| Po-210 | 1.61E-11 | 7.53E-09 | 5.11E-12 | 2.40E-09 | 5.11E-12 | 2.40E-09 |
| Bi-214 | 3.90E-11 | 1.83E-08 | 1.24E-11 | 5.81E-09 | 1.24E-11 | 5.81E-09 |
| Pb-214 | 3.90E-11 | 1.83E-08 | 1.24E-11 | 5.81E-09 | 1.24E-11 | 5.81E-09 |
| Po-218 | 3.90E-11 | 1.83E-08 | 1.24E-11 | 5.81E-09 | 1.24E-11 | 5.81E-09 |
| Rn-222 | 3.90E-11 | 1.83E-08 | 1.24E-11 | 5.81E-09 | 1.24E-11 | 5.81E-09 |
| Ra-226 | 3.90E-11 | 1.83E-08 | 1.24E-11 | 5.81E-09 | 1.24E-11 | 5.81E-09 |
| Th-230 | 3.21E-09 | 1.50E-06 | 1.02E-09 | 4.78E-07 | 1.02E-09 | 4.78E-07 |
| U-233 | 6.80E-11 | 3.19E-08 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Pa-234 | 5.58E-05 | 2.62E-02 | 1.78E-05 | 8.32E-03 | 1.78E-05 | 8.32E-03 |
| Pa-234m | 3.49E-02 | 1.64E+01 | 1.11E-02 | 5.20E+00 | 1.11E-02 | 5.20E+00 |
| Th-234 | 3.49E-02 | 1.64E+01 | 1.11E-02 | 5.20E+00 | 1.11E-02 | 5.20E+00 |
| U-234 | 8.40E-06 | 3.94E-03 | 2.67E-06 | 1.25E-03 | 2.67E-06 | 1.25E-03 |
| U-238 | 3.49E-02 | 1.64E+01 | 1.11E-02 | 5.20E+00 | 1.11E-02 | 5.20E+00 |
| Pu-239 | 8.82E-09 | 4.13E-06 | 4.41E-09 | 2.07E-06 | 1.10E-09 | 5.14E-07 |

Table 2. Nonradiological inventory for EBR-II alternatives.

| Metal | Alternative 1 | Alternative 3 | Alternative 4 |
|---|---|---|---|
| Aluminum (kg) | 6.87E+03 | NP | NP |
| Antimony (kg) | 1.36E+00 | NP | NP |
| Boron (kg) | 4.09E+02 | NP | NP |
| Chromium (Cr-III) (kg) | 5.48E+04 | 1.62E+04 | 4.32E+01 |
| Copper (kg) | 2.45E+04 | 1.82E+02 | 1.82E+02 |
| Lead (kg) | 1.36E+01 | NP | NP |
| Manganese (kg) | 2.29E+04 | 2.26E+03 | 5.56E+02 |
| Nickel (kg) | 3.79E+04 | 8.82E+03 | 3.15E+02 |
| Uranium(kg) | 1.20E+02 | 3.32E+01 | 3.32E+01 |
| Zinc (kg) | 1.25E+03 | 7.27E+01 | 7.27E+01 |

NP = Metal not present in inventory.

Table 3. Screening results for nonradiological source term.

| | | Alternative 1 | | Alternative 3 | | Alternative 4 | |
|---|---|---|---|---|---|---|---|
| Metal | RSL (mg/kg) | Soil Conc. (mg/kg) | Exceeds RSL? | Soil Conc. (mg/kg) | Exceeds RSL? | Soil Conc. (mg/kg) | Exceeds RSL? |
| Aluminum | 7.70E+04 | 3.22E+03 | No | NP | — | NP | — |
| Antimony | 3.10E+01 | 6.39E-01 | No | NP | — | NP | — |
| Boron | 1.60E+04 | 1.92E+02 | No | NP | — | NP | — |
| Chromium (Cr-III) | 1.20E+05 | 2.57E+04 | No | 7.59E+03 | No | 2.02E+01 | No |
| Copper | 3.10E+03 | 1.15E+04 | Yes | 8.52E+01 | No | 8.52E+01 | No |
| Lead | 4.00E+02 | 6.39E+00 | No | NP | — | NP | — |
| Manganese | 1.80E+03 | 1.07E+04 | Yes | 1.06E+03 | No | 2.61E+02 | No |
| Nickel | 1.50E+03 | 1.78E+04 | Yes | 4.13E+03 | Yes | 1.48E+02 | No |
| Uranium | 2.30E+02 | 5.65E+01 | No | 1.56E+01 | No | 1.56E+01 | No |
| Zinc | 2.30E+04 | 5.88E+02 | No | 3.41E+01 | No | 3.41E+01 | No |

NP = Metal not present in inventory.

RSL = Regional screening level (http://www.epa.gov/region09/superfund/prg/pdf/composite_sl_table_run_APRIL2009.pdf).

# 5. HUMAN HEALTH RISK ASSESSMENT

This risk assessment propagates conservatism throughout the analysis. It assumes that:

- The radionuclides present within activated metal components and all metals in EBR-II corrode and become mixed with soil after 85 years
- A hypothetical future resident builds a home and resides at the location of the former EBR-II reactor
- The resident is exposed to contaminated soil via the ingestion, inhalation, and external exposure pathways.

## 5.1 Radiological Risk

Human health risk was assessed on the radionuclides not eliminated in the screening procedure. The EPA's risk calculator on the Risk Assessment Information System Web site (EPA 2009c) was used to calculate risk. The calculator uses equations from the *Risk Assessment Guidance for Superfund: Volume I, Human Health Evaluation Manual (Part A, B, C, D, E & F)* (EPA 1989) and *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988). The calculated risk represents the incremental probability of an individual developing cancer over a lifetime. For calculations of exposure to soil, the Boise climatic zone, and a site area of 0.5 acres were selected. For all other parameters, default values were used.

## 5.2 Nonradiological Risk

Risk was assessed for those metals exceeding regional screening levels using EPA's risk calculator at http://rais.ornl.gov/cgi-bin/prg/RISK_search?select=chem (EPA 2009d).

## 5.3 Human Health Results

### 5.3.1 Radiological Risk

The results of the soil pathways radiological risk analysis for D&D of EBR-II are shown in Tables 4–6 for Alternatives 1, 3 and 4, respectively. With the No Action alternative (1), the acceptable carcinogenic risk range of 1E-04 is exceeded (1.9E-04) for the sum of all exposure pathways, with Sr-90 representing the largest contribution to the risk (1.7E-04); Sr-90 is, therefore, the radionuclide of concern. Ingestion of soil and external exposure to soil, combined, are the "pathways of concern" for Alternative 1. This soil pathway risk analysis includes all contamination above and below ground level throughout the EBR-II facility.

Table 4. Risk by radionuclide and pathway for EBR-II Alternative 1 in the year 2095.

| Radionuclide | Ingestion of Soil Risk | Inhalation of Soil Particulates and Volatiles Risk | External Exposure to Soil Risk | Total Soil Risk |
|---|---|---|---|---|
| Cs-137+D | 1.87E-09 | 1.97E-14 | 7.85E-07 | 7.87E-07 |
| H-3 | 3.48E-12 | 1.20E-16 | — | 3.48E-12 |
| Ni-59 | 3.71E-12 | 9.02E-17 | 0.00E+00 | 3.71E-12 |
| Ni-63 | 5.13E-10 | 1.80E-14 | 0.00E+00 | 5.13E-10 |
| Pa-234 | 8.54E-15 | 6.77E-20 | 7.52E-11 | 7.53E-11 |
| Pa-234m | — | — | 1.08E-12 | 1.08E-12 |
| Sr-90+D | 8.58E-05 | 2.57E-09 | 8.31E-05 | 1.69E-04 |
| Th-234 | 4.40E-09 | 7.70E-14 | 7.61E-09 | 1.20E-08 |
| U-234 | 7.84E-10 | 2.16E-12 | 8.90E-12 | 7.95E-10 |
| U-238+D | 4.34E-06 | 7.38E-09 | 1.68E-05 | 2.11E-05 |
| Total Risk | 9.02E-05 | 9.96E-09 | 1.01E-04 | 1.9E-04 |

Table 5. Risk by radionuclide and pathway for EBR-II Alternative 3 in the year 2095.

| Radionuclide | Ingestion of Soil Risk | Inhalation of Soil Particulates and Volatiles Risk | External Exposure to Soil Risk | Total Soil Risk |
|---|---|---|---|---|
| Cs-137+D | 4.45E-10 | 4.67E-15 | 1.86E-07 | 1.87E-07 |
| H-3 | 1.36E-12 | 4.69E-17 | — | 1.36E-12 |
| Pa-234 | 2.68E-15 | 2.13E-20 | 2.36E-11 | 2.36E-11 |
| Pa-234m | — | — | 3.43E-13 | 3.43E-13 |
| Sr-90+D | 4.29E-05 | 1.29E-09 | 4.16E-05 | 8.45E-05 |
| Th-234 | 1.39E-09 | 2.44E-14 | 2.41E-09 | 3.81E-09 |
| U-234 | 2.49E-10 | 6.86E-13 | 2.82E-12 | 2.52E-10 |
| U-238+D | 1.38E-06 | 2.34E-09 | 5.31E-06 | 6.69E-06 |
| Total Risk | 4.43E-05 | 3.63E-09 | 4.71E-05 | 9.1E-05 |

Table 6. Risk by radionuclide and pathway for EBR-II Alternative 4 in the year 2095.

| Radionucide | Ingestion of Soil Risk | Inhalation of Soil Particulates and Volatiles Risk | External Exposure to Soil Risk | Total Soil Risk |
|---|---|---|---|---|
| Cs-137+D | 1.11E-10 | 1.17E-15 | 4.67E-08 | 4.68E-08 |
| Pa-234 | 2.68E-15 | 2.13E-20 | 2.36E-11 | 2.36E-11 |
| Pa-234m | — | — | 3.43E-13 | 3.43E-13 |
| Th-234 | 1.39E-09 | 2.44E-14 | 2.41E-09 | 3.81E-09 |
| U-234 | 2.49E-10 | 6.86E-13 | 2.82E-12 | 2.52E-10 |
| U-238+D | 1.38E-06 | 2.34E-09 | 5.31E-06 | 6.69E-06 |
| Total Risk | 1.38E-06 | 2.34E-09 | 5.36E-06 | 6.7E-06 |

Under Alternative 3, most aboveground-level systems and structures would be demolished, and the remaining belowground-level systems and structures, including the EBR-II reactor vessel, would be grouted in place. 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, and support structure. 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 would extend approximately 8 feet above grade and would be finished to facilitate drainage away from the site. Residual radioactive materials remaining after D&D are completed would stay in place and be managed under the Sitewide Institutional Control Program.

The radiological risk from Alternative 3 (see Table 5) would be below the 1E-04-risk threshold at 9.1E-05.

Alternative 4 would take place after RCRA closure of the facility and would include removal and disposal of the EBR-II reactor vessel. To allow removal of the reactor vessel, the primary coolant tank, primary coolant tank cover, tank support structure, heat exchanger, coolant pumps, and much of the coolant lines would have to be removed. The containment building would be demolished to ground level or below. 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 waste acceptance criteria (DOE-ID 2009). Void spaces would be grouted as practicable, including the void left by removing the primary coolant tank. Residual radioactive materials remaining after D&D are completed would stay in place and be managed under the Sitewide Institutional Control Program.

The radiological risk from Alternative 4 (see Table 6), at 6.7E-06, would be well below the acceptable level of 1E-04. Removal of the reactor vessel and its associated Sr-90 would result in the least radiological risk to a future resident of the alternatives.

### 5.3.2 Nonradiological Risk

Nonradiological risk is presented for only those metals with soil concentrations exceeding EPA regional screening levels (see Table 3).

Nonradiological risk from the No Action alternative is summarized in Table 7. The hazard index (HI) of 2 exceeds the target index of 1, with most of the risk due to nickel. Smaller contributions to the risk come from copper and manganese. The soil ingestion exposure route dominates the risk, and is a "pathway of concern" for both adult and child future residents.

Nonradiological risk from the Alternative 3 is summarized in Table 8. The total HI is less than 1 (from nickel alone), but the pathway "child ingestion of soil" remains a "pathway of concern" at an HI of 2.6.

All metal soil concentrations for Alternative 4 were below EPA regional screening levels; therefore, no risk numbers were calculated.

Table 7. Risk by metal and pathway for EBR-II No Action alternative.

| Metal | Soil Conc. (mg/kg) | Adult Ingestion of Soil HI | Child Ingestion of Soil HI | Inhalation of Soil Particulates and Volatiles HI | Dermal Soil HI | Total Soil HQ |
|---|---|---|---|---|---|---|
| Copper | 1.15E+04 | 3.94E-01 | 3.68E+00 | — | 5.24E-03 | 0.399 |
| Manganese | 1.07E+04 | 3.19E-01 | 2.97E+00 | 5.23E-02 | 3.18E-02 | 0.403 |
| Nickel | 1.78E+04 | 1.22E+00 | 1.14E+01 | — | 1.80E-02 | 1.24 |
| Hazard index | NA | 1.93E+00 | 1.80E+01 | 5.23E-02 | 5.50E-02 | 2.0 |

HI hazard index
HQ hazard quotient
NA not applicable

Table 8. Risk by metal and pathway for EBR-II Alternative 3.

| Metal | Soil Conc. (mg/kg) | Adult Ingestion of Soil HI | Child Ingestion of Soil HI | Inhalation of Soil Particulates and Volatiles HI | Dermal Soil HI | Total Soil HQ |
|---|---|---|---|---|---|---|
| Nickel | 4.13E+03 | 2.83E-01 | 2.64E+00 | — | 4.18E-03 | 0.287 |
| Hazard index | NA | 2.83E-01 | 2.64E+00 | 0.00E+00 | 4.18E-03 | 0.3 |

HI hazard index
HQ hazard quotient
NA not applicable

## 5.4 Human Health Risk Summary

Results of the radiological and nonradiological human risk assessment for EBR-II D&D alternatives are summarized in Table 9. Based on this analysis, Alternatives 3 and 4 would present acceptable risks to a future resident at the EBR-II site.

Table 9. Summary of human health risks from EBR-II alternatives.

| Risk | Alternative 1 (No Action) | Alternative 3 | Alternative 4 |
|---|---|---|---|
| Radiological risk | 1.9E-04 | 9.1E-05 | 6.7E-06 |
| Nonrdiological risk (hazard index) | 2.0 | 0.3 | 0 |

# 6. ECOLOGICAL RISK ASSESSMENT OF THE EBR-II REMOVAL ALTERNATIVES

The screening ecological risk assessment followed the approach presented in the *Guidance Manual for Conducting Screening Level Ecological Risk Assessments at the INEL* (VanHorn, Hampton, and Morris 1995) and documented in the *Comprehensive Remedial Investigation/Feasibility Study for Waste Area Groups 6 and 10 Operable Unit 10-04* (DOE-ID 2001) and the *Risk-Based Screening and Assessment Report for Waste Area Group 1 Soils* (Van Horn and Stacey 2004). Contaminants of potential concern that exceeded screening were further evaluated.

The initial screening process includes three major steps:

1. First, the ecological screening process is to distinguish potential contamination associated with the site from naturally occurring background conditions. The comparison is primarily conducted using the composite background values from the *Background Dose Equivalent Rates and Surficial Soil Metal and Radionuclide Concentrations for the Idaho National Engineering Laboratory* (Rood, Harris, and White 1996) or from other sources, as identified.

2. Step 2 of the ecological screening process is an essential nutrient analysis. Site chemicals that are considered essential nutrients are not evaluated further unless the concentration is much greater (10 times) than the background value. The six metals routinely eliminated by this screening step are aluminum, calcium, iron, magnesium, potassium, and sodium (Cirone 1991).

3. For the remaining chemicals, the third step in the ecological chemical screening process is to compare potential contaminants associated with the site with ecologically based screening levels or EPA ecological soil screening levels, as noted. If the maximum concentration for a given chemical is greater than or equal to the most conservative ecologically based screening level or other screening level, then the chemical is retained for further evaluation. The screening levels used for the screening are consistent with the INL-wide screening levels. Details for INL-specific ecologically based screening level development and values are documented in Appendix D2 of the *Work Plan for Waste Area Groups 6 and 10 Operable Unit 10 04 Comprehensive Remedial*

*Investigation/Feasibility Study* (DOE-ID 1999). New ecological soil screening levels provided in the new or updated chemical-specific documents from EPA (EPA 2008) were included, as available.

## 6.1 Initial Ecological Screening

This ecological risk screening used the concentrations by alternatives developed for soils as discussed previously. The initial screening tables are presented in Appendix A. No radionuclide concentrations exceed screening levels, and they are eliminated as a concern to ecological receptors. Several nonradionuclides exceed screening levels, and the results are presented in Table 10.

For Alternative 1, the soil concentrations of boron, chromium III, copper, manganese, nickel, uranium, and zinc exceed ecological risk-based screening levels. For Alternative 3, the soil concentrations of chromium III, copper, manganese, nickel, and uranium exceed ecological risk-based screening levels. For Alternative 4, the soil concentrations of copper, nickel, and uranium exceed ecological risk-based screening levels. These nonradionuclides are further assessed in the following section.

Table 10. Results of nonradionuclide screening against ecological soil screening levels.

| Nonradionuclide | Alternative 1[a] | Alternative 3[a] | Alternative 4[a] |
|---|---|---|---|
| Aluminum | No | No | No |
| Antimony | No | No | No |
| Boron | Yes | No | No |
| Chromium III | Yes | Yes | No |
| Copper | Yes | Yes | Yes |
| Lead | No | No | No |
| Manganese | Yes | Yes | No |
| Nickel | Yes | Yes | Yes |
| Uranium | Yes | Yes | Yes |
| Zinc | Yes | No | No |

a. "Yes" indicates that the contaminant remains a concern, and "No" indicates that it is no longer a concern.

## 6.2 Further Evaluation of Nonradionuclides

Several nonradionuclides had soil concentrations above screening levels. Hazard quotients (HQs) and hazard indices (HIs) were calculated for these nonradionuclides using the approach documented in the *Comprehensive Remedial Investigation/Feasibility Study for Waste Area Groups 6 and 10 Operable Unit 10-04* (DOE-ID 2001). Changes based on the new or updated chemical-specific documents from EPA (EPA 2008) were included for boron, chromium III (no value is now recommended for exposure to plants), copper, manganese, nickel, and zinc. In addition, nickel uptake values were updated for the

soil-to-invertebrate bioaccumulation factors provided by EPA (EPA 1999). By using a less conservative value (than the 1.0 previously used), a more realistic exposure assessment could be developed. This impacted the selected insectivores in the assessment, including the sage sparrow and burrowing owl. The input values used in the calculations are presented in Appendix A.

Using this approach, an HQ was developed for each contaminant by dividing the maximum calculated dose by its toxicity value. The HQs are then summed across species to develop an HI. At the INL Site, it is accepted that if the total HI does not exceed 10, then the contaminants remaining can be eliminated for risk to ecological receptors at the population level.

### 6.2.1 Alternative 1

Table 11 presents the calculated dose, and Table 12 presents the calculated HQs and HIs for Alternative 1. As Table 12 shows, the HQs for many of the species assessed are greater than 1. Also, many HQs are greater than 10, up to 380 (exposure of plants to boron). Modeling for the metals remaining after closure of this site is highly conservative. Concentrations were calculated by assuming that all the metal (e.g., part of reactors, wiring, and piping) remaining would be uniformly mixed throughout the soil. This mixture would then be in a chemical form that would be bioavailable to receptors using the area. It is highly unlikely that either copper, components of stainless steel, or other metals in this form would be in a bioavailable form for exposure and uptake by ecological receptors.

### 6.2.2 Alternative 3

Table 13 presents the calculated dose, and Table 14 presents the calculated HQs and HIs for Alternative 3. As Table 14 shows, the HQs calculated for many of the species assessed are greater than 1. However, a few HQs exceed 10. These include the chromium, manganese, and nickel HQ calculated for exposure to deer mice (70, 20, and 40, respectively). The pygmy rabbit exposure also resulted in HQs greater than 10 from these three metals. Exposure to manganese also resulted in a calculated HQ of 10 for sage sparrow exposure and an HQ of 50 for plants. Uranium has no acceptable toxicity reference values for assessment and was not evaluated quantitatively. As with all the alternatives, modeling for the metals remaining after closure of this site is highly conservative. The concentrations were calculated by assuming that all the metals were totally available to the receptors.

### 6.2.3 Alternative 4

Table 15 presents the calculated dose, and Table 16 presents the calculated HQs and HIs for Alternative 4. As Table 16 shows, none of the HQs of the three relationships examined are over 10. Those over 1 include the HQ for pygmy rabbit from exposure to copper (1.0) and the HQ for deer mouse from exposure from both metals (2). Uranium has no acceptable toxicity reference values for assessment and was not evaluated quantitatively.

Table 11. Nonradionuclide calculated dose for Alternative 1 (0.05 hectares for site size).

| Concentration | Boron | Chromium III | Copper | Manganese | Nickel | Uranium | Zinc |
|---|---|---|---|---|---|---|---|
| Estimated concentration in soil (mg/kg) | 1.91E+02 | 2.57E+04 | 1.15E+04 | 1.07E+04 | 1.78E+04 | 5.65E+01 | 5.88E+02 |
| Species | Dose (mg/kg-d) | | | | | | |
| Great Basin spadefoot toad | 3.74E-02 | 5.77E+00 | 3.65E+00 | 1.03E+01 | 5.84E+01 | 2.18E-02 | 1.93E+00 |
| Mourning dove | 1.11E-01 | 2.96E+00 | 5.36E+00 | 6.04E+01 | 7.18E-01 | 7.83E-04 | 5.11E-01 |
| Sage sparrow | 5.57E-01 | 2.77E+01 | 5.60E+01 | 2.68E+02 | 1.61E+01 | 1.67E-01 | 7.26E+00 |
| Ferruginous hawk | 1.25E-05 | 1.74E-02 | 7.80E-03 | 8.90E-03 | 4.40E-03 | 1.43E-05 | 1.30E-03 |
| Loggerhead shrike | 4.76E-03 | 6.65E+00 | 2.98E+00 | 3.40E+00 | 1.68E+00 | 5.47E-03 | 4.98E-01 |
| Burrowing owl | 1.35E-03 | 1.33E+00 | 5.93E-01 | 6.71E-01 | 3.61E-01 | 1.17E-03 | 9.60E-02 |
| Black-billed magpie | 4.56E-02 | 2.47E+00 | 2.32E+00 | 2.52E+01 | 4.50E+00 | 1.37E-02 | 3.47E-01 |
| Mule deer | 3.33E-02 | 9.24E-01 | 1.61E+00 | 1.80E+01 | 2.45E-01 | 3.32E-04 | 1.53E-01 |
| Pygmy rabbit | 2.08E+01 | 5.77E+02 | 1.01E+03 | 1.12E+04 | 1.53E+02 | 2.07E-01 | 9.54E+01 |
| Townsend's western big-eared bat | 9.29E-03 | 8.04E+00 | 5.19E+01 | 1.24E+01 | 1.03E+01 | 2.55E-01 | 8.82E+00 |
| Coyote | 1.73E-06 | 1.79E-03 | 8.03E-04 | 9.10E-04 | 1.89E-04 | 1.57E-06 | 1.31E-04 |
| Deer mouse | 1.58E+01 | 5.92E+02 | 1.68E+03 | 8.55E+03 | 3.11E+02 | 5.23E-01 | 2.28E+02 |
| Sagebrush lizard | 1.95E-02 | 8.76E+00 | 4.75E+01 | 1.18E+01 | 1.04E+01 | 2.33E-01 | 8.00E+00 |
| Plants | 1.91E+02 | 4.88E+03 | 9.20E+03 | 1.05E+05 | 1.07E+03 | 7.91E-01 | 8.82E+02 |
| Soil invertebrates | NA | NA | 1.15E+04 | 1.07E+04 | 1.78E+04 | NA | NA |

NA not applicable

Table 12. Nonradionuclide hazard quotients and indices for Alternative 1.

| Species | Boron[a] | Chromium III[a] | Copper[a] | Manganese[a] | Nickel[a] | Uranium | Zinc[a] |
|---|---|---|---|---|---|---|---|
| Great Basin spadefoot toad | NA | NA | NA | NA | NA | NA | NA |
| Mourning dove | 7.71E-03 | **1.11E+00** | **1.32E+00** | **3.37E+01** | 1.07E-01 | 4.89E-05 | 7.73E-03 |
| Sage sparrow | 5.8E-02 | **1.0E+01** | **1.4E+01** | **1.5E+02** | **2.4E+00** | 1.0E-02 | 1.1E-01 |
| Ferruginous hawk | 1.3E-06 | 6.6E-03 | 1.9E-03 | 5.0E-03 | 6.6E-04 | 9.0E-07 | 2.0E-05 |
| Loggerhead shrike | 5.0E-04 | **2.5E+00** | 7.4E-01 | **1.9E+00** | 2.5E-01 | 3.4E-04 | 7.5E-03 |
| Burrowing owl | 1.4E-04 | 5.0E-01 | 1.5E-01 | 3.7E-01 | 5.4E-02 | 7.3E-05 | 1.5E-03 |
| Black-billed magpie | 4.8E-03 | 9.3E-01 | 5.7E-01 | **1.4E+01** | 6.7E-01 | 8.5E-04 | 5.2E-03 |
| Mule deer | 1.1E-02 | 3.9E-01 | 2.9E-01 | 3.5E-01 | 1.4E-01 | 5.4E-05 | 2.0E-03 |
| Pygmy rabbit | **7.1E+00** | **2.4E+02** | **1.8E+02** | **2.2E+02** | **9.0E+01** | 3.4E-02 | **1.3E+00** |
| Townsend's western big-eared bat | 3.2E-03 | **3.4E+00** | **9.3E+00** | 2.4E-01 | **6.1E+00** | 4.2E-02 | 1.2E-01 |
| Coyote | 5.9E-07 | 7.5E-04 | 1.4E-04 | 1.8E-05 | 1.1E-04 | 2.6E-07 | 1.7E-06 |
| Deer mouse | **3.6E+00** | **2.5E+02** | **3.0E+02** | **1.7E+02** | **1.8E+02** | 8.6E-02 | **3.0E+00** |
| Sagebrush lizard | NA | NA | NA | NA | NA | NA | NA |
| Plants | **3.8E+02** | NA | **1.3E+02** | **4.8E+02** | **2.8E+01** | 1.6E-01 | **5.5E+00** |
| Soil invertebrates | NA | NA | **1.4E+02** | **2.4E+01** | **6.4E+01** | NA | NA |

a. **Bold** = Exceeds hazard quotient or hazard index of 1.

NA = Values not calculated due to lack of toxicity values.

Table 13. Nonradionuclide calculated dose for Alternative 3 (0.05 hectares for site size).

| Concentration | Chromium III | Copper | Manganese | Nickel | Uranium |
|---|---|---|---|---|---|
| Calculated concentration in soil (mg/kg) | 7.59E+03 | 8.52E+01 | 1.06E+03 | 4.13E+03 | 1.56E+01 |
| Species | | | Dose (mg/kg-day) | | |
| Great Basin spadefoot toad | 1.70E+00 | 2.70E-02 | 1.02E+00 | 1.35E+01 | 6.01E-03 |
| Mourning dove | 8.73E-01 | 3.97E-02 | 5.98E+00 | 1.67E-01 | 2.16E-04 |
| Sage sparrow | 8.17E+00 | 4.15E-01 | 2.66E+01 | 3.74E+00 | 4.60E-02 |
| Ferruginous hawk | 5.15E-03 | 5.78E-05 | 8.82E-04 | 1.02E-03 | 3.96E-06 |
| Loggerhead shrike | 1.97E+00 | 2.21E-02 | 3.37E-01 | 3.90E-01 | 1.51E-03 |
| Burrowing owl | 3.91E-01 | 4.39E-03 | 6.65E-02 | 8.38E-02 | 3.24E-04 |
| Black-billed magpie | 7.29E-01 | 1.72E-02 | 2.50E+00 | 1.04E+00 | 3.78E-03 |
| Mule deer | 2.73E-01 | 1.19E-02 | 1.78E+00 | 5.68E-02 | 9.18E-05 |
| Pygmy rabbit | 1.70E+02 | 7.46E+00 | 1.11E+03 | 3.54E+01 | 5.73E-02 |
| Townsend's western big-eared bat | 2.38E+00 | 3.84E-01 | 1.23E+00 | 2.40E+00 | 7.03E-02 |
| Coyote | 5.30E-04 | 5.95E-06 | 9.02E-05 | 4.39E-05 | 4.32E-07 |
| Deer mouse | 1.75E+02 | 1.24E+01 | 8.47E+02 | 7.22E+01 | 1.44E-01 |
| Sagebrush lizard | 2.59E+00 | 3.52E-01 | 1.17E+00 | 2.41E+00 | 6.44E-02 |
| Plants | 1.44E+03 | 6.82E+01 | 1.04E+04 | 2.48E+02 | 2.18E-01 |
| Soil invertebrates | 7.59E+03 | 3.41E+00 | 1.06E+03 | NA | NA |

NA not applicable

Table 14. Nonradionuclide hazard quotients and indices for Alternative 3.

| Species | Chromium III[a] | Copper[a] | Manganese[a] | Nickel[a] | Uranium |
|---|---|---|---|---|---|
| Great Basin spadefoot toad | NA | NA | NA | NA | NA |
| Mourning dove | 3.E-01 | 1.E-02 | **3.E+00** | 2.E-02 | 1.E-05 |
| Sage sparrow | **3.E+00** | 1.E-01 | **1.E+01** | 6.E-01 | 3.E-03 |
| Ferruginous hawk | 2.E-03 | 1.E-05 | 5.E-04 | 2.E-04 | 2.E-07 |
| Loggerhead shrike | 7.E-01 | 5.E-03 | 2.E-01 | 6.E-02 | 9.E-05 |
| Burrowing owl | 1.E-01 | 1.E-03 | 4.E-02 | 1.E-02 | 2.E-05 |
| Black-billed magpie | 3.E-01 | 4.E-03 | **1.E+00** | 2.E-01 | 2.E-04 |
| Mule deer | 1.E-01 | 2.E-03 | 3.E-02 | 3.E-02 | 2.E-05 |
| Pygmy rabbit | **7.E+01** | **1.E+00** | **2.E+01** | **2.E+01** | 9.E-03 |
| Townsend's western big-eared bat | 1.E+00 | 7.E-02 | 2.E-02 | **1.E+00** | 1.E-02 |
| Coyote | 2.E-04 | 1.E-06 | 2.E-06 | 3.E-05 | 7.E-08 |
| Deer mouse | **7.E+01** | **2.E+00** | **2.E+01** | **4.E+01** | 2.E-02 |
| Sagebrush lizard | NA | NA | NA | NA | NA |
| Plants | NA | 1.E+00 | **5.E+01** | **7.E+00** | 4.E-02 |
| Soil invertebrates | NA | NA | NA | NA | NA |

a. **Bold =** Exceeds hazard quotient or hazard index of 1.

NA = Not calculated due to lack of toxicity values.

Table 15. Nonradionuclide calculated dose for Alternative 4 (0.05 hectares for site size).

| Concentration | Copper | Nickel | Uranium |
|---|---|---|---|
| Calculated concentration in soil (mg/kg) | 8.52E+01 | 1.48E+02 | 1.56E+01 |
| Species | | Dose (mg/kg-day) | |
| Great Basin spadefoot toad | 2.70E-02 | 4.86E-01 | 6.01E-03 |
| Mourning dove | 3.97E-02 | 5.97E-03 | 2.16E-04 |
| Sage sparrow | 4.15E-01 | 1.34E-01 | 4.60E-02 |
| Ferruginous hawk | 5.78E-05 | 3.66E-05 | 3.96E-06 |
| Loggerhead shrike | 2.21E-02 | 1.40E-02 | 1.51E-03 |
| Burrowing owl | 4.39E-03 | 3.00E-03 | 3.24E-04 |
| Black-billed magpie | 1.72E-02 | 3.74E-02 | 3.78E-03 |
| Mule deer | 1.19E-02 | 2.03E-03 | 9.18E-05 |
| Pygmy rabbit | 7.46E+00 | 1.27E+00 | 5.73E-02 |
| Townsend's western big-eared bat | 3.84E-01 | 8.59E-02 | 7.03E-02 |
| Coyote | 5.95E-06 | 1.57E-06 | 4.32E-07 |
| Deer mouse | 1.24E+01 | 2.59E+00 | 1.44E-01 |
| Sagebrush lizard | 3.52E-01 | 8.63E-02 | 6.44E-02 |
| Plants | 6.82E+01 | 8.88E+00 | 2.18E-01 |
| Soil invertebrates | 3.41E+00 | NA | NA |

NA not applicable

Table 16. Nonradionuclide hazard quotients and indices for Alternative 4.

| Species | Hazard Quotient (unitless) | | |
|---|---|---|---|
| | Copper[a] | Nickel[a] | Uranium |
| Great Basin spadefoot toad | NA | NA | NA |
| Mourning dove | 1.E-02 | 9.E-04 | 1.E-05 |
| Sage sparrow | 1.E-01 | 2.E-02 | 3.E-03 |
| Ferruginous hawk | 1.E-05 | 5.E-06 | 2.E-07 |
| Loggerhead shrike | 5.E-03 | 2.E-03 | 9.E-05 |
| Burrowing owl | 1.E-03 | 4.E-04 | 2.E-05 |
| Black-billed magpie | 4.E-03 | 6.E-03 | 2.E-04 |
| Mule deer | 2.E-03 | 1.E-03 | 2.E-05 |
| Pygmy rabbit | **1.E+00** | 7.E-01 | 9.E-03 |
| Townsend's western big-eared bat | 7.E-02 | 5.E-02 | 1.E-02 |
| Coyote | 1.E-06 | 9.E-07 | 7.E-08 |
| Deer mouse | **2.E+00** | **2.E+00** | 2.E-02 |
| Sagebrush lizard | NA | NA | NA |
| Plants | 1.E+00 | 2.E-01 | 4.E-02 |
| Soil invertebrates | NA | NA | NA |

a. **Bold** = Exceeds hazard quotient or hazard index of 1.

NA = Not calculated due to lack of toxicity values.

## 6.3 Ecological Risk Discussion

As discussed previously, the EBR-II metal inventory was determined by the inspection of drawings and system description documents, measurements, and order of magnitude estimates taken of the EBR-II reactor building. Building materials, such as carbon steel and stainless steel, were further broken down into their component chemicals, such as chromium, manganese, and nickel. As Tables 12, 14, and 16 show, the modeled concentrations of chromium, copper, manganese, nickel, and zinc may present risk to ecological receptors, depending on the alternative. It is assumed that all the possible sources of these metals (including piping, wiring, and stainless steel structures from the surface to over 26 ft below ground surface) are bioavailable. First, not all of these metals would be in a depth range that ecological receptors could reach. Second, the risk assessment uses a toxicity value based on compounds of these metals. For example, in the case of copper, toxicity is tested most commonly using $CuSO_4$ and CuEDTA, while chromium toxicity is tested most commonly using $K_2CrO_4$, $Na_2Cr_4$, and $CrCl_3$. Finally, as discussed below, these metals will not be easily degraded to the highly bioavailable forms of these contaminants. For conservatism, the model assumed that metals (primarily in the form of wire or piping or both) will corrode and be uniformly spread throughout the soils within the area. Corrosion is fundamentally a return of metals to their native state as oxides and salts. Only noble metals and copper exist in nature in their metallic state. Copper in the metallic form is insoluble to water and, therefore, is likely to remain in the environment in this form. It is unlikely that copper concentrations in soil will pose a risk to ecological receptors.

Similar to copper, chromium, nickel, and manganese were modeled as being present from the corrosion of stainless steel remaining at the site. Depending on the stainless steel type, the percent of chromium can be 16 to 20, the percent of nickel can be 8 to 14, and the percent of manganese can be 0 to 3. The addition of a minimum of 12% of chromium to the steel makes it resist rust or stain less than other steel types. The chromium in the steel combines with oxygen in the atmosphere to form a thin, invisible layer of chrome-containing oxide, called the passive film. The sizes of chromium atoms and their oxides are similar; thus, they pack neatly together on the surface of the metal, forming a stable layer only a few atoms thick. If the metal is cut or scratched and the passive film is disrupted, more oxide will quickly form and recover the exposed surface, protecting it from oxidative corrosion. The passive film requires oxygen to self-repair, so stainless steel should remain in this form for many years (Helmenstine 2009). Therefore, the stainless steel remaining at the site will not degrade as modeled. In combination with the extremely conservative assumptions made in the development of the concentrations of metals remaining at EBR-II, it is unlikely that these concentrations will be seen at these sites and result in risk to ecological receptors.

## 6.4 Ecological Risk Summary

To support the closure alternatives at EBR-II, the ecological risk was evaluated. A screening approach was used to evaluate risk to ecological receptors. No radionuclide concentrations exceed ecologically based screening levels for Alternatives 1, 3, and 4.

The metals were evaluated, and many of the metal concentrations for all three alternatives exceed the ecologically based screening levels. Further evaluation of Alternative 1 indicates that boron, chromium, copper, manganese, and nickel concentrations have HQs greater than 10. Of the four metals requiring further assessment for Alternative 3, only chromium, manganese, and nickel have HQs greater than 10. None of the metals concentrations that required further assessment (copper and nickel) for Alternative 4 resulted in HQs greater than 10.

It is important to remember how the metal inventories associated with EBR-II were developed. They indicate that belowgrade structures and systems (including piping, wiring, stainless steel, and utility systems) were included in the source-term development. As discussed, including these items in the overall soil concentration is a highly conservative assumption. In the environment at this site, items such as wiring, piping, and large stainless steel equipment pieces will not degrade to a bioavailable form uniformly throughout this soil as was modeled. It is also assumed that all the contents of the building to below 26 ft below ground are included. Therefore, any concentration of concern would be highly localized, and it is unlikely that it would pose a risk to ecological receptors at a population level. Therefore, the metals also are eliminated as a concern. Given the approach to concentrations in the soil, the risk values calculated are most valuable for comparison purposes. It is apparent from the evaluation of the alternatives that Alternative 4 would leave a smaller quantity of metals in the environment. However, as stated previously, the exposure will not be as great as modeled, and the worker risk in removing these structures also must be considered. The ecological screening tables are provided in Appendix A.

# 7. SUMMARY

Human and ecological risks were assessed for three alternatives to the EBR-II removal action. Radiological risks to a hypothetical future (human) resident on the EBR-II site from Alternatives 3 and 4 would be within acceptable levels, i.e., below a 1E-04 cancer risk. Radiological risks to a future resident from the No Action alternative, however, would be greater than 1E-04. Nonradiological risks to a human receptor would be within acceptable levels (HI less than 1) for Alternatives 3 and 4, but greater than 1 for the No Action alternative.

Radiological risks to ecological receptors would be below screening levels. The risks from nonradionuclides (metals) to ecological receptors are calculated to be above 10 for five metals in Alternative 1, and for three metals in Alternative 3. However, the extremely conservative assumption that 100% of metal masses are available to ecological receptors makes it highly unlikely that these metals pose an ecological risk.

# 8. REFERENCES

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# Appendix A

# Ecological Screening Tables

# Appendix A

# Ecological Screening Tables

Table A-1. Initial ecological risk screening for EBR-II alternatives.

| Contaminant | Soil Concentration (pCi/g or mg/g) | Background Concentration (mg/kg or pCi/g) | Max. Concentration > Background? | Nontoxic Metal? | Screening Value (pCi/g) | Max. Concentration > Screening Values? | Remains a Concern? |
|---|---|---|---|---|---|---|---|
| **Alternative 1** | | | | | | | |
| Aluminum | 3.22E+03 | 1.60E+04 | No | Yes | Not toxic | No | No |
| Antimony | 6.39E-01 | 4.80E+00 | No | No | 2.70E-01 | Yes | No |
| Boron | 1.92E+02 | NA | NA | No | 5.00E-01 | Yes | Yes |
| Chromium III | 2.57E+04 | NA | NA | No | 2.60E+01 | Yes | Yes |
| Copper | 1.15E+04 | 2.20E+01 | Yes | No | 2.80E+01 | Yes | Yes |
| Lead | 6.39E+00 | 1.70E+01 | No | No | 1.10E+01 | No | No |
| Manganese | 1.07E+04 | 4.90E+02 | Yes | No | 2.20E+02 | Yes | Yes |
| Nickel | 1.78E+04 | 3.50E+01 | Yes | No | 3.80E+01 | Yes | Yes |
| Uranium | 5.65E+01 | NA | NA | No | 1.66E+00 | Yes | Yes |
| Zinc | 5.88E+02 | 1.50E+02 | Yes | No | 4.60E+01 | Yes | Yes |
| H-3 | 2.59E-02 | NA | NA | No | 3.43E+05 | No | No |
| C-14 | 6.08E-04 | NA | NA | No | 3.94E+04 | No | No |
| Cl-36 | 1.31E-05 | NA | NA | No | 7.84E+03 | No | No |
| Ca-41 | 1.12E-07 | NA | NA | No | No EBSL | No EBSL | No EBSL |
| Mn-53 | 6.47E-08 | NA | NA | No | 2.25E+06 | No | No |

Table A-1. (continued).

| Contaminant | Soil Concentration (pCi/g or mg/g) | Background Concentration (mg/kg or pCi/g) | Max. Concentration > Background? | Nontoxic Metal? | Screening Value (pCi/g) | Max. Concentration > Screening Values? | Remains a Concern? |
|---|---|---|---|---|---|---|---|
| Ni-59 | 4.02E-03 | NA | NA | No | 1.24E+06 | No | No |
| Co-60 | 6.02E-06 | NA | NA | No | 1.18E+03 | No | No |
| Ni-63 | 2.53E-01 | NA | NA | No | 1.14E+05 | No | No |
| Se-79 | 1.12E-08 | NA | NA | No | No EBSL | No EBSL | No EBSL |
| Sr-90 | 6.62E+02 | 4.90E-01 | Yes | No | 3.34E+03 | No | No |
| Zr-93 | 8.06E-10 | NA | NA | No | 9.95E+04 | No | No |
| Mo-93 | 1.01E-05 | NA | NA | No | No EBSL | No EBSL | No EBSL |
| Nb-94 | 7.01E-06 | NA | NA | No | 1.87E+03 | No | No |
| Tc-99 | 2.25E-06 | NA | NA | No | 1.60E+04 | No | No |
| Ag-108m | 1.26E-06 | NA | NA | No | 1.82E+03 | No | No |
| Ba-133 | 9.07E-08 | NA | NA | No | 7.34E+03 | No | No |
| Cs-137 | 4.76E-02 | 8.20E-01 | No | No | 4.95E+03 | No | No |
| Pm-145 | 5.78E-10 | NA | NA | No | No EBSL | No EBSL | No EBSL |
| Sm-151 | 2.56E-06 | NA | NA | No | No EBSL | No EBSL | No EBSL |
| Eu-152 | 4.34E-06 | NA | NA | No | 2.18E+03 | No | No |
| Eu-154 | 4.14E-08 | NA | NA | No | 2.48E+03 | No | No |
| Ho-166m | 2.65E-06 | NA | NA | No | No EBSL | No EBSL | No EBSL |
| Bi-210 | 7.71E-09 | NA | NA | No | 5.10E+03 | No | No |
| Pb-210 | 7.72E-09 | NA | NA | No | 2.74E+05 | No | No |
| Po-210 | 7.53E-09 | NA | NA | No | 1.84E+01 | No | No |
| Bi-214 | 1.83E-08 | NA | NA | No | 1.99E+03 | No | No |

Table A-1. (continued).

| Contaminant | Soil Concentration (pCi/g or mg/g) | Background Concentration (mg/kg or pCi/g) | Max. Concentration > Background? | Nontoxic Metal? | Screening Value (pCi/g) | Max. Concentration > Screening Values? | Remains a Concern? |
|---|---|---|---|---|---|---|---|
| Pb-214 | 1.83E-08 | NA | NA | No | 6.78E+03 | No | No |
| Po-218 | 1.83E-08 | NA | NA | No | 1.62E+01 | No | No |
| Rn-222 | 1.83E-08 | NA | NA | No | 1.78E+01 | No | No |
| Ra-226 | 1.83E-08 | NA | NA | No | 2.04E+01 | No | No |
| Th-230 | 1.50E-06 | 1.41E+00 | No | No | 2.09E+01 | No | No |
| U-233 | 3.19E-08 | NA | NA | No | 2.03E+01 | No | No |
| Pa-234 | 2.62E-02 | NA | NA | No | No EBSL | No EBSL | No EBSL |
| Pa-234m | 1.64E+01 | NA | NA | No | 2.37E+03 | No | No |
| Th-234 | 1.64E+01 | NA | NA | No | 4.16E+04 | No | No |
| U-234 | 3.94E-03 | 1.44E+00 | No | No | 2.05E+01 | No | No |
| U-238 | 1.64E+01 | 1.40E+00 | Yes | No | 2.32E+01 | No | No |
| Pu-239 | 4.13E-06 | 1.00E-01 | No | No | 1.89E+01 | No | No |
| **Alternative 3** | | | | | | | |
| Aluminum | 0.00E+00 | 1.60E+04 | No | Yes | Not toxic | No | No |
| Antimony | 0.00E+00 | 4.80E+00 | No | No | 2.70E-01 | No | No |
| Boron | 0.00E+00 | NA | NA | No | 5.00E-01 | No | No |
| Chromium III | 7.59E+03 | NA | NA | No | 2.60E+01 | Yes | Yes |
| Copper | 8.52E+01 | 2.20E+01 | Yes | No | 2.80E+01 | Yes | Yes |
| Lead | — | 1.70E+01 | Yes | No | 1.10E+01 | Yes | — |
| Manganese | 1.06E+03 | 4.90E+02 | Yes | No | 2.20E+02 | Yes | Yes |
| Nickel | 4.13E+03 | 3.50E+01 | Yes | No | 3.80E+01 | Yes | Yes |

Table A-1. (continued).

| Contaminant | Soil Concentration (pCi/g or mg/g) | Background Concentration (mg/kg or pCi/g) | Max. Concentration > Background? | Nontoxic Metal? | Screening Value (pCi/g) | Max. Concentration > Screening Values? | Remains a Concern? |
|---|---|---|---|---|---|---|---|
| Uranium | 1.56E+01 | NA | NA | No | 1.66E+00 | Yes | Yes |
| Zinc | 3.41E+01 | 1.50E+02 | No | No | 4.60E+01 | No | No |
| H-3 | 1.23E+00 | NA | NA | No | 3.43E+05 | No | No |
| Na-22 | 1.35E-03 | NA | NA | No | 2.31E+03 | No | No |
| Mn-54 | 3.77E+00 | NA | NA | No | 3.53E+03 | No | No |
| Sr-90 | 2.60E+03 | 4.90E-01 | Yes | No | 3.34E+03 | No | No |
| Ag-110m | 5.86E-15 | NA | NA | No | 1.08E+03 | No | No |
| Sb-125 | 4.10E-05 | NA | NA | No | 8.42E+04 | No | No |
| Cs-134 | 1.12E-06 | NA | NA | No | 1.90E+03 | No | No |
| Cs-137 | 7.97E-02 | 8.20E-01 | No | No | 4.95E+03 | No | No |
| U-238 | 5.22E+00 | 1.40E+00 | Yes | No | 2.32E+01 | No | No |
| Pu-239 | 2.07E-06 | 1.00E-01 | No | No | 1.89E+01 | No | No |
| **Alternative 4** | | | | | | | |
| Aluminum | 0.00E+00 | 1.60E+04 | No | Yes | Not toxic | No | No |
| Antimony | 0.00E+00 | 4.80E+00 | No | No | 2.70E-01 | No | No |
| Boron | 0.00E+00 | NA | NA | No | 5.00E-01 | Yes | — |
| Chromium III | 2.02E+01 | NA | NA | No | 2.60E+01 | No | No |
| Copper | 8.52E+01 | 2.20E+01 | Yes | No | 2.80E+01 | Yes | Yes |
| Lead | 0.00E+00 | 1.70E+01 | No | No | 1.10E+01 | No | No |
| Manganese | 2.61E+02 | 4.90E+02 | No | No | 2.20E+02 | Yes | No |
| Nickel | 1.48E+02 | 3.50E+01 | Yes | No | 3.80E+01 | Yes | Yes |

Table A-1. (continued).

| Contaminant | Soil Concentration (pCi/g or mg/g) | Background Concentration (mg/kg or pCi/g) | Max. Concentration > Background? | Nontoxic Metal? | Screening Value (pCi/g) | Max. Concentration > Screening Values? | Remains a Concern? |
|---|---|---|---|---|---|---|---|
| Uranium | 1.56E+01 | NA | NA | No | 1.66E+00 | Yes | Yes |
| Zinc | 3.41E+01 | 1.50E+02 | No | No | 4.60E+01 | No | No |
| H-3 | 7.76E-02 | NA | NA | No | 3.43E+05 | No | No |
| Na-22 | 8.53E-05 | NA | NA | No | 2.31E+03 | No | No |
| Mn-54 | 7.23E-14 | NA | NA | No | 3.53E+03 | No | No |
| Sr-90 | 1.08E-04 | 4.90E-01 | No | No | 3.34E+03 | No | No |
| Ag-110m | 1.46E-15 | NA | NA | No | 1.08E+03 | No | No |
| Sb-125 | 1.03E-05 | NA | NA | No | 6.02E+03 | No | No |
| Cs-134 | 2.81E-07 | NA | NA | No | 2.04E+05 | No | No |
| Cs-137 | 1.99E-02 | 8.20E-01 | No | No | 4.95E+03 | No | No |
| U-238 | 5.22E+00 | 1.40E+00 | Yes | No | 2.37E+01 | No | No |
| Pu-239 | 5.18E-07 | 1.00E-01 | No | No | 2.33E+04 | No | No |

EBSL ecologically based screening level

NA not applicable

Table A-2. Toxicity reference values used for calculation of hazard quotients (mg/kg-day).

| Representative Species | Antimony[a] | Boron[b] | Chromium III[a] | Copper[a] | Lead[a] | Manganese[a] | Nickel[a] | Uranium[c] | Zinc[a] |
|---|---|---|---|---|---|---|---|---|---|
| Great Basin spadefoot toad (Spea intermontana) | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Mourning dove (Zenaida macroura) | NA | 1.44E+01 | 2.66E+00 | 4.05E+00 | 1.63E+00 | 1.79E+00 | 6.71E+00 | 1.6E+01 | 6.61E+01 |
| Sage sparrow (Amphispiza belli) | NA | 9.60E+00 | 2.66E+00 | 4.05E+00 | 1.63E+00 | 1.79E+00 | 6.71E+00 | 1.6E+01 | 6.61E+01 |
| Ferruginous hawk (Accipiter gentilis) | NA | 9.60E+00 | 2.66E+00 | 4.05E+00 | 1.63E+00 | 1.79E+00 | 6.71E+00 | 1.6E+01 | 6.61E+01 |
| Loggerhead shrike (Lanius ludovicianus) | NA | 9.60E+00 | 2.66E+00 | 4.05E+00 | 1.63E+00 | 1.79E+00 | 6.71E+00 | 1.6E+01 | 6.61E+01 |
| Burrowing owl (Athene cunicularia) | NA | 9.60E+00 | 2.66E+00 | 4.05E+00 | 1.63E+00 | 1.79E+00 | 6.71E+00 | 1.6E+01 | 6.61E+01 |
| Black-billed magpie (Pica hudsonia) | NA | 9.60E+00 | 2.66E+00 | 4.05E+00 | 1.63E+00 | 1.79E+00 | 6.71E+00 | 1.6E+01 | 6.61E+01 |
| Mule deer (Odocoileus hemionus) | 5.90E-02 | 2.92E+00 | 2.40E+00 | 5.60E+00 | 4.70E+00 | 5.15E+01 | 1.70E+00 | 1.6E+01 | 7.54E+01 |
| Pygmy rabbit (Brachylagus idahoensis) | 5.90E-02 | 2.92E+00 | 2.40E+00 | 5.60E+00 | 4.70E+00 | 5.15E+01 | 1.70E+00 | 6.1E+00 | 7.54E+01 |
| Townsend's western big-eared bat (210A) (Corynorhinus townsendii) | 5.90E-02 | 2.92E+00 | 2.40E+00 | 5.60E+00 | 4.70E+00 | 5.15E+01 | 1.70E+00 | 6.1E+00 | 7.54E+01 |
| Coyote (Canis latrans), | 5.90E-02 | 2.92E+00 | 2.40E+00 | 5.60E+00 | 4.70E+00 | 5.15E+01 | 1.70E+00 | 6.1E+00 | 7.54E+01 |
| Deer mouse (Peromyscus maniculatus) | 5.90E-02 | 4.38E+00 | 2.40E+00 | 5.60E+00 | 4.70E+00 | 5.15E+01 | 1.70E+00 | 6.1E+00 | 7.54E+01 |
| Sagebrush lizard (Sceloporus graciosus) | NA | NA | NA | NA | NA | NA | NA | 6.1E+00 | NA |
| Plants | 5.00E+00 | 5.00E-01 | Na | 7.00E+01 | 1.20E+02 | 2.20E+02 | 3.80E+01 | 5.0E+00 | 1.60E+02 |
| Soil invertebrates | 7.8E+01 | NA | NA | 8.0E+01 | 1.7E+03 | 4.5E+02 | 2.8E+02 | NA | 1.2E+02 |

a. Toxicity reference values from appropriate ecological soil screening level document available at Web site: http://www.epa.gov/ecotox/ecossl/.

b. Toxicity reference values from DOE-ID, 1999, *Work Plan for Waste Area Groups 6 and 10 Operable Unit 10-04 Comprehensive Remedial Investigation/Feasibility Study,* DOE/ID-10554, Rev. 0, U.S. Department of Energy Idaho Operations Office, April 1999.

c. Toxicity reference value for uranium from Sample, B. E., D. M. Opresko, and G. W. Suter, 1996, *Toxicological Benchmarks for Wildlife: 1996 Revision*, U.S. Department of Energy, Office of Environmental Management, Washington, D.C.

NA not applicable

Table A-3. Input parameters for calculation of ecological dose.

| Representative Species | Percent Prey | Percent Vegetation | Percent Soil | Exposure Duration | Ingestion Rate (kg/day) | Nagy Equation | Body Weight (kg) | Home Range (Ha) |
|---|---|---|---|---|---|---|---|---|
| Great Basin spadefoot toad | 9.41E-01 | 0.00E+00 | 5.90E-02 | 1.00E+00 | 6.49E-05 | Amphibian insectivores | 8.00E-03 | 1.24E-01 |
| Mourning dove | 0.00E+00 | 9.90E-01 | 1.00E-02 | 1.00E+00 | 1.49E-02 | All birds | 1.23E-01 | 1.04E+01 |
| Blue-winged teal | 0.00E+00 | 9.80E-01 | 2.00E-02 | 6.50E-01 | 3.25E-02 | All birds | 4.09E-01 | Aquatic |
| Sage sparrow | 4.90E-01 | 4.90E-01 | 9.30E-02 | 6.50E-01 | 4.45E-03 | All birds | 1.93E-02 | 1.50E+00 |
| Ferruginous hawk | 9.80E-01 | 0.00E+00 | 2.00E-02 | 6.50E-01 | 6.65E-02 | All birds | 1.23E+00 | 5.60E+02 |
| Loggerhead shrike | 9.80E-01 | 0.00E+00 | 2.00E-02 | 6.50E-01 | 7.99E-03 | All birds | 4.74E-02 | 4.57E+00 |
| Burrowing owl | 9.70E-01 | 0.00E+00 | 3.00E-02 | 2.50E-01 | 1.76E-02 | All birds | 1.59E-01 | 6.00E+00 |
| Black-billed magpie | 4.95E-01 | 4.95E-01 | 1.00E-02 | 1.00E+00 | 1.97E-02 | All birds | 1.89E-01 | 1.10E+01 |
| Mule deer | 0.00E+00 | 9.80E-01 | 2.00E-02 | 1.00E+00 | 3.83E+00 | Mammal herbivore | 1.81E+02 | 6.07E+00 |
| Pygmy rabbit | 0.00E+00 | 9.80E-01 | 2.00E-02 | 1.00E+00 | 4.90E-02 | Mammal herbivore | 4.50E-01 | 2.51E-03 |
| Townsend's western big-eared bat | 9.90E-01 | 0.00E+00 | 1.00E-02 | 1.00E+00 | 2.37E-03 | Rodents | 1.10E-02 | 2.39E+00 |
| Coyote | 9.72E-01 | 0.00E+00 | 2.80E-02 | 1.00E+00 | 7.73E-01 | All mammals | 1.90E+01 | 6.48E+03 |
| Deer mouse | 4.90E-01 | 4.90E-01 | 2.00E-02 | 1.00E+00 | 3.56E-03 | Rodents | 2.20E-02 | 1.40E-02 |
| Sagebrush lizard | 9.76E-01 | 0.00E+00 | 2.40E-02 | 1.00E+00 | 3.47E-04 | Reptile insectivores | 7.00E-02 | 6.00E-02 |
| Plants | 0.00E+00 | 0.00E+00 | 1.00E+00 | 1.00E+00 | NA | NA | NA | 1.00E-07 |
| Soil invertebrates | 0.00E+00 | 0.00E+00 | 1.00E+00 | 1.00E+00 | NA | NA | NA | 1.00E-07 |

NA not applicable

Table A-4. Uptake factors used (unitless-dry weight).

| Metal | Feed to Mammal Herbivore | Feed to Avian Herbivore | Soil to Plants | Soil to Invertebrates |
|---|---|---|---|---|
| Boron | 8.0E-04 | 8.0E-04 | 1.0E+00 | 8.0E-04 |
| Chromium III | 2.0E-01 | 2.0E-01 | 1.9E-01 | 6.0E-02 |
| Copper | 2.0E-01 | 2.0E-01 | 8.0E-01 | 1.0E+00 |
| Manganese | 2.5E-01 | 2.5E-01 | 9.8E+00 | 2.5E-01 |
| Nickel | 6.0E-02 | 6.0E-03 | 6.0E-02 | 1.2E-01 |
| Uranium | 6.2E-02 | 6.2E-02 | 1.4E-02 | 1.0E+00 |
| Zinc | 7.0E-01 | 7.0E-01 | 1.5E+00 | 3.35E+00 |