APPENDIX C

ANALYSIS OF CHRONIC RISK TO HUMANS AND ECOLOGICAL RECEPTORS FROM URANIUM DEPOSITED ON SOIL AND SURFACE WATER FOR URANIUM MANAGEMENT PROGRAMMATIC ENVIRONMENTAL ASSESSMENT

TABLE OF CONTENTS

LIST OF TABLES

ACRONYMS

AF	adherence factor
AT	averaging time
BW	body weight
CASRN	Chemical Abstract Services Registry Number
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CF	conversion factor
Ci/g	curies per gram
CSFx	cancer slope factor (pathway x)
DCFx	dose conversion factor (pathway x)
DNA	deoxyribonucleic acid
DOE	U.S. Department of Energy
ED	exposure duration
EF	exposure frequency
EFetx	exposure frequency (gamma)
EM	emergency management
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ET	exposure time
GI	gastrointestinal
HQ	hazard quotient
ICRP	International Commission on Radiological Protection
INEEL	Idaho National Engineering and Environmental Laboratory
IRair	inhalation rate (dust)
IRsoil	ingestion rate (soil)
NOAEL	No observed adverse effect level
PEA	programmatic environmental assessment
PEF	particulate emission factors
PGDP	Paducah Gaseous Diffusion Plant
PORTS	Portsmouth Gaseous Diffusion Plant
RAGS	Risk Assessment Guidance
RfD	reference dose
SA	surface area
Se	gamma shielding factor
SRS	Savannah River Site
Te	gamma exposure time
TRV	toxicity reference value
U_T	total uranium

C.1 INTRODUCTION

This appendix presents an assessment of chronic risks to humans and ecological receptors of airborne uranium deposited on soil and surface water and from water to sediment. It does the following:

- describes methods to calculate deposition rates of particulate and particulate-bound airborne uranium under conditions described in Appendix A;
- presents methods to determine the concentrations of uranium in surface soil, surface water, and sediment and the calculated concentrations after releases resulting from accidents described in Appendix A;
- assesses exposure of nearby human receptors to the chronic chemical, radiological, and carcinogenic effects of uranium in soil; and
- assesses exposure of terrestrial and aquatic ecological receptors and consumers of aquatic and benthic (sediment-dwelling) biota to the chemical and radiological effects of uranium in soil, surface water, and sediment.

The resulting hazards and risks are organized into categories according to the severity of the consequences (negligible, low, moderate, and high). These consequence categories are combined with the expected frequencies of the associated accidents to predict the overall risk from each proposed alternative at each location.

C.2 DEVELOPMENT OF SOURCE TERMS FOR CONTAMINATED SOIL, SURFACE WATER, AND SEDIMENT

An accident that releases airborne uranium will result in deposition of uranium on soil and water and from water to sediment in a downwind direction from the release. Humans and ecological receptors located in the area of deposition will be chronically exposed to the contaminated soil, surface water, and sediment. This section describes the calculation of concentrations in those media as a result of deposition.

C.2.1 DEPOSITION RATES

Deposition rates in the downwind direction were modeled for dry air. It was assumed that all of the airborne uranium is particulate or becomes associated with particles and is deposited as the particles settle. Deposition of particles was modeled with a simple Gaussian plume model in which the horizontal axis of the plume descends with distance from the source as particles settle out (Pasquill 1974). The accident scenarios result in release to the atmosphere of uranium in amounts that vary with the scenario and the location. In all cases, it was assumed that all of the uranium that is released is released in 1 hour (Appendix A, Sect. A.3.4.1). Although that is not likely to be true in any given case, the entire released source term is accounted for, so the assumption is acceptable.

The equation for deposition rate was adapted from Pasquill (1974) by omitting the term Q for release rate, which is different for different scenarios. The result of the equation is equivalent to the rate of deposition when the release rate is 1 g/s. The equation is as follows:

$$Ds = \frac{v_s}{2\,\pi\,U\,\sigma_y\,\sigma_z} \exp\left[\frac{-y^2}{2(\sigma_y)^2}\right] \exp\left[\frac{-\left((h-z)-{}^{v_s x}\!/_{U}\right)^2}{2(\sigma_z)^2}\right]$$

where

Ds = relative deposition rate per unit area (m^{-2}),
v_s = deposition velocity (m/s),
U = average wind velocity (m/s),
σ_y = crosswind dispersion coefficient (m),
σ_z = vertical dispersion coefficient (m),
y = lateral distance of the deposition point from the plume centerline at the downwind location (m),
h = elevation of the initial centerline of the plume above the release point (m) ,
z = elevation of the deposition point above the release point (m),
x = distance downwind from the release point (m).

C.2.1.1 Parameters

The deposition velocity was assumed to be 2 cm/s (2×10^{-2} m/s), a typical velocity for particles of approximately 10 μm in diameter (Hanna, Briggs, and Hosker 1982). The average wind velocity (1.5 m/s) and crosswind dispersion coefficient (calculated for atmospheric stability class F, which is the most stable, thus providing the least mixing and, as a result, the most conservative class) were discussed in Appendix A, Sect. A.3.4.2. Releases to the environment from a fire were assumed to occur at a height of 15 m, and releases from a seismic event were assumed to begin at a height of 5 m.

C.2.1.2 Deposition model results

The deposition model predicts that the concentrations are highest along the centerline of the plume (directly downwind from the release), decreasing with lateral distance from the centerline. The maximum deposition rates occurred about 550 m from the release point in the case of fires and at 175 m in the case of seismic events.

As a conservative estimate of exposure, the habitats in which biota are exposed were assumed to be located directly downwind of the release point. The deposition rate was the maximum deposition rate for the condition (fire or seismic event), regardless of the size of the habitat. Deposition rates and total uranium deposited per unit area are shown in Table C.1. Concentrations of uranium in soil, surface water, and sediment were calculated from the amount of uranium deposited per unit area.

Table C.1. Rates and amounts of deposition of uranium resulting from bounding accident scenarios[a]

Alternative	Accident scenario	Site	Airborne release rate (mg/s)	Maximum deposition rate[b] ($mg/m^2/s$)	Total deposition[c] (mg/m^2)
All	General container handling	All	1.84E+00	1.28E-04	4.61E-01
No Action	Storage area fire	INEEL	4.28E+01	3.35E-04	1.21E+00
		PGDP	1.74E-01	1.36E-06	4.91E-03
		PORTS	4.94E+02	3.87E-03	1.39E+01
		SRS	9.78E+01	7.66E-04	2.76E+00
		Oak Ridge	4.69E+01	3.68E-04	1.32E+00
		Max other	5.79E+01	4.54E-04	1.63E+00
	Seismic (direct release)	INEEL	2.90E+00	2.02E-04	7.26E-01
		PGDP	7.25E-02	5.04E-06	1.82E-02
		PORTS	1.89E+02	1.31E-02	4.73E+01
		SRS	1.23E+01	8.55E-04	3.08E+00
		Oak Ridge	5.80E+00	4.03E-04	1.45E+00
		Max other	2.41E+01	1.68E-03	6.03E+00
	Seismic (fire)	INEEL	2.80E+00	2.19E-05	7.90E-02
		PGDP	4.35E-02	3.41E-07	1.23E-03
		PORTS	1.15E+02	9.01E-04	3.24E+00
		SRS	9.40E+00	7.37E-05	2.65E-01
		Oak Ridge	4.45E+00	3.49E-05	1.26E-01
		Max other	1.45E+01	1.14E-04	4.09E-01
Centralized storage at a single site	Storage area fire	All	1.01E+03	7.91E-03	2.85E+01
	Seismic (direct release)	All	3.27E+02	2.27E-02	8.19E+01
	Seismic (fire)	All	2.03E+02	1.59E-03	5.73E+00
Partially consolidated storage at several DOE sites	Storage area fire	INEEL	9.89E+01	7.75E-04	2.79E+00
		PGDP	1.48E+01	1.16E-04	4.18E-01
		PORTS	6.80E+02	5.33E-03	1.92E+01
		SRS	1.00E+02	7.84E-04	2.82E+00
		Oak Ridge	1.21E+02	9.48E-04	3.41E+00
	Seismic (direct release)	INEEL	1.06E+01	7.37E-04	2.65E+00
		PGDP	2.98E+00	2.07E-04	7.46E-01
		PORTS	2.63E+02	1.83E-02	6.59E+01
		SRS	1.33E+01	9.25E-04	3.33E+00
		Oak Ridge	3.66E+01	2.55E-03	9.16E+00
	Seismic (fire)	INEEL	8.52E+00	6.68E-05	2.40E-01
		PGDP	2.01E+00	1.58E-05	5.67E-02
		PORTS	1.59E+02	1.25E-03	4.49E+00
		SRS	9.97E+00	7.81E-05	2.81E-01
		Oak Ridge	2.29E+01	1.79E-04	6.46E-01
Partially consolidated storage at two sites	Storage area fire	East	9.13E+02	7.15E-03	2.58E+01
		West	1.02E+02	7.99E-04	2.88E+00
	Seismic (direct release)	East	3.15E+02	2.19E-02	7.89E+01
		West	1.19E+01	8.28E-04	2.98E+00
	Seismic (fire)	East	1.94E+02	1.52E-03	5.47E+00
		West	9.29E+00	7.28E-05	2.62E-01

Table C.1. Rates and amounts of deposition of uranium resulting from bounding accident scenarios[a] (continued)

Alternative	Accident scenario	Site	Airborne release rate (mg/s)	Maximum deposition rate[b] ($mg/m^2/s$)	Total deposition[c] (mg/m^2)
Partially consolidated storage based on physical form	Storage area fire	PORTS	4.38E+02	3.43E-03	1.24E+01
		SRS	2.47E+02	1.94E-03	6.97E+00
		INEEL	3.01E+01	2.36E-04	8.49E-01
	Seismic (direct release)	PORTS	3.07E+02	2.14E-02	7.69E+01
		SRS	1.54E+01	1.07E-03	3.86E+00
		INEEL	4.01E+00	2.79E-04	1.00E+00
	Seismic (fire)	PORTS	1.84E+02	1.44E-03	5.19E+00
		SRS	1.54E+01	1.21E-04	4.34E-01
		INEEL	3.01E+00	2.36E-05	8.49E-02
Transfer to research facility	Facility fire	Generic	3.56E+00	2.79E-05	1.00E-01
	Seismic (direct release)	Generic	1.15E+00	9.01E-06	3.24E-02
	Seismic (fire)	Generic	7.13E-01	5.59E-06	2.01E-02
Transfer to other government agencies	Facility fire	Generic	1.78E+02	1.39E-03	5.02E+00
	Seismic (direct release)	Generic	5.74E+01	4.50E-04	1.62E+00
	Seismic (fire)	Generic	3.56E+01	2.79E-04	1.00E+00
Foreign sales	Facility fire	Generic	3.52E+02	2.76E-03	9.93E+00
	Seismic (direct release)	Generic	1.24E+02	9.72E-04	3.50E+00
	Seismic (fire)	Generic	7.60E+01	5.96E-04	2.14E+00

[a]Airborne release rates from Appendix A, Table A-7.
[b]Q (mg/s) × max unit deposition (m^{-2}).
[c]Max rate × 3600 sec.
DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

C.2.2 Media Concentrations

Concentrations of uranium in soil, surface water, and sediment as a consequence of accidental releases were calculated as described below.

C.2.2.1 Soil

Uranium concentrations in the upper 5 cm (2 in.) of dry soil were calculated using a U.S. Environmental Protection Agency (EPA) model (EPA 1999). The calculation was done with the following equation:

$$Cs = Q \times Ds \times t \times 1000 / (0.05 \times 1600) \ ,$$

where

Cs = concentration in the soil (mg/kg),
Q = release rate (g/s) [Appendix A, Table A-7],
Ds = relative deposition rate per unit area (m^{-2}),
t = duration of release (s),
1000 = conversion factor (mg/g),
0.05 = volume conversion factor (m^{-3} per m^{-2}),
1600 = density of soil (kg/m^3).

To illustrate the distribution of uranium concentrations in soil downwind from a release, a fractional release rate was calculated, with Q equal to 1 g/s. As previously described, the release was assumed to occur over a period of 1 hour and to include the entire airborne source term in that time period. The resulting soil concentrations per unit area (mg/kg) in soil are shown in Table C.2.

C.2.2.2 Surface water

Uranium was assumed to be deposited in a pond with an average depth of 2 m. Concentrations of uranium in the surface water were assumed to be determined by the ratios of dissolved-to-sediment-bound uranium as well as the deposition rate. The fraction of uranium in the water column (F_w) was calculated by using an equation presented by EPA (Eq. B-2-10, EPA 1999):

$$F_{wc} = [(1 + Kd_{sw} \times TSS \times 10^{-6}) \times d_{wc}/d_z] / [(1 + Kd_{sw} \times TSS \times 10^{-6}) \times d_{wc}/d_z) + (q_{bs} + Kd_{bs} \times BS) \times d_{bs}/d_z] \ ,$$

where

F_{wc} = fraction of deposited uranium concentration in the water column,
Kd_{sw} = suspended sediment/water partitioning coefficient (450 L/kg),
TSS = total suspended solids (assumed to be 10 mg/L),
10^{-6} = conversion factor (kg/mg),
d_{wc} = depth of the water column (assumed to be 2 m),
d_{bs} = depth of the upper sediment layer [0.03 m, default value (EPA 1999)],
d_z = combined depth of water column and sediment layer (2.03 m),
Kd_{bs} = bed sediment/water partitioning coefficient (450 L/kg),
q_{bs} = bed sediment porosity (0.6 L water/L sediment, EPA default [EPA 1999]),
BS = benthic solids concentration (1 kg/L).

Using these parameters, the value of F_{wc} was calculated as 0.13.

Table C.2. Concentrations of uranium in soil, surface water, and sediment resulting from deposition of uranium after accidents[a]

Alternative	Accident scenario	Site	Untilled soil (5-cm depth) Concentration[b] (mg/kg)	Untilled soil (5-cm depth) Activity[c] (pCi/g)	Tilled soil Concentration[e] (mg/kg)	Tilled soil Activity[d] (pCi/g)	Surface water (2-m depth) Concentration[d] (mg/L)	Surface water (2-m depth) Activity[e] (pCi/L)	Sediment (3-cm depth) Concentration[f] (mg/kg)	Sediment (3-cm depth) Activity[c] (pCi/g)
All	General container handling	All	5.76E-03	4.03E-03	1.44E-03	1.01E-03	2.94E-05	2.06E-02	8.36E-03	5.85E-03
No Action	Storage area fire	INEEL	1.51E-02	1.06E-02	3.77E-03	2.64E-03	7.81E-05	5.47E-02	2.19E-02	1.53E-02
		PGDP	6.14E-05	4.30E-05	1.53E-05	1.07E-05	3.18E-07	2.22E-04	8.90E-05	6.23E-05
		PORTS	1.74E-01	1.22E-01	4.36E-02	3.05E-02	9.02E-04	6.31E-01	2.53E-01	1.77E-01
		SRS	3.45E-02	2.41E-02	8.62E-03	6.04E-03	1.78E-04	1.25E-01	5.00E-02	3.50E-02
		Oak Ridge	1.65E-02	1.16E-02	4.13E-03	2.89E-03	8.56E-05	5.99E-02	2.40E-02	1.68E-02
		Max other	2.04E-02	1.43E-02	5.10E-03	3.57E-03	1.06E-04	7.40E-02	2.96E-02	2.07E-02
	Seismic (direct release)	INEEL	9.08E-03	6.35E-03	2.27E-03	1.59E-03	4.70E-05	3.29E-02	1.32E-02	9.22E-03
		PGDP	2.27E-04	1.59E-04	5.67E-05	3.97E-05	1.17E-06	8.22E-04	3.29E-04	2.30E-04
		PORTS	5.92E-01	4.14E-01	1.48E-01	1.04E-01	3.06E-03	2.14E+00	8.58E-01	6.01E-01
		SRS	3.85E-02	2.69E-02	9.62E-03	6.74E-03	1.99E-04	1.39E-01	5.59E-02	3.91E-02
		Oak Ridge	1.82E-02	1.27E-02	4.54E-03	3.18E-03	9.40E-05	6.58E-02	2.63E-02	1.84E-02
		Max other	7.54E-02	5.28E-02	1.89E-02	1.32E-02	3.90E-04	2.73E-01	1.09E-01	7.66E-02
	Seismic (fire)	INEEL	9.87E-04	6.91E-04	2.47E-04	1.73E-04	5.11E-06	3.58E-03	1.43E-03	1.00E-03
		PGDP	1.53E-05	1.07E-05	3.83E-06	2.68E-06	7.94E-08	5.56E-05	2.23E-05	1.56E-05
		PORTS	4.06E-02	2.84E-02	1.01E-02	7.10E-03	2.10E-04	1.47E-01	5.88E-02	4.12E-02
		SRS	3.31E-03	2.32E-03	8.29E-04	5.80E-04	1.72E-05	1.20E-02	4.81E-03	3.37E-03
		Oak Ridge	1.57E-03	1.10E-03	3.92E-04	2.75E-04	8.12E-06	5.69E-03	2.28E-03	1.59E-03
		Max other	5.11E-03	3.58E-03	1.28E-03	8.95E-04	2.65E-05	1.85E-02	7.42E-03	5.19E-03
Centralized storage at a single site	Storage area fire	All	3.56E-01	2.49E-01	8.90E-02	6.23E-02	1.84E-03	1.29E+00	5.17E-01	3.62E-01
	Seismic (direct release)	All	1.02E+00	7.16E-01	2.56E-01	1.79E-01	5.30E-03	3.71E+00	1.49E+00	1.04E+00
	Seismic (fire)	All	7.16E-02	5.01E-02	1.79E-02	1.25E-02	3.70E-04	2.59E-01	1.04E-01	7.27E-02
Partially consolidated storage at several DOE sites	Storage area fire	INEEL	3.49E-02	2.44E-02	8.72E-03	6.10E-03	1.80E-04	1.26E-01	5.06E-02	3.54E-02
		PGDP	5.22E-03	3.65E-03	1.30E-03	9.13E-04	2.70E-05	1.89E-02	7.57E-03	5.30E-03
		PORTS	2.40E-01	1.68E-01	5.99E-02	4.20E-02	1.24E-03	8.69E-01	3.48E-01	2.44E-01
		SRS	3.53E-02	2.47E-02	8.82E-03	6.17E-03	1.83E-04	1.28E-01	5.12E-02	3.58E-02
		Oak Ridge	4.27E-02	2.99E-02	1.07E-02	7.47E-03	2.21E-04	1.55E-01	6.19E-02	4.33E-02

Table C.2. Concentrations of uranium in soil, surface water, and sediment resulting from deposition of uranium after accidents[a] (continued)

Alternative	Accident scenario	Site	Untilled soil (5-cm depth) Concentration[b] (mg/kg)	Untilled soil (5-cm depth) Activity[c] (pCi/g)	Tilled soil Concentration[e] (mg/kg)	Tilled soil Activity[d] (pCi/g)	Surface water (2-m depth) Concentration[d] (mg/L)	Surface water (2-m depth) Activity[e] (pCi/L)	Sediment (3-cm depth) Concentration[f] (mg/kg)	Sediment (3-cm depth) Activity[c] (pCi/g)
	Seismic (direct release)	INEEL	3.32E-02	2.32E-02	8.29E-03	5.81E-03	1.72E-04	1.20E-01	4.81E-02	3.37E-02
		PGDP	9.33E-03	6.53E-03	2.33E-03	1.63E-03	4.83E-05	3.38E-02	1.35E-02	9.47E-03
		PORTS	8.23E-01	5.76E-01	2.06E-01	1.44E-01	4.26E-03	2.98E+00	1.19E+00	8.36E-01
		SRS	4.16E-02	2.91E-02	1.04E-02	7.28E-03	2.15E-04	1.51E-01	6.04E-02	4.23E-02
		Oak Ridge	1.15E-01	8.02E-02	2.86E-02	2.00E-02	5.93E-04	4.15E-01	1.66E-01	1.16E-01
	Seismic (fire)	INEEL	3.00E-03	2.10E-03	7.51E-04	5.26E-04	1.55E-05	1.09E-02	4.36E-03	3.05E-03
		PGDP	7.09E-04	4.96E-04	1.77E-04	1.24E-04	3.67E-06	2.57E-03	1.03E-03	7.20E-04
		PORTS	5.61E-02	3.92E-02	1.40E-02	9.81E-03	2.90E-04	2.03E-01	8.14E-02	5.69E-02
		SRS	3.52E-03	2.46E-03	8.79E-04	6.15E-04	1.82E-05	1.27E-02	5.10E-03	3.57E-03
		Oak Ridge	8.08E-03	5.65E-03	2.02E-03	1.41E-03	4.18E-05	2.93E-02	1.17E-02	8.20E-03
Partially consolidated storage at two sites	Storage area fire	East	3.22E-01	2.25E-01	8.05E-02	5.63E-02	1.67E-03	1.17E+00	4.67E-01	3.27E-01
		West	3.60E-02	2.52E-02	8.99E-03	6.29E-03	1.86E-04	1.30E-01	5.22E-02	3.65E-02
	Seismic (direct release)	East	9.86E-01	6.90E-01	2.46E-01	1.73E-01	5.10E-03	3.57E+00	1.43E+00	1.00E+00
		West	3.72E-02	2.61E-02	9.31E-03	6.52E-03	1.93E-04	1.35E-01	5.40E-02	3.78E-02
	Seismic (fire)	East	6.84E-02	4.79E-02	1.71E-02	1.20E-02	3.54E-04	2.48E-01	9.93E-02	6.95E-02
		West	3.28E-03	2.29E-03	8.19E-04	5.73E-04	1.70E-05	1.19E-02	4.75E-03	3.33E-03
Partially consolidated storage based on physical form	Storage area fire	PORTS	1.54E-01	1.08E-01	3.86E-02	2.70E-02	7.99E-04	5.60E-01	2.24E-01	1.57E-01
		SRS	8.71E-02	6.10E-02	2.18E-02	1.52E-02	4.51E-04	3.16E-01	1.26E-01	8.85E-02
		INEEL	1.06E-02	7.43E-03	2.65E-03	1.86E-03	5.49E-05	3.85E-02	1.54E-02	1.08E-02
	Seismic (direct release)	PORTS	9.61E-01	6.73E-01	2.40E-01	1.68E-01	4.97E-03	3.48E+00	1.39E+00	9.76E-01
		SRS	4.82E-02	3.37E-02	1.20E-02	8.43E-03	2.49E-04	1.75E-01	6.99E-02	4.90E-02
		INEEL	1.26E-02	8.79E-03	3.14E-03	2.20E-03	6.50E-05	4.55E-02	1.82E-02	1.27E-02
	Seismic (fire)	PORTS	6.49E-02	4.54E-02	1.62E-02	1.14E-02	3.36E-04	2.35E-01	9.41E-02	6.59E-02
		SRS	5.43E-03	3.80E-03	1.36E-03	9.50E-04	2.81E-05	1.97E-02	7.88E-03	5.52E-03
		INEEL	1.06E-03	7.43E-04	2.65E-04	1.86E-04	5.49E-06	3.85E-03	1.54E-03	1.08E-03
Transfer to research facility	Facility fire	Generic	1.26E-03	8.79E-04	3.14E-04	2.20E-04	6.50E-06	4.55E-03	1.82E-03	1.28E-03
	Seismic (direct release)	Generic	4.06E-04	2.84E-04	1.01E-04	7.10E-05	2.10E-06	1.47E-03	5.88E-04	4.12E-04
	Seismic (fire)	Generic	2.51E-04	1.76E-04	6.29E-05	4.40E-05	1.30E-06	9.11E-04	3.65E-04	2.55E-04

Table C.2. Concentrations of uranium in soil, surface water, and sediment resulting from deposition of uranium after accidents[a] (continued)

Transfer to other government agencies	Facility fire	Generic	6.28E-02	4.39E-02	1.57E-02	1.10E-02	3.25E-04	2.27E-01	9.11E-02	6.38E-02
	Seismic (direct release)	Generic	2.02E-02	1.42E-02	5.06E-03	3.54E-03	1.05E-04	7.33E-02	2.94E-02	2.06E-02
	Seismic (fire)	Generic	1.26E-02	8.79E-03	3.14E-03	2.20E-03	6.50E-05	4.55E-02	1.82E-02	1.28E-02
Foreign sales	Facility fire	Generic	1.24E-01	8.69E-02	3.10E-02	2.17E-02	6.42E-04	4.50E-01	1.80E-01	1.26E-01
	Seismic (direct release)	Generic	4.37E-02	3.06E-02	1.09E-02	7.65E-03	2.26E-04	1.58E-01	6.34E-02	4.44E-02
	Seismic (fire)	Generic	2.68E-02	1.88E-02	6.70E-03	4.69E-03	1.39E-04	9.71E-02	3.89E-02	2.72E-02

[a]Calculated from data in Table C.1 using methods discussed in Sect. 5.
[b]Deposition (mg/m^2) / (0.05 m^3/m^2 at 5 cm depth * 1600 kg/m^3 density of soil).
[c]Concentration (mg U/kg soil) * 1E-3 kg soil/g soil * 1E-3 g U/mg U * 7E-7 Ci/g U * 1E12 pCi/Ci = 7E-1 pCi/g per mg/kg.
[d]Calculated as described in Sect. 2.2.2.
[e]C mg U/L * 1E-3 g U/mg U * 7E-7 Ci/g U * 1E12 pCi/Ci = 7E2 pCi/L per mg/L.
[f]Calculated as described in Sect. 2.2.3.
DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

The concentration of uranium in the surface water is given (Eq. B-2-17, EPA 1999) by:

$$C_{wctot} = F_{wc} \times C_{wtot} \times d_z/d_{wc} \ ,$$

where

C_{wctot} = total uranium concentration in the water column (mg/L),
F_{wc} = fraction of uranium in the water column (0.13 from equation above),
C_{wtot} = total uranium concentration including water and bed sediment (total deposited per m^2/2.03 m),
d_z = combined depth of water column and sediment layer (2.03 m),
d_{wc} = depth of water column (2 m).

C_{wctot} was calculated to be 6.37×10^{-5} mg/L per mg/m^2 deposited. The resulting concentrations in surface water are shown in Table C.2.

C.2.2.3 Sediment

Concentrations in pond sediment were estimated by assuming that the uranium is deposited on a pond. It was assumed that in the long-term, the total mass of uranium comes to equilibrium between sediment and surface water. The uranium was assumed to become adsorbed to sediment particles in the upper 2 cm of bottom sediment.

The fraction of uranium in bed sediment (F_{bs}) is 1-F_{wc} = 0.87, and the concentration of uranium in the sediment is given (Eq. B-2-19, EPA 1999) by:

$$C_{sed} = F_{bs} \times C_{wtot} \times [Kd_{bs}/(q_{bs} + Kd_{bs} \times BS)] \times [(d_{wc} + d_{bs})/d_{bs}] \ ,$$

where

C_{sed} = concentration in bed sediment (mg/kg),
F_{bs} = fraction of uranium in bed sediment (0.87),
C_{wtot} = total uranium concentration including water and bed sediment (total deposited per m^2/2.03 m),
Kd_{bs} = bed sediment/water partitioning coefficient (450 L/kg),
q_{bs} = bed sediment porosity [0.6 L water/L sediment, EPA default (EPA 1999)],
BS = benthic solids concentration (1 kg/L),
d_{wc} = depth of water column (2 m),
d_{bs} = depth of bed sediment (0.03 m).

C_{sed} was calculated to be 1.81×10^{-2} mg/kg per mg/m^2 deposited on the water surface. The resulting concentrations in sediment are shown in Table C.2.

C.3 ASSESSMENT OF CHRONIC HUMAN EXPOSURE TO URANIUM

The purpose of this assessment is to evaluate chronic exposure to uranium potentially released from the U.S. Department of Energy's uranium management activities. This assessment considered three exposure scenarios, including an emergency management (EM) cleanup worker, a standard industrial worker, and a standard resident. The standard resident was presented as a worst-case scenario for comparison, although residential exposure is considered implausible under current site conditions. All receptors were assumed to be exposed to uranium deposited over surface soils. Exposure pathways include soil ingestion, dust inhalation,

dermal contact, and external gamma exposure. Carcinogenic risks, non-carcinogenic hazards, and radiological doses were estimated for these pathway and receptor combinations.

This assessment was performed with the initial assumption that all chronic exposures would be within or below tolerable limits where tolerable limits are defined as follows:

1. radiological dose less than 1 mrem/year was considered *de minimus*;

2. noncarcinogenic risk (hazard) less than 0.1 was considered *de minimus*;

3. carcinogenic risk less than 10^{-6} was considered *de minimus*; and

4. carcinogenic risk within the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) target risk range of 10^{-4} to 10^{-6} was considered tolerable.

Using this approach, dose and risk calculations were performed using the highest modeled soil concentrations. If risk or dose estimates were above tolerable limits, additional calculations were performed to identify those areas that pose the highest dose and risk under chronic exposure conditions. If risk and dose estimates using the highest modeled soil concentrations were below tolerable limits, no additional evaluation was performed.

The following sections provide a more detailed description of methods used to estimate receptor risk and dose estimates. This description is supplemented by the information tabulated in Tables C.3 through C.8. In general, the methods follow those described in Risk Assessment Guidance (RAGS) Part A (EPA 1989).

C.3.1 EXPOSURE POINT CONCENTRATIONS

Based on the data presented in the programmatic environmental assessment (PEA), the maximum uranium concentration is 1.02 mg/kg, which is associated with a direct release during a seismic incident at a central storage facility at a single site (Table C.2). While concentrations in mg/kg are sufficient for noncarcinogenic risk estimates, concentrations must be expressed per radioisotope in pCi/g units in order to complete carcinogenic risk and radiological dose estimates. This conversion was completed in two steps beginning with the conversion from mg/kg uranium to total uranium (U_T) activity:

$$U_T \text{ (pCi/g)} = U_T \text{ (mg/kg)} * 1´10^{-6} \text{ kg soil/mg soil} * 7´10^{-7} \text{ Ci/g U} * 1´10^{12} \text{ pCi/Ci}$$
$$U_T = 3.55 \text{ pCi/g}$$

The value 7×10^{-7} curies per gram of uranium (Ci/g) represents the specific activity of normal uranium. Normal uranium was assumed, although the PEA indicates that the uranium distribution would be 85% depleted, with a specific activity of ~3.5E-7 Ci/g. The more conservative conversion factor is used to provide an upper-bound estimate of carcinogenic risk and radiological dose (there is no impact to noncarcinogenic risk).

Table C.3. Human health exposure parameters for the uranium accident and hazard analysis

Receptor	EF (d/y)	ED (y)	BW (kg)	AT (d)	CF[a] (g/kg)	IR_{soil} (kg/d)	ET (hr/hr)	IR_{air} (m^3/d)	SA (m^2/d)	AF (mg/cm^2)	Se (unitless)	Te (hr/hr)	EF_{ext} (d/d)	PEF (m^3/kg)
EM worker[b]	5	1	70	365	1000	5.E-05	1.0	20	0.53	1.0	0.2	0.333	0.014	5.38E+09
Industrial[c]	250	25	70	9125	1000	5.E-05	1.0	20	0.53	1.0	0.2	0.333	0.685	5.38E+09
Resident[d]	350	30	70	10950	1000	1E-04	1.0	20	0.53	1.0	0.2	1.0	0.959	5.38E+09

[a]For dermal: 0.01 = CFd = (kg-cm^2)/(mg-m^2).
Also w/ dermal: 0.01 = ABS = absorption fraction.
1.0 = FI = fraction ingested.
AT for dermal pathway only.
SA for average surface area for head, hands, forearm, and lower legs for an adult.
AF for soil.

[b]EM (emergency management) worker assumed to be present for cleanup activities only–40-h total.
[c]Assumed to be standard default industrial worker–8 h/day for 250 days/year.
[d]Assumed to be standard adult resident–24 h/day for 350 days/year.

Radiological risk equations
Ingestion risk = EPC * IRsoil * EF * ED * CF * CSFing
Inhalation risk = EPC *IRair * (1/PEF) * ET * EF * ED * CF * CSFinh
External exposure risk = EPC * (1-Se) * Te * EFext * ED * CSFext

Non-carcinogenic risk equations
Dermal hazard = EPC * CFd * AF * ABS * SA * ED * EF * (1/RfD) / (AT * BW)
Oral hazard = EPC * FI * IRsoil * ED * EF * (1/RfD) / (AT * BW)

Radiological dose equations
Ingestion dose = EPC * IRsoil * EF * CF * DCFing
Inhalation dose = EPC *IRair * (1/PEF) * ET * EF * CF * DCFinh
External dose = EPC * (1-Se) * Te * EFext * DCFext

Variable	Description
AF	adherence factor
AT	averaging time
BW	body weight
CF	conversion factor
CSFx	cancer slope factor (pathway x)
DCFx	dose conversion factor (pathway x)
ED	exposure duration
EF	exposure frequency
EFetx	exposure frequency (gamma)
EPC	exposure point concentration
ET	exposure time
IRair	inhalation rate (dust)
IRsoil	ingestion rate (soil)
PEF	particulate emission factors
RfD	reference dose
SA	surface area
Se	gamma shielding factor
Te	gamma exposure time

Table C.4. Summary of cancer risks

Analyte	EPC[a] (pCi/g)	Cancer intakes (pCi)[b]			Cancer risks			
		Ingestion	Inhalation	External	Ingestion	Inhalation	External[c]	Total
Short-term Emergency Worker								
Uranium-234	3.50E-01	8.8E-02	6.5E-06	1.3E-03	1.4E-11	7.4E-14	3.2E-13	1.4E-11
Uranium-235+D	1.61E-02	4.0E-03	3.0E-07	5.9E-05	6.6E-13	3.0E-15	3.2E-11	3.3E-11
Uranium-238+D	3.50E-01	8.8E-02	6.5E-06	1.3E-03	1.8E-11	6.1E-14	1.5E-10	1.6E-10
Pathway total					3.3E-11	1.4E-13	1.8E-10	2.1E-10
Standard Industrial Worker								
Uranium-234	3.50E-01	1.1E+02	8.1E-03	1.6E+00	1.7E-08	9.3E-11	4.0E-10	1.8E-08
Uranium-235+D	1.61E-02	5.0E+00	3.7E-04	7.4E-02	8.2E-10	3.8E-12	4.0E-08	4.1E-08
Uranium-238+D	3.50E-01	1.1E+02	8.1E-03	1.6E+00	2.3E-08	7.6E-11	1.8E-07	2.1E-07
Pathway total					4.1E-08	1.7E-10	2.2E-07	2.6E-07
Standard Adult Resident								
Uranium-234	3.50E-01	3.7E+02	1.4E-02	8.1E+00	5.8E-08	1.6E-10	2.0E-09	6.0E-08
Uranium-235+D	1.61E-02	1.7E+01	6.3E-04	3.7E-01	2.8E-09	6.4E-12	2.0E-07	2.0E-07
Uranium-238+D	3.50E-01	3.7E+02	1.4E-02	8.1E+00	7.7E-08	1.3E-10	9.2E-07	1.0E-06
Pathway total					1.4E-07	2.9E-10	1.1E-06	1.3E-06

[a]EPC = Exposure point concentration; maximum values used to provide conservative exposure estimate.
[b]Or pCi*yr/g for external gamma.
[c]Using slope factors for infinite depth.

Table C.5. Summary of radiological dose

Analyte	EPC[a] (pCi/g)	Intakes (pCi/yr)[b] Ingestion	Inhalation	External	Dose (mrem/yr) Ingestion	Inhalation	External[c]	Total
			Short-term Emergency Worker					
Uranium-234	3.50E-01	8.8E-02	6.5E-06	1.3E-03	2.5E-05	5.1E-08	5.1E-07	2.5E-05
Uranium-235+D	1.61E-02	4.0E-03	3.0E-07	5.9E-05	1.1E-06	2.2E-09	4.5E-05	4.6E-05
Uranium-238+D	3.50E-01	8.8E-02	6.5E-06	1.3E-03	2.4E-05	4.6E-08	1.6E-04	1.9E-04
Pathway total					4.9E-05	1.0E-07	2.1E-04	2.6E-04
			Standard Industrial Worker					
Uranium-234	3.50E-01	4.4E+00	3.3E-04	6.4E-02	1.2E-03	2.6E-06	2.6E-05	1.3E-03
Uranium-235+D	1.61E-02	2.0E-01	1.5E-05	2.9E-03	5.4E-05	1.1E-07	2.2E-03	2.3E-03
Uranium-238+D	3.50E-01	4.4E+00	3.3E-04	6.4E-02	1.2E-03	2.3E-06	8.2E-03	9.4E-03
Pathway total					2.5E-03	5.0E-06	1.1E-02	1.3E-02
			Standard Adult Resident					
Uranium-234	3.50E-01	1.2E+01	4.6E-04	2.7E-01	3.5E-03	3.6E-06	1.1E-04	3.6E-03
Uranium-235+D	1.61E-02	5.6E-01	2.1E-05	1.2E-02	1.5E-04	1.5E-07	9.4E-03	9.5E-03
Uranium-238+D	3.50E-01	1.2E+01	4.6E-04	2.7E-01	3.3E-03	3.2E-06	3.5E-02	3.8E-02
Pathway total					6.9E-03	7.0E-06	4.4E-02	5.1E-02

[a]EPC = Exposure point concentration; maximum values used to provide conservative exposure estimate.
[b]Or pCi*yr/g for external gamma.
[c]Using slope factors for infinite depth.

Table C.6. Summary of non-carcinogenic hazard

Analyte	EPC[a] (mg/kg)	Intakes (mg/kg-day)		Hazard		
		Ingestion	Dermal	Ingestion	Dermal	Total
Short-term Emergency Worker						
Uranium	1.02E+00	1.0E-08	1.1E-08	6.0E-12	5.4E-12	1.1E-11
Pathway total				6.0E-12	5.4E-12	1.1E-11
Standard Industrial Worker						
Uranium	1.02E+00	5.0E-07	5.3E-07	3.0E-10	2.7E-10	5.7E-10
Pathway total				3.0E-10	2.7E-10	5.7E-10
Standard Adult Resident						
Uranium	1.02E+00	1.4E-06	7.4E-07	8.4E-10	3.8E-10	1.2E-09
Pathway total				8.4E-10	3.8E-10	1.2E-09

[a]EPC = Exposure point concentration; maximum values used to provide conservative exposure estimate.

Table C.7. Toxicity values for human health risk and dose calculations

Radionuclide	CASRN	ICRP lung type	Soil ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External exposure (Risk/yr/ pCi/g)	Oral chronic RfD (mg/kg-day)	Dermal chronic RfD (mg/kg-day)	GI absorption factor	Dermal absorption factor	Soil ingestion (mrem/pCi)	Inhalation (mrem/pCi)	External exposure (mrem/yr/ pCi/g)
Uranium-234	013966-29-5	M	1.58E-10	1.14E-08	2.52E-10					2.84E-04	7.89E-03	4.02E-04
Uranium-235+D	015117-96-1(+D)	M	1.63E-10	1.01E-08	5.43E-07					2.68E-04	7.30E-03	7.58E-01
Uranium-238+D	007440-61-1(+D)	M	2.10E-10	9.35E-09	1.14E-07					2.68E-04	7.07E-03	1.29E-01
Uranium	NA					6.00E-04	5.10E-04	0.8500	0.001			

Dose factors from Federal Guidance Reports 11 and 12

Isotopes	Ingestion dose conversion factor			Inhalation dose conversion factor			External infinite		
	Sv/Bq Effective	mrem/pCi Effective	basis	Sv/Bq Effective	mrem/pCi Effective	basis	Sv per Bq s m-3	mrem/s per pCi/m3	mrem/yr per pCi/g
Uranium-234	7.66E-08	2.8E-04	0.05	2.13E-06	7.89E-03	W	2.15E-21	7.96E-18	4.02E-04
Uranium-235+D	7.23E-08	2.68E-04		1.97E-06	7.30E-03		4.06E-18	1.50E-14	7.58E-01
U-235	7.19E-08	2.66E-04	0.05	1.97E-06	7.30E-03	W	3.86E-18	1.43E-14	7.21E-01
Th-231	3.65E-10	1.35E-06		2.33E-10	8.63E-07	W	1.95E-19	7.22E-16	3.64E-02
Uranium-238+D	7.25E-08	2.68E-04		1.91E-06	7.07E-03		6.90E-19	2.56E-15	1.29E-01
U-238	6.88E-08	2.55E-04	0.05	1.90E-06	7.04E-03	W	5.52E-22	2.04E-18	1.03E-04
Th-234	3.69E-09	1.37E-05		8.04E-09	2.98E-05	W	1.29E-19	4.78E-16	2.41E-02
Pa-234m							4.80E-19	1.78E-15	8.97E-02
Pa-234	5.84E-10	2.16E-06		1.98E-10	7.33E-07	W	6.18E-17	2.29E-13	1.15E+01

For lung class, W = M.

CASRN = Chemical Abstract Services Registry Number.
GI = gastrointestinal.
ICRP = International Commission on Radiological Protection.
RfD = reference dose.

Table C.8. Uranium source term

Accident scenario	Site	Material	Concentration (mg/kg)	Normal uranium			
				U-total activity[a] (pCi/g)	U-234 activity[b] (pCi/g)	U-235 activity[b] (pCi/g)	U-238 activity[b] (pCi/g)
All	General container handling	Composite/T Hopper	5.76E-03	4.03E-03	1.97E-03	9.06E-05	1.97E-03
No Action	Storage area fire	INEEL	1.51E-02	1.06E-02	5.16E-03	2.38E-04	5.16E-03
		PGDP	6.14E-05	4.30E-05	2.10E-05	9.66E-07	2.10E-05
		PORTS	1.74E-01	1.22E-01	5.96E-02	2.74E-03	5.96E-02
		SRS	3.45E-02	2.41E-02	1.18E-02	5.43E-04	1.18E-02
		Oak Ridge	1.65E-02	1.16E-02	5.66E-03	2.60E-04	5.66E-03
		Max other	2.04E-02	1.43E-02	6.99E-03	3.21E-04	6.99E-03
	Seismic (direct release)	INEEL	9.08E-03	6.35E-03	3.11E-03	1.43E-04	3.11E-03
		PGDP	2.27E-04	1.59E-04	7.76E-05	3.57E-06	7.76E-05
		PORTS	5.92E-01	4.14E-01	2.02E-01	9.31E-03	2.02E-01
		SRS	3.85E-02	2.69E-02	1.32E-02	6.06E-04	1.32E-02
		Oak Ridge	1.82E-02	1.27E-02	6.21E-03	2.86E-04	6.21E-03
		Max other	7.54E-02	5.28E-02	2.58E-02	1.19E-03	2.58E-02
	Seismic (fire)	INEEL	9.87E-04	6.91E-04	3.38E-04	1.55E-05	3.38E-04
		PGDP	1.53E-05	1.07E-05	5.25E-06	2.41E-07	5.25E-06
		PORTS	4.06E-02	2.84E-02	1.39E-02	6.38E-04	1.39E-02
		SRS	3.31E-03	2.32E-03	1.13E-03	5.22E-05	1.13E-03
		Oak Ridge	1.57E-03	1.10E-03	5.37E-04	2.47E-05	5.37E-04
		Max other	5.11E-03	3.58E-03	1.75E-03	8.05E-05	1.75E-03
Long-term centralized storage	Storage area fire	All	3.56E-01	2.49E-01	1.22E-01	5.61E-03	1.22E-01
	Seismic (direct release)	All	1.02E+00	7.16E-01	3.50E-01	1.61E-02	3.50E-01
	Seismic (fire)	All	7.16E-02	5.01E-02	2.45E-02	1.13E-03	2.45E-02
Consolidate at several sites	Storage area fire	INEEL	3.49E-02	2.44E-02	1.19E-02	5.49E-04	1.19E-02
		PGDP	5.22E-03	3.65E-03	1.79E-03	8.21E-05	1.79E-03
		PORTS	2.40E-01	1.68E-01	8.20E-02	3.77E-03	8.20E-02
		SRS	3.53E-02	2.47E-02	1.21E-02	5.55E-04	1.21E-02
		Oak Ridge	4.27E-02	2.99E-02	1.46E-02	6.72E-04	1.46E-02

Table C.8. Uranium source term (continued)

Accident scenario	Site	Material	Concentration (mg/kg)	Normal uranium			
				U-total activity[a] (pCi/g)	U-234 activity[b] (pCi/g)	U-235 activity[b] (pCi/g)	U-238 activity[b] (pCi/g)
	Seismic (direct release)	INEEL	3.32E-02	2.32E-02	1.14E-02	5.22E-04	1.14E-02
		PGDP	9.33E-03	6.53E-03	3.19E-03	1.47E-04	3.19E-03
		PORTS	8.23E-01	5.76E-01	2.82E-01	1.30E-02	2.82E-01
		SRS	4.16E-02	2.91E-02	1.42E-02	6.55E-04	1.42E-02
		Oak Ridge	1.15E-01	8.02E-02	3.92E-02	1.80E-03	3.92E-02
	Seismic (fire)	INEEL	3.00E-03	2.10E-03	1.03E-03	4.73E-05	1.03E-03
		PGDP	7.09E-04	4.96E-04	2.43E-04	1.12E-05	2.43E-04
		PORTS	5.61E-02	3.92E-02	1.92E-02	8.82E-04	1.92E-02
		SRS	3.52E-03	2.46E-03	1.20E-03	5.53E-05	1.20E-03
		Oak Ridge	8.08E-03	5.65E-03	2.76E-03	1.27E-04	2.76E-03
Consolidate at one western site and one eastern site	Storage area fire	East	3.22E-01	2.25E-01	1.10E-01	5.07E-03	1.10E-01
		West	3.60E-02	2.52E-02	1.23E-02	5.66E-04	1.23E-02
	Seismic (direct release)	East	9.86E-01	6.90E-01	3.37E-01	1.55E-02	3.37E-01
		West	3.72E-02	2.61E-02	1.27E-02	5.86E-04	1.27E-02
	Seismic (fire)	East	6.84E-02	4.79E-02	2.34E-02	1.08E-03	2.34E-02
		West	3.28E-03	2.29E-03	1.12E-03	5.16E-05	1.12E-03
Consolidate by physical form	Storage area fire	PORTS/compound, misc., oxide	1.54E-01	1.08E-01	5.28E-02	2.43E-03	5.28E-02
		SRS/metal	8.71E-02	6.10E-02	2.98E-02	1.37E-03	2.98E-02
		INEEL/reactfuel, source	1.06E-02	7.43E-03	3.63E-03	1.67E-04	3.63E-03
	Seismic (direct release)	PORTS/compound, misc., oxide	9.61E-01	6.73E-01	3.29E-01	1.51E-02	3.29E-01
		SRS/metal	4.82E-02	3.37E-02	1.65E-02	7.59E-04	1.65E-02
		INEEL/reactfuel, source	1.26E-02	8.79E-03	4.29E-03	1.98E-04	4.29E-03
	Seismic (fire)	PORTS/compound, misc., oxide	6.49E-02	4.54E-02	2.22E-02	1.02E-03	2.22E-02
		SRS/metal	5.43E-03	3.80E-03	1.86E-03	8.55E-05	1.86E-03
		INEEL/reactfuel, source	1.06E-03	7.43E-04	3.63E-04	1.67E-05	3.63E-04
Transfer to research facility	Storage area fire	Generic	1.26E-03	8.79E-04	4.30E-04	1.98E-05	4.30E-04
	Seismic (direct release)	Generic	4.06E-04	2.84E-04	1.39E-04	6.38E-06	1.39E-04
	Seismic (fire)	Generic	2.51E-04	1.76E-04	8.60E-05	3.96E-06	8.60E-05

Table C.8. Uranium source term (continued)

Accident scenario	Site	Material	Concentration (mg/kg)	Normal uranium			
				U-total activity[a] (pCi/g)	U-234 activity[b] (pCi/g)	U-235 activity[b] (pCi/g)	U-238 activity[b] (pCi/g)
Transfer to other government agencies	Storage area fire	Generic	6.28E-02	4.39E-02	2.15E-02	9.88E-04	2.15E-02
	Seismic (direct release)	Generic	2.02E-02	1.42E-02	6.93E-03	3.19E-04	6.93E-03
	Seismic (fire)	Generic	1.26E-02	8.79E-03	4.30E-03	1.98E-04	4.30E-03
Foreign sales	Storage area fire	Generic	1.24E-01	8.69E-02	4.25E-02	1.95E-03	4.25E-02
	Seismic (direct release)	Generic	4.37E-02	3.06E-02	1.50E-02	6.88E-04	1.50E-02
	Seismic (fire)	Generic	2.68E-02	1.88E-02	9.17E-03	4.22E-04	9.17E-03
			1.02E+00	7.16E-01	3.50E-01	1.61E-02	3.50E-01

[a]mg U/kg soil * 1E-3 kg soil/g soil * 1E-3 g U/mg U * 7E-7 Ci/g U * 1E12 pCi/Ci = 7E-1 pCi/g per mg/kg.
[b]Total-U (pCi/g)/2.046 for U-234 and U-238 or Total-U (pCi/g)*0.046/2.046 for U-235.
U-235 = (21.6 * %enrichment * 0.01 * U-238) / {3.35*[1-(%enrichment*0.01)]}.
U-234 = U-235 × {27.18 - 0.3004(U-238/U-235) + [0.00143(U-238/U-235)]^2}.
Estimated based on a best-fit curve from Fig. 2-2 of the *Health Physics Manual of Good Practices for Uranium Facilities*.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

The second step of unit conversions was to partition the total activity among uranium isotopes. This was accomplished using guidance from the *Health Physics Manual of Good Practices for Uranium Facilities* (DOE 1988). Concentrations of individual uranium isotopes were calculated based on the following equations:

$$\text{U-234 (pCi/g)} = \text{U-238 (pCi/g)} = U_T \text{ (pCi/g)} / 2.046 = 3.55 / 2.046 = 1.73 \text{ pCi/g}$$

$$\text{U-235 (pCi/g)} = U_T \text{ (pCi/g)} * 0.046 / 2.046 = (3.55*0.046) / 2.046 = 0.080 \text{ pCi/g}$$

This approach assumes a concentration ratio of 1.0-to-0.046-to-1.0 for ^{234}U, ^{235}U, and ^{238}U, respectively. For this assessment it was also assumed that short-lived decay products (i.e., with half-life less than 6 months) of ^{235}U and ^{238}U were present at equilibrium concentrations. Modeled soil concentrations are tabulated in Table C.8.

C.3.2 EXPOSURE PATHWAYS

The complete exposure pathway is dependent on the following four conditions:

- a source of contamination,
- a route of transport to an exposure point,
- a receptor at the exposure point, and
- a route of exposure to the receptor.

For the accident condition considered, the soil is the source of contamination, and it is assumed that the identified receptors will be exposed to the contaminated soil. Routes of exposure are inhalation, ingestion, dermal contact, and external exposure to radiation.

Three receptors were evaluated in this assessment: an EM worker, an industrial worker, and a resident. The EM worker is assumed to be exposed to contaminants for 40 hours while conducting cleanup activities. The industrial worker is assumed to work in the area and is exposed for 8 hours/day, 250 days/year, for 25 years. The resident is assumed to live on-site and is exposed for 24 hours/day, 350 days/year, for 30 years. The receptors have been chosen to represent a range of hypothetical exposures and provide an upper-bound estimate on potential health risks, although the residential receptor is not considered plausible under current site conditions The exposure parameters used in the evaluation are presented in Table C.3 and are used along with toxicity data presented in the following section to calculate risks and hazards.

C.3.3 TOXICITY ASSESSMENT

Table C.7 presents toxicity data, including cancer slope factors, reference doses (RfDs), and dose conversion factors. Slope factors were taken from EPA's Health Effects Assessment Summary Table, and RfDs were taken from EPA's Integrated Risk Information System. The dose conversion factors were derived from Federal Guidance Report No. 11 (EPA 1988) and Federal Guidance Report No. 12 (EPA 1993a).

C.3.4 CHARACTERIZATION OF CONSEQUENCES

The exposure parameters and toxicity data are used to calculate the overall risks, doses, and hazards to the exposed receptors.

C.3.4.1 Method

Risks from the uranium isotopes were evaluated using the following equations per RAGS, Part A (see Table C.3 for details):

- Ingestion risk = EPC * IR_{soil} * EF * ED * CF * CSF_{ing}
- Inhalation risk = EPC *IR_{air} * (1/PEF) * ET * EF * ED * CF * CSF_{inh}
- External exposure risk = EPC * (1-S_e) * Te * EF_{ext} * ED * CSF_{ext}

Hazards associated with total uranium were calculated with the following equations:

- Oral hazard = EPC * FI * IR_{soil} * ED * EF * (1/RfD) / (AT * BW)
- Dermal hazard = EPC * CF_d * AF * ABS * SA * ED * EF * (1/RfD) / (AT * BW)

Doses were estimated for the uranium isotopes, with the following equations using modified RAGS, Part A, equations for dose versus risk estimates:

- Ingestion dose = EPC * IR_{soil} * EF * CF * DCF_{ing}
- Inhalation dose = EPC *IR_{air} * (1/PEF) * ET * EF * CF * DCF_{inh}
- External dose = EPC * (1-S_e) * T_e * EF_{ext} * DCF_{ext}

Total risk, hazard, and dose calculations were performed for each receptor and were calculated by summing across exposure pathways. The results of the carcinogenic risk, radiological dose, and noncarcinogenic hazard are presented in Tables C-4, C-5, and C-6, respectively.

C.3.4.2 Results

The maximum total risks for all isotopes are 2.1×10^{-10} for the EM worker, 2.6×10^{-7} for the standard industrial worker, and 1.3×10^{-6} for the standard resident. While only the EM worker risk is *de minimus*, all carcinogenic risk estimates are within or below the CERCLA target range of 10^{-4} to 10^{-6}. The maximum calculated dose is 0.051 mrem/year for the implausible standard resident; thus, all doses are considered *de minimus*. The maximum calculated hazard is 1.2×10^{-9} for the implausible standard resident; thus, all hazards are considered *de minimus*. Overall the risks, doses, and hazards are within, or below, tolerable limits even using the conservative residential scenario and using the maximum modeled concentrations. These results indicate a low probability of adverse health effects from chronic exposure associated with the most serious accident scenario.

C.3.5 OVERALL RISK EVALUATION

Overall risks were evaluated by combining the consequences of an alternative-specific accident and the likelihood of the accident, as shown in Appendix A, Fig. A.1. Following are cancer risk categories: $<10^{-6}$, negligible; between 10^{-6} and 10^{-5}, low; between 10^{-5} and 10^{-4}, moderate; and $>10^{-4}$, high. Radiological consequence categories are shown in Appendix A, Tables A.11 and A.12. Following are toxicological consequence categories: hazard quotient (HQ) <0.1, negligible; HQ between 0.1 and 1, low; and HQ >1, high

(the moderate consequence category is not defined). The accident frequency and consequence categories for the proposed alternatives are shown in Tables C-9 and C-10, along with the resulting overall risks.

C.4 ALTERNATIVE-SPECIFIC EVALUATION OF IMPACTS TO ECOLOGICAL RECEPTORS

C.4.1 GENERAL APPROACH

Potential ecological exposures were evaluated for each alternative. It was assumed that airborne uranium will be deposited on soil and surface water. From surface water it will accumulate in sediment. Plants and terrestrial invertebrates are exposed to uranium by direct uptake from soil. Terrestrial vertebrates are exposed by direct uptake from soil and by ingestion of contaminated food. Aquatic biota and benthic invertebrates are exposed directly to uranium in surface water and sediment, respectively. Also evaluated are carnivores that prey on aquatic and benthic biota. All indicator receptors are exposed to the chemical effects of incorporated uranium as well as both external radiation from contaminated media and internal radiation from incorporated uranium.

C.4.2 HAZARD IDENTIFICATION

The indicator terrestrial vertebrates used in this evaluation are short-tailed shrews and American robins, which are highly exposed to soil contaminants because they ingest relatively large quantities of soil along with a diet of plants and terrestrial invertebrates. The indicator vertebrate exposed to contaminants in water is the great blue heron, which is highly exposed because it ingests water and sediment as well as fish and sediment-dwelling benthic invertebrates. Because uranium does not bioaccumulate up the food chain, these receptors are expected to be more exposed than carnivores at a higher trophic level. For simplicity, it is assumed that the habitats of all of the indicator receptors occur within the path of the airborne uranium.

C.4.3 EXPOSURE ASSESSMENT

The following three subsections describe the assessment of exposure of the ecological receptors, evaluation of the environmental toxicity of uranium, and an evaluation of the risks resulting from deposition of uranium after the hypothetical accidents described in the description of alternatives.

The exposure assessment includes an estimate of exposure concentrations at the locations where biota are expected to be maximally exposed under each alternative at each site. Concentrations of uranium in soil and water were based on estimates of the rate of deposition of airborne uranium released by accidents under each alternative. Estimates of media concentrations were made as described in Chap. 5.

Terrestrial biota are assumed to be exposed to uranium by uptake or ingestion and by direct exposure to contaminated soil. Aquatic biota and predators of aquatic biota are assumed to be exposed by uptake or ingestion and by direct exposure to contaminated surface water and sediment. It was assumed that the uranium in soil had the isotopic distribution of normal uranium (i.e., 48.8% of total U activity as ^{234}U, 2.4% as ^{235}U, and 48.8% as ^{238}U).

Table C.9. Summary of chronic radiation risks to human receptors due to deposition of uranium on soil under bounding accident scenarios

Alternative	Accident scenario	Site	Frequency	Radiation risk			Radiation exposure		
				Maximum risk	Consequence level	Risk	Maximum dose	Consequence level	Risk
All	General container handling	All	Anticipated	7.6E-09	Negligible	Negligible	3.1E-04	Negligible	Negligible
No Action	Storage area fire	INEEL	Extremely unlikely	2.0E-08	Negligible	Negligible	8.0E-04	Negligible	Negligible
		PGDP		8.1E-11	Negligible	Negligible	3.3E-06	Negligible	Negligible
		PORTS		2.3E-07	Negligible	Negligible	9.3E-03	Negligible	Negligible
		SRS		4.6E-08	Negligible	Negligible	1.8E-03	Negligible	Negligible
		Oak Ridge		2.2E-08	Negligible	Negligible	8.8E-04	Negligible	Negligible
		Max other		2.7E-08	Negligible	Negligible	1.1E-03	Negligible	Negligible
	Seismic (direct release)	INEEL	Extremely unlikely	1.2E-08	Negligible	Negligible	4.8E-04	Negligible	Negligible
		PGDP		3.0E-10	Negligible	Negligible	1.2E-05	Negligible	Negligible
		PORTS		7.8E-07	Negligible	Negligible	3.2E-02	Negligible	Negligible
		SRS		5.1E-08	Negligible	Negligible	2.1E-03	Negligible	Negligible
		Oak Ridge		2.4E-08	Negligible	Negligible	9.7E-04	Negligible	Negligible
		Max other		1.0E-07	Negligible	Negligible	4.0E-03	Negligible	Negligible
	Seismic (fire)	INEEL	Extremely unlikely	1.3E-09	Negligible	Negligible	5.3E-05	Negligible	Negligible
		PGDP		2.0E-11	Negligible	Negligible	8.2E-07	Negligible	Negligible
		PORTS		5.4E-08	Negligible	Negligible	2.2E-03	Negligible	Negligible
		SRS		4.4E-09	Negligible	Negligible	1.8E-04	Negligible	Negligible
		Oak Ridge		2.1E-09	Negligible	Negligible	8.4E-05	Negligible	Negligible
		Max other		6.8E-09	Negligible	Negligible	2.7E-04	Negligible	Negligible
Centralized storage at a single site	Storage area fire	All	Extremely unlikely	4.7E-07	Negligible	Negligible	1.9E-02	Negligible	Negligible
	Seismic (direct release)	All	Extremely unlikely	1.4E-06	Low	Low	5.5E-02	Negligible	Negligible
	Seismic (fire)	All	Extremely unlikely	9.5E-08	Negligible	Negligible	3.8E-03	Negligible	Negligible
Partially consolidated storage at several DOE sites	Storage area fire	INEEL	Extremely unlikely	4.6E-08	Negligible	Negligible	1.9E-03	Negligible	Negligible
		PGDP		6.9E-09	Negligible	Negligible	2.8E-04	Negligible	Negligible
		PORTS		3.2E-07	Negligible	Negligible	1.3E-02	Negligible	Negligible
		SRS		4.7E-08	Negligible	Negligible	1.9E-03	Negligible	Negligible
		Oak Ridge		5.6E-08	Negligible	Negligible	2.3E-03	Negligible	Negligible

Table C.9. Summary of chronic radiation risks to human receptors due to deposition of uranium on soil under bounding accident scenarios (continued)

Alternative	Accident scenario	Site	Frequency	Radiation risk: Maximum risk	Radiation risk: Consequence level	Radiation risk: Risk	Radiation exposure: Maximum dose	Radiation exposure: Consequence level	Radiation exposure: Risk
	Seismic (direct release)	INEEL	Extremely unlikely	4.4E-08	Negligible	Negligible	1.8E-03	Negligible	Negligible
		PGDP		1.2E-08	Negligible	Negligible	5.0E-04	Negligible	Negligible
		PORTS		1.1E-06	Low	Low	4.4E-02	Negligible	Negligible
		SRS		5.5E-08	Negligible	Negligible	2.2E-03	Negligible	Negligible
		Oak Ridge		1.5E-07	Negligible	Negligible	6.1E-03	Negligible	Negligible
	Seismic (fire)	INEEL	Extremely unlikely	4.0E-09	Negligible	Negligible	1.6E-04	Negligible	Negligible
		PGDP		9.4E-10	Negligible	Negligible	3.8E-05	Negligible	Negligible
		PORTS		7.4E-08	Negligible	Negligible	3.0E-03	Negligible	Negligible
		SRS		4.6E-09	Negligible	Negligible	1.9E-04	Negligible	Negligible
		Oak Ridge		1.1E-08	Negligible	Negligible	4.3E-04	Negligible	Negligible
Partially consolidated storage at two sites	Storage area fire	East	Extremely unlikely	4.3E-07	Negligible	Negligible	1.7E-02	Negligible	Negligible
		West		4.8E-08	Negligible	Negligible	1.9E-03	Negligible	Negligible
	Seismic (direct release)	East	Extremely unlikely	1.3E-06	Low	Low	5.3E-02	Negligible	Negligible
		West		4.9E-08	Negligible	Negligible	2.0E-03	Negligible	Negligible
	Seismic (fire)	East	Extremely unlikely	9.0E-08	Negligible	Negligible	3.6E-03	Negligible	Negligible
		West		4.3E-09	Negligible	Negligible	1.7E-04	Negligible	Negligible
Partially consolidated storage based on physical form	Storage area fire	PORTS	Extremely unlikely	2.0E-07	Negligible	Negligible	8.2E-03	Negligible	Negligible
		SRS		1.2E-07	Negligible	Negligible	4.6E-03	Negligible	Negligible
		INEEL		1.4E-08	Negligible	Negligible	5.7E-04	Negligible	Negligible
	Seismic (direct release)	PORTS	Extremely unlikely	1.3E-06	Low	Low	5.1E-02	Negligible	Negligible
		SRS		6.4E-08	Negligible	Negligible	2.6E-03	Negligible	Negligible
		INEEL		1.7E-08	Negligible	Negligible	6.7E-04	Negligible	Negligible
	Seismic (fire)	PORTS	Extremely unlikely	8.6E-08	Negligible	Negligible	3.5E-03	Negligible	Negligible
		SRS		7.2E-09	Negligible	Negligible	2.9E-04	Negligible	Negligible
		INEEL		1.4E-09	Negligible	Negligible	5.7E-05	Negligible	Negligible
Transfer to research facility	Facility fire	Generic	Extremely unlikely	1.7E-09	Negligible	Negligible	6.7E-05	Negligible	Negligible
	Seismic (direct release)	Generic		5.4E-10	Negligible	Negligible	2.2E-05	Negligible	Negligible
	Seismic (fire)	Generic		3.3E-10	Negligible	Negligible	1.3E-05	Negligible	Negligible

Table C.9. Summary of chronic radiation risks to human receptors due to deposition of uranium on soil under bounding accident scenarios (continued)

Alternative	Accident scenario	Site	Frequency	Radiation risk: Maximum risk	Radiation risk: Consequence level	Radiation risk: Risk	Radiation exposure: Maximum dose	Radiation exposure: Consequence level	Radiation exposure: Risk
Transfer to other government agencies	Facility fire	Generic	Extremely unlikely	8.3E-08	Negligible	Negligible	3.3E-03	Negligible	Negligible
	Seismic (direct release)	Generic		2.7E-08	Negligible	Negligible	1.1E-03	Negligible	Negligible
	Seismic (fire)	Generic		1.7E-08	Negligible	Negligible	6.7E-04	Negligible	Negligible
Foreign sales	Facility fire	Generic	Extremely unlikely	1.6E-07	Negligible	Negligible	6.6E-03	Negligible	Negligible
	Seismic (direct release)	Generic		5.8E-08	Negligible	Negligible	2.3E-03	Negligible	Negligible
	Seismic (fire)	Generic		3.5E-08	Negligible	Negligible	1.4E-03	Negligible	Negligible

DOE = U.S. Department of Energy.
HQ = hazard quotient.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

Table C.10. Summary of chronic chemical risks to human receptors due to deposition of uranium on soil under bounding accident scenarios

				Chemical exposure		
Alternative	Accident scenario	Site	Frequency	Maximum HQ	Consequence level	Risk
All	General container handling	All	Anticipated	4.8E-12	Negligible	Negligible
No Action	Storage area fire	INEEL	Extremely unlikely	1.3E-11	Negligible	Negligible
		PGDP		5.1E-14	Negligible	Negligible
		PORTS		1.4E-10	Negligible	Negligible
		SRS		2.9E-11	Negligible	Negligible
		Oak Ridge		1.4E-11	Negligible	Negligible
		Max other		1.7E-11	Negligible	Negligible
	Seismic (direct release)	INEEL	Extremely unlikely	7.5E-12	Negligible	Negligible
		PGDP		1.9E-13	Negligible	Negligible
		PORTS		4.9E-10	Negligible	Negligible
		SRS		3.2E-11	Negligible	Negligible
		Oak Ridge		1.5E-11	Negligible	Negligible
		Max other		6.2E-11	Negligible	Negligible
	Seismic (fire)	INEEL	Extremely unlikely	8.2E-13	Negligible	Negligible
		PGDP		1.3E-14	Negligible	Negligible
		PORTS		3.4E-11	Negligible	Negligible
		SRS		2.7E-12	Negligible	Negligible
		Oak Ridge		1.3E-12	Negligible	Negligible
		Max other		4.2E-12	Negligible	Negligible
Centralized storage at a single site	Storage area fire	All	Extremely unlikely	3.0E-10	Negligible	Negligible
	Seismic (direct release)	All	Extremely unlikely	8.5E-10	Negligible	Negligible
	Seismic (fire)	All	Extremely unlikely	5.9E-11	Negligible	Negligible
Partially consolidated storage at several DOE sites	Storage area fire	INEEL	Extremely unlikely	2.9E-11	Negligible	Negligible
		PGDP		4.3E-12	Negligible	Negligible
		PORTS		2.0E-10	Negligible	Negligible
		SRS		2.9E-11	Negligible	Negligible
		Oak Ridge		3.5E-11	Negligible	Negligible
	Seismic (direct release)	INEEL	Extremely unlikely	2.7E-11	Negligible	Negligible
		PGDP		7.7E-12	Negligible	Negligible
		PORTS		6.8E-10	Negligible	Negligible
		SRS		3.4E-11	Negligible	Negligible
		Oak Ridge		9.5E-11	Negligible	Negligible
	Seismic (fire)	INEEL	Extremely unlikely	2.5E-12	Negligible	Negligible
		PGDP		5.9E-13	Negligible	Negligible
		PORTS		4.6E-11	Negligible	Negligible
		SRS		2.9E-12	Negligible	Negligible
		Oak Ridge		6.7E-12	Negligible	Negligible

Table C.10. Summary of chronic chemical risks to human receptors due to deposition of uranium on soil under bounding accident scenarios (continued)

				Chemical exposure		
				Maximum	Consequence	
Alternative	Accident scenario	Site	Frequency	HQ	level	Risk
Partially consolidated storage at two sites	Storage area fire	East	Extremely	2.7E-10	Negligible	Negligible
		West	unlikely	3.0E-11	Negligible	Negligible
	Seismic (direct release)	East	Extremely	8.2E-10	Negligible	Negligible
		West	unlikely	3.1E-11	Negligible	Negligible
	Seismic (fire)	East	Extremely	5.7E-11	Negligible	Negligible
		West	unlikely	2.7E-12	Negligible	Negligible
Partially consolidated storage based on physical form	Storage area fire	PORTS	Extremely	1.3E-10	Negligible	Negligible
		SRS	unlikely	7.2E-11	Negligible	Negligible
		INEEL		8.8E-12	Negligible	Negligible
	Seismic (direct release)	PORTS	Extremely	8.0E-10	Negligible	Negligible
		SRS	unlikely	4.0E-11	Negligible	Negligible
		INEEL		1.0E-11	Negligible	Negligible
	Seismic (fire)	PORTS	Extremely	5.4E-11	Negligible	Negligible
		SRS	unlikely	4.5E-12	Negligible	Negligible
		INEEL		8.8E-13	Negligible	Negligible
Transfer to research facility	Facility fire	Generic	Extremely	1.0E-12	Negligible	Negligible
	Seismic (direct release)	Generic	unlikely	3.4E-13	Negligible	Negligible
	Seismic (fire)	Generic		2.1E-13	Negligible	Negligible
Transfer to other government agencies	Facility fire	Generic	Extremely	5.2E-11	Negligible	Negligible
	Seismic (direct release)	Generic	unlikely	1.7E-11	Negligible	Negligible
	Seismic (fire)	Generic		1.0E-11	Negligible	Negligible
Foreign sales	Facility fire	Generic	Extremely	1.0E-10	Negligible	Negligible
	Seismic (direct release)	Generic	unlikely	3.6E-11	Negligible	Negligible
	Seismic (fire)	Generic		2.2E-11	Negligible	Negligible

DOE = U.S. Department of Energy.
HQ = hazard quotient.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

C.4.3.1 Terrestrial biota exposed to chemical toxicity of uranium

Plants and earthworms are exposed by direct contact and uptake of uranium from the surrounding soil. The concentration of uranium in plant and earthworm tissues is calculated by multiplying the soil concentration by a soil-to-tissue bioconcentration factor (Table C.11). Exposure of shrews and robins, the indicator receptors, is calculated by multiplying their rates of ingestion of plants, earthworms, and soil by the concentration of uranium in each of those ingested materials. Ingestion rates were published by EPA (1993b). The dose per unit body weight was calculated using body weights published by EPA (1993b). Daily doses in mg/kg body weight/day per mg U/kg soil were calculated as shown in Table C.11.

C.4.3.2 Terrestrial biota exposed to radiological effects of uranium

The terrestrial receptors are exposed to external radiation from the surrounding soil and to internal radiation from incorporated uranium. External radiation doses were calculated for both surface exposure and subsurface exposure.

Table C.11. Chemical toxicity rates to ecological receptors from uranium in soil[a]

Receptor	Fraction of time below ground surface[b] (F_{below})	Fraction of time above ground surface[b] (F_{above})	BCF[c] (soil to tissue) (g soil/ g tissue)	Ba[c] (food to tissue) (d/kg)	IR[d] (kg/d)	BAF[e] (food to tissue) (g food/ g tissue)	Tissue concen-tration[f] (mg/kg)	Dose[g] (mg/kg or mg/kg/day)	TRV[h] (mg/kg or mg/kg/day)	HQ per mg/kg soil (dose/TRV)
Plant	0	1	1.70E-03	NA	NA		1.70E-03	1	5	0.2
Earthworm	0.9	0.1	3.30E-03	NA	NA		3.30E-03	1	No TRV	None
Shrew	0.25	0.75	NA	2.00E-04						
Plant					1.24E-03	2.47E-07	NA	4.20E-10		
Earthworm					8.27E-03	1.65E-06	NA	5.45E-09		
Soil					1.24E-03	2.47E-07	NA	2.47E-07		
Total								2.53E-07	3.07E+00	8.24E-08
Robin	0	0.5	NA	2.00E-04						
Plant					6.08E-02	1.22E-05	NA	2.07E-08		
Earthworm					6.08E-02	1.22E-05	NA	4.01E-08		
Soil					1.26E-02	2.53E-06	NA	2.53E-06		
Total								2.59E-06	1.60E+01	1.62E-07

[a]Doses were calculated for a concentration of 1 mg/kg in soil.
[b]Assumed values.
[c]Bioconcentration factors:
For plants, taken from Baes et al. (1984), adjusted to wet-weight basis by multiplying by 0.2, assuming earthworm is 80% water.
For earthworms, taken from DOE (1997), Appendix G, Table G.39, mean uptake value.
For mammals and birds, Ba is the biotransfer factor taken from Baes et al. (1984).
[d]Ingestion rate (EPA 1993b).
[e]Ba × IR.
[f]Soil concentration (1 mg/kg) × BCF.
[g]For plants and earthworms, soil concentration; for shrews and robins, BAF × ingested soil and tissue concentration.
[h]See Table C.15.
HQ = hazard quotient.
NA = not applicable.
TRV = toxicity reference value.

External subsurface exposure. The equation for subsurface exposure by immersion in soil is modified (Sample et al. 1997) from an equation for immersion in water (Blaylock, Frank, and O'Neal 1993):

$$D_{sub}\ (rad/d) = 1.05 \times F_{below} \times CFa \times C_{soil} \times (F_b \times E_b n_b + F_g \times E_g n_g)\ ,$$

where

D_{sub} = dose (rad/d) from uranium in soil by immersion in soil,
1.05 = conversion factor to account for immersion in soil rather than water,
F_{below} = fraction of time spent below ground surface (unitless; Table C.12),
CFa = conversion factor to convert MeV/event to rad/d per pCi/g = 5.12×10^{-5},
C_{soil} = activity of uranium in soil (pCi/g),
$F_{b\_}$ = absorbed fraction of energy E_ = 1 (Blaylock, Frank, and O'Neal 1993; Table C.12),
$E_b n_b$ = beta energy of the radionuclide (MeV) × proportion of disintegrations producing a g-particle (Table A.1, EPA 1993a; Table C.12),
$F_{g\_}$ = absorbed fraction of energy E_ (Blaylock, Frank, and O'Neal 1993 and DOE 1997; Table C.12),
$E_g n_g$ = photon energy emitted during transition from a higher to a lower energy state (MeV) × proportion of disintegrations producing a g-particle (Table A.1, EPA 1993a; Table C.12).

The external subsurface dose rates per pCi/g of total uranium in soil were calculated to be 0 for plants, 6.47×10^{-7} for earthworms, 1.83×10^{-7} for shrews, and 0 for robins (Table C.12).

External surface exposure. The equation for external radiation from surface exposure to uranium in soil (Sample et al. 1977) is:

$$D_{sur} = C_{soil} \times F_{ruf} \times CFb \times DCF_{soil} \times ECF\ ,$$

where

D_{sur} = dose from surface soil (rad/d),
C_{soil} = activity of uranium in soil (pCi/g),
F_{above} = fraction of time spent above ground (unitless, Table C.12),
F_{ruf} = dose rate reduction factor accounting for ground roughness (unitless) = 0.7 (Sample et al. 1997),
CFb = conversion factor to convert Sv/s per Bq/m^3 to rad/d per pCi/g = 5.12×10^{11},
DCF_{soil} = external dose conversion factor for soil contaminated to a depth of 5 cm for ^{234}U (1.82×10^{-21}), ^{235}U (2.65×10^{-18}), or ^{238}U (5.45×10^{-22}) [Table III.5 EPA 1993a; Table C.12],
ECF = elevation correction factor to adjust dose coefficients to value representative of effective height of receptor above ground (Sample et al. 1997; Table C.12).

The external surface dose rates per pCi/g of total uranium in soil were calculated to be 4.72×10^{-8} for plants, 4.72×10^{-9} for earthworms, 3.54×10^{-8} for shrews, and 2.36×10^{-8} for robins (Table C.12).

Table C.12. Radiation dose rates to ecological receptors from uranium in soil[a]

Receptor	Fraction of time below ground Surface[b] (F_{below})	Fraction of time above ground Surface[b] (F_{above})	BCF[c] (soil to tissue) (g soil/ g tissue)	Ba[c] (food to tissue) (d/kg)	IR[d] (kg/d)	BAF[e] (food to tissue) (g food/ g tissue)	Tissue activity[f] (pCi/ g tissue)	Radiation dose (rad/d) per pCi/g soil[g]			
								Subsurface	Surface	Internal	Total
Plant	0	1	1.70E-03	NA	NA		1.70E-03	0.00E+00	4.72E-08	1.88E-06	1.93E-06
Earthworm	0.9	0.1	3.30E-03	NA	NA		3.30E-03	6.47E-07	4.72E-09	3.65E-06	4.30E-06
Shrew	0.25	0.75	NA	2.00E-04							
Plant					1.24E-03	2.47E-07	4.20E-10				
Earthworm					8.27E-03	1.65E-06	5.45E-09				
Soil					1.24E-03	2.47E-07	2.47E-07				
Total							2.53E-07	1.83E-07	3.54E-08	2.80E-10	2.19E-07
Robin	0	0.5	NA	2.00E-04							
Plant					6.08E-02	1.22E-05	2.07E-08				
Earthworm					6.08E-02	1.22E-05	4.01E-08				
Soil					1.26E-02	2.53E-06	2.53E-06				
Total							2.59E-06	0.00E+00	2.36E-08	2.87E-09	2.64E-08

[a]Doses were calculated for an activity of 1 pCi/g in soil.
[b]Assumed values.
[c]Bioconcentration factors (EPA 1999).
[d]Ingestion rate (EPA 1993b).
[e]Ba × IR.
[f]Soil concentration (1 mg/kg) × BCF.
[g]Calculated by equipments found in Sect. C.4.3.2. Radiation dose parameters are as follows:

Isotope	U-234	U-235	U-238
DCF	1.82E-21	2.65E-18	5.45E-22
E n	4.46	4.4	4.19
E n	0.013	0.049	0.01
E n	0.002	0.156	0.001

F_g for:	U-234	U-235	U-238
Plants	0.63	0.008	0.63
Earthworms	0.63	0.008	0.63
Shrew	0.79	0.0115	0.79
Robin	0.79	0.0115	0.79

Internal exposure. Internal exposures were calculated by multiplying the tissue activity by decay energy and absorption factors and conversion factors (Blaylock, Frank, and O'Neal 1993; Sample et al. 1997):

$$D_{int} = C_{tiss} \times CFa \times (QF \times F_a \times E_a n_a + F_b \times E_b n_b + F_g E_g n_g) ,$$

where

D_{int} = internal radiation dose from incorporated uranium (rad/d),
C_{tiss} = uranium activity in receptor tissues (pCi/g tissue),
CFa = conversion factor to convert MeV/event to rad/d per pCi/g = 5.12×10^{-5},
QF = quality factor to account for greater biological effectiveness of alpha particles = 5,
F_a = absorbed fraction of energy E_ = 1 (Blaylock, Frank, and O'Neal 1993),
$E_a n_a$ = alpha energy of the radionuclide (MeV) × proportion of disintegrations producing an a-particle (Table A.1, EPA 1993a; Table C.12),
F_b = absorbed fraction of energy E_ = 1 (Blaylock, Frank, and O'Neal 1993),
$E_b n_b$ = beta energy of the radionuclide (MeV) × proportion of disintegrations producing a b-particle (Table A.1, EPA 1993a; Table C.12),
F_g = absorbed fraction of energy E_ (Blaylock, Frank, and O'Neal 1993 and DOE 1997; Table C.12),
$E_g n_g$ = photon energy emitted during transition from a higher to a lower energy state (MeV) × proportion of disintegrations producing a g-particle (Table A.1, EPA 1993a; Table C.12).

Alpha radiation has a higher biological effect on biological tissue than beta and gamma radiation because of the momentum carried by the large mass of the alpha particle. To account for the higher effect of alpha radiation, the alpha radiation dose is multiplied by a quality factor of 5.

The internal dose rates per pCi/g of total uranium in soil were calculated to be 1.88×10^{-6} for plants, 4.30×10^{-6} for earthworms, 2.19×10^{-7} for shrews, and 2.64×10^{-8} for robins (Table C.12).

C.4.3.3 Aquatic biota exposed to chemical toxicity of uranium

Aquatic biota (represented by fish) and benthic invertebrates are exposed by direct contact and uptake of uranium from the surrounding surface water and sediment. The concentration of uranium in fish tissues is calculated by multiplying the surface water concentration by a water-to-tissue bioconcentration factor [50 L/kg tissue (NRC 1992); Table C.13]. The concentration of uranium in benthic invertebrate tissues was calculated by multiplying the sediment concentration by a sediment-to-tissue bioconcentration factor [0.9 kg sediment/kg tissue (EPA 1999); Table C.13]. Exposure of great blue herons, the indicator receptors, was calculated by multiplying their rates of ingestion of fish, benthic invertebrates, surface water, and sediment by the concentration of uranium in each of those ingested materials. Ingestion rates were published by EPA (1993b). The dose per unit body weight was calculated using body weights published by EPA (1993b). Daily doses in mg/kg body weight/day per mg U/L water were calculated as shown in Table C.13. The daily dose for herons was calculated to be 6.40×10^{-3} mg/kg/d per mg/L (Table C.13).

Table C.13. Chemical toxicity rates to ecological receptors from uranium in surface water and sediment[a]

Receptor	Fraction of time exposed to sediment[b] (F_{sed})	Fraction of time exposed to water[b] (F_{water})	BCF[c] (medium to tissue) (kg sed or L water/ kg tissue)	Ba[c] (food to tissue) (d/kg)	IR[d] (kg/d or L/d))	BAF[e] (food to tissue) (g food/ g tissue)	Tissue concen-tration[f] (mg/kg)	Dose[g] (mg/kg or mg/L or mg/kg/day)	TRV[h] (mg/kg or mg/L or mg/kg/day)	HQ dose/TRV
Aquatic biota	0	1	5.00E+01	NA	NA		5.00E+01	1.00E+00	2.60E+00	3.85E-01
Sed. Inverts	0.9	0.1	9.00E-01	NA	NA		2.52E+02	2.80E+02	No TRV	None
Heron	0	0.5								
Fish			NA	2.00E-04	4.09E-01	8.17E-05	NA	4.09E-03		
Inverts			NA	2.00E-04	2.15E-02	4.30E-06	NA	1.08E-03		
Water			NA	2.00E-04	1.08E-01	2.15E-05	NA	2.15E-05		
Sediment			NA	2.00E-04	2.15E-02	4.30E-06	NA	1.20E-03		
Total								6.40E-03	1.60E+01	4.00E-04

[a]Doses were calculated for a concentration of 1 mg/L in surface water.
[b]Assumed values.
[c]Bioconcentration factors (EPA 1999).
For aquatic biota, taken from NRC (1992).
For benthic invertebrates, taken from EPA (1999).
For great blue herons, Ba is the biotransfer factor taken from Baes et al. (1984).
[d]Ingestion rate (EPA 1993b).
[e]Ba × IR.
[f]Surface water concentration (1 mg/L) × BCF; also multiplied by 280 to account for binding of uranium to sediment.
[g]For aquatic biota, surface water concentration; for benthic invertebrates, sediment concentration.
[h]See Table C.15.
HQ = hazard quotient.
NA = not applicable.
TRV = toxicity reference value.

C.4.3.4 Aquatic biota exposed to radiological effects of uranium

The aquatic receptors are exposed to external radiation from the surrounding water and sediment and to internal radiation from incorporated uranium. External radiation doses were calculated for both immersion in surface water and immersion in sediment.

External exposure to surface water. The equation for external exposure by immersion in surface water is given by Blaylock, Frank, and O'Neal (1993):

$$D_{sw} = F_{below} \times CFa \times C_{sw} \times 0.001 \times E_g n_g \times (1 - F_g) \ ,$$

where

D_{sw} = dose from uranium by immersion in surface water (rad/d),
F_{below} = fraction of time spent immersed in water or, for the heron, close enough to the water surface to receive external radiation (unitless, Table C.14),
CFa = conversion factor to convert MeV/event to rad/d per pCi/g water = 5.12×10^{-5},
C_{sw} = activity of uranium in surface water (pCi/L),
0.001 = L water/g water,
$E_g n_g$ = photon energy emitted during transition from a higher to a lower energy state (MeV) × proportion of disintegrations producing a g-particle (Table A.1, EPA 1993a; Table C.14),
F_g = absorbed fraction of energy E_g (Blaylock, Frank, and O'Neal 1993 and DOE 1997; Table C.14).

The external water dose rates per pCi/L of total uranium in surface water were calculated to be 1.81×10^{-10} for fish, 2.21×10^{-11} for benthic invertebrates, and 9.38×10^{-11} for great blue herons (Table C.14).

External exposure to surface water. The equation for external exposure by immersion in sediment is given by Blaylock, Frank, and O'Neal (1993):

$$D_{sw} = F_{below} \times CFa \times C_{sw} \times 280 \times E_g n_g \times (1 - F_g) \ ,$$

where

D_{sw} = dose from uranium by immersion in sediment (rad/d),
F_{below} = fraction of time spent immersed in sediment (unitless, Table C.14),
CFa = conversion factor to convert MeV/event to rad/d per pCi/g sediment = 5.12×10^{-5},
C_{sw} = activity of uranium in surface water (pCi/L),
280 = mg U/kg sediment per mg U/L water,
$E_g n_g$ = photon energy emitted during transition from a higher to a lower energy state (MeV) × proportion of disintegrations producing a g-particle (Table A.1, EPA 1993a; Table C.14),
F_g = absorbed fraction of energy E_g (Blaylock, Frank, and O'Neal 1993 and DOE 1997; Table C.14).

The external sediment dose rates per pCi/L of total uranium in surface water were calculated to be 0 for fish, 9.80×10^{-5} for benthic invertebrates, and 0 for great blue herons (Table C.14).

Internal exposure to incorporated uranium. Internal exposures of fish, benthic invertebrates, and herons were calculated as described for terrestrial receptors and are shown in Table C.14. The internal dose rates per pCi/L total uranium in surface water were calculated to be 4.05×10^{-6} for fish, 1.18×10^{-4} for benthic invertebrates, and 9.97×10^{-8} for great blue herons (Table C.14).

Table C.14. Radiation dose rates to ecological receptors from uranium in surface water and sediment[a]

Receptor	Fraction of time exposed to sediment[b] (F_{sed})	Fraction of time exposed to water[b] (F_{water})	BCF[c] (medium to tissue) (kg sed or L water/ kg tissue)	Ba[c] (food to tissue) (d/kg)	IR[d] (kg/d or L/d)	BAF[e] (food to tissue) (g food/ g tissue)	Tissue activity (pCi/ g tissue)	Radiation dose (rad/d per pCi/L)			
								Sediment	Water	Internal	Total
Aquatic biota	0	1	5.00E+01	NA	NA		5.00E-02	0.00E+00	1.81E-10	4.05E-06	4.05E-06
Sed. Inverts	0.9	0.1	9.00E-01	NA	NA		2.52E-01	9.80E-05	2.21E-11	2.04E-05	1.18E-04
Heron	0	0.5									
Fish			NA	2.00E-04	4.09E-01	8.17E-05	4.09E-06				
Inverts			NA	2.00E-04	2.15E-02	4.30E-06	1.08E-06				
Water			NA	2.00E-04	1.08E-01	2.15E-05	2.15E-05				
Sediment			NA	2.00E-04	2.15E-02	4.30E-06	1.20E-03				
Total							1.23E-03	0.00E+00	9.38E-11	9.96E-08	9.97E-08

[a]Doses were calculated for a concentration of 1 mg/L in surface water.
[b]Assumed values.
[c]Bioconcentration factors (EPA 1999).
[d]Ingestion rate (EPA 1993b).
[e]Ba × IR.
[f]Surface water concentration (1 mg/L) × BCF; also multiplied by 280 to account for binding of uranium to sediment.
[g]For aquatic biota, surface water concentration; for benthic invertebrates, sediment concentration; for herons, BAF × ingested water, sediment, and tissue concentration.
[h]Calculated by equations found in Section C.4.3.2. Radiation dose parameters are as follows:

Isotope	U-234	U-235	U-238	F_g for:	U-234	U-235	U-238
DCF	1.82E-21	2.65E-18	5.45E-22	Aquatic biota	0.94	0.0949	0.94
E_an_a	4.46	4.4	4.19	Benthic invertebrates	0.63	0.008	0.63
E_bn_b	0.013	0.049	0.01	Heron	0.94	0.06	0.94
E_gn_g	0.002	0.156	0.001				

NA = not applicable.

C.4.4 EFFECTS ASSESSMENT

C.4.4.1 Chemical effects

The toxic effects of uranium were evaluated for all receptors. Effects evaluated were toxicity of uranium in soil to plants (Efroymson et al. 1997) and earthworms (Efroymson, Will, and Suter 1997); toxicity of ingested uranium to shrews, robins, and herons (Sample, Opresko, and Suter 1996); toxicity of uranium in water to fish (Suter and Tsao 1996); and toxicity of uranium in sediment to benthic invertebrates (Jones, Suter, and Hull 1997). The toxicity endpoints, benchmarks used, and their sources are described in Table C.15.

C.4.4.2 Irradiation

Ionizing radiation (alpha, beta, and gamma radiation) interacts with biological molecules to produce free radicals and ions. High doses can cause death from radiation sickness induced by high levels of damage. However, at low doses, the major concern is damage to deoxyribonucleic acid (DNA). DNA damage that is not repaired by the organism can cause cancerous tumors, leukemia, and heritable genetic damage. The endpoint for radiation toxicity to ecological receptors is maintenance of populations. The benchmark values given by the International Atomic Energy Agency (IAEA 1992) are 0.1 rad/day for terrestrial mammals and birds and 1 rad/day for plants, invertebrates, and aquatic biota. These values were used as benchmarks in this assessment.

C.4.5 CONSEQUENCE EVALUATION

Hypothetical accident scenarios, identified in Sect. 1.2 and evaluated for acute risk to humans in Sect. 1.3, are evaluated in this section for chronic risk to the environment. Accident scenarios are described in detail in Sect. 1.3 and are referred to only by alternative in this section. For each alternative, each location, and each receptor, the daily dose was divided by the benchmark dose to calculate the HQ. If the HQ is above 1, exposure above the benchmark is indicated and further evaluation is required to determine whether unacceptable ecological risks are indicated. Consequences of exposure to uranium in soil were evaluated by comparing the modeled chemical and radiological doses to benchmarks for toxicity to plants and soil invertebrates (earthworms), which are exposed directly to soil contaminants, and to small mammals (shrews) and songbirds (robins), which are exposed by eating soil and prey that have accumulated uranium from the soil (Tables C.16 and C.17). Consequences of exposure to uranium in surface water were evaluated by comparing concentrations in water or chemical and radiological doses to benchmarks for aquatic biota (fish), which are exposed directly to waterborne contaminants; to benthic invertebrates, which are exposed directly to sediment contaminants; and to herons, which are exposed by ingesting prey that have accumulated uranium from the water, surface water, and sediment and by direct exposure to surface water (Tables C.18 and C.19).

C.4.5.1 Soil

Tables C.16 and C.17 show that no alternative resulted in unacceptable risks to terrestrial receptors. The highest chemical risk, with an HQ of 0.205 (Table C.16), was to plants exposed to uranium in soil after a direct seismic release under centralized storage at a single site. This HQ is rather uncertain for a large population of plants for a number of reasons. First, it assumes that all plants are exposed at the maximum soil concentration, whereas the deposition model shows that the concentrations fall off rapidly with both lateral and longitudinal distance from the maximum point. Second, the model assumes that the wind blows in only one direction, whereas variable wind directions will realistically result in a variety of downwind directions, so deposition will be dispersed rather than along a single centerline of the plume. Third, exceeding the toxicity benchmark by 1% may inhibit growth of plants but is not likely to be detrimental to the plant population. The highest chemical HQ for other terrestrial animal receptors is 1.7×10^{-7} for exposure of robins to soil uranium.

Table C.15. Uranium toxicity benchmarks for ecological receptors

Receptor	Concentration or dose	Justification	Reference
Terrestrial plants	5 mg/kg	Inhibition of root growth	Efroymson et al. 1997
Earthworms	No data	Not applicable	Not applicable
Short-tailed shrew	3.07 mg/kg BW/day	Chronic NOAEL for decreased reproduction	
American robin	16.0 mg/kg BW/day	No observed effect from subchronic exposure at 160 mg/kg; uncertainty factor of 10 used to estimate chronic NOAEL	Sample, Opresko, and Suter 1996
Aquatic biota	2.6 mg/L	Tier II Secondary chronic value	Suter and Tsao 1996
Benthic invertebrates	No data	Not applicable	Not applicable
Great blue heron	16.0 mg/kg BW/day	No observed effect from subchronic exposure at 160 mg/kg; uncertainty factor of 10 used to estimate chronic NOAEL	Sample, Opresko, and Suter 1996

BW = body weight.
NOAEL = No observed adverse effect level.

Table C.16. Chemical toxicity consequences to ecological receptors due to deposition of uranium on soil under bounding accident scenarios

Alternative	Accident scenario	Site	Untilled soil concentration (mg/kg)	HQ for ecological receptors		
				Plants	Shrews	Robins
All	General container handling	All	5.76E-03	1.15E-03	4.75E-10	9.33E-10
No Action	Storage area fire	INEEL	1.51E-02	3.02E-03	1.24E-09	2.45E-09
		PGDP	6.14E-05	1.23E-05	5.06E-12	9.94E-12
		PORTS	1.74E-01	3.48E-02	1.44E-08	2.82E-08
		SRS	3.45E-02	6.90E-03	2.84E-09	5.59E-09
		Oak Ridge	1.65E-02	3.31E-03	1.36E-09	2.68E-09
		Max other	2.04E-02	4.08E-03	1.68E-09	3.31E-09
	Seismic (direct release)	INEEL	9.08E-03	1.82E-03	7.48E-10	1.47E-09
		PGDP	2.27E-04	4.54E-05	1.87E-11	3.68E-11
		PORTS	5.92E-01	1.18E-01	4.87E-08	9.58E-08
		SRS	3.85E-02	7.70E-03	3.17E-09	6.24E-09
		Oak Ridge	1.82E-02	3.63E-03	1.50E-09	2.94E-09
		Max other	7.54E-02	1.51E-02	6.22E-09	1.22E-08
	Seismic (fire)	INEEL	9.87E-04	1.97E-04	8.14E-11	1.60E-10
		PGDP	1.53E-05	3.07E-06	1.26E-12	2.49E-12
		PORTS	4.06E-02	8.11E-03	3.34E-09	6.57E-09
		SRS	3.31E-03	6.63E-04	2.73E-10	5.37E-10
		Oak Ridge	1.57E-03	3.14E-04	1.29E-10	2.54E-10
		Max other	5.11E-03	1.02E-03	4.21E-10	8.28E-10
Centralized storage at a single site	Storage area fire	All	3.56E-01	7.12E-02	2.93E-08	5.77E-08
	Seismic (direct release)	All	1.02E+00	2.05E-01	8.43E-08	1.66E-07
	Seismic (fire)	All	7.16E-02	1.43E-02	5.90E-09	1.16E-08
Partially consolidated storage at several DOE sites	Storage area fire	INEEL	3.49E-02	6.98E-03	2.87E-09	5.65E-09
		PGDP	5.22E-03	1.04E-03	4.30E-10	8.45E-10
		PORTS	2.40E-01	4.80E-02	1.98E-08	3.88E-08
		SRS	3.53E-02	7.05E-03	2.91E-09	5.71E-09
		Oak Ridge	4.27E-02	8.53E-03	3.52E-09	6.91E-09
	Seismic (direct release)	INEEL	3.32E-02	6.64E-03	2.73E-09	5.37E-09
		PGDP	9.33E-03	1.87E-03	7.69E-10	1.51E-09
		PORTS	8.23E-01	1.65E-01	6.78E-08	1.33E-07
		SRS	4.16E-02	8.33E-03	3.43E-09	6.74E-09
		Oak Ridge	1.15E-01	2.29E-02	9.44E-09	1.86E-08
	Seismic (fire)	INEEL	3.00E-03	6.01E-04	2.48E-10	4.87E-10
		PGDP	7.09E-04	1.42E-04	5.84E-11	1.15E-10
		PORTS	5.61E-02	1.12E-02	4.62E-09	9.08E-09
		SRS	3.52E-03	7.03E-04	2.90E-10	5.70E-10
		Oak Ridge	8.08E-03	1.62E-03	6.65E-10	1.31E-09
Partially consolidated storage at two sites	Storage area fire	East	3.22E-01	6.44E-02	2.65E-08	5.22E-08
		West	3.60E-02	7.19E-03	2.96E-09	5.83E-09
	Seismic (direct release)	East	9.86E-01	1.97E-01	8.12E-08	1.60E-07
		West	3.72E-02	7.45E-03	3.07E-09	6.03E-09
	Seismic (fire)	East	6.84E-02	1.37E-02	5.64E-09	1.11E-08
		West	3.28E-03	6.55E-04	2.70E-10	5.31E-10

Table C.16. Chemical toxicity consequences to ecological receptors due to deposition of uranium on soil under bounding accident scenarios (continued)

Alternative	Accident scenario	Site	Untilled soil concentration (mg/kg)	HQ for ecological receptors		
				Plants	Shrews	Robins
Partially consolidated storage based on physical form	Storage area fire	PORTS	1.54E-01	3.09E-02	1.27E-08	2.50E-08
		SRS	8.71E-02	1.74E-02	7.18E-09	1.41E-08
		INEEL	1.06E-02	2.12E-03	8.75E-10	1.72E-09
	Seismic (direct release)	PORTS	9.61E-01	1.92E-01	7.92E-08	1.56E-07
		SRS	4.82E-02	9.64E-03	3.97E-09	7.81E-09
		INEEL	1.26E-02	2.51E-03	1.03E-09	2.03E-09
	Seismic (fire)	PORTS	6.49E-02	1.30E-02	5.35E-09	1.05E-08
		SRS	5.43E-03	1.09E-03	4.47E-10	8.80E-10
		INEEL	1.06E-03	2.12E-04	8.75E-11	1.72E-10
Transfer to research facility	Facility fire	Generic	1.26E-03	2.51E-04	1.03E-10	2.03E-10
	Seismic (direct release)	Generic	4.06E-04	8.11E-05	3.34E-11	6.57E-11
	Seismic (fire)	Generic	2.51E-04	5.03E-05	2.07E-11	4.07E-11
Transfer to other government agencies	Facility fire	Generic	6.28E-02	1.26E-02	5.17E-09	1.02E-08
	Seismic (direct release)	Generic	2.02E-02	4.05E-03	1.67E-09	3.28E-09
	Seismic (fire)	Generic	1.26E-02	2.51E-03	1.03E-09	2.03E-09
Foreign sales	Facility fire	Generic	1.24E-01	2.48E-02	1.02E-08	2.01E-08
	Seismic (direct release)	Generic	4.37E-02	8.75E-03	3.60E-09	7.08E-09
	Seismic (fire)	Generic	2.68E-02	5.36E-03	2.21E-09	4.34E-09
				2.05E-01	8.43E-08	1.66E-07

DOE = U.S. Department of Energy.
HQ = hazard quotient.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

Table C.17. Radiological consequences to ecological receptors due to deposition of uranium on soil under bounding accident scenarios

Alternative	Accident scenario	Site	Untilled soil activity (pCi/g)	HQ for ecological receptors			
				Plants	Soil invertebrates	Shrews	Robins
All	General container handling	All	4.03E-03	7.78E-09	1.73E-08	8.83E-10	1.06E-10
No Action	Storage area fire	INEEL	1.06E-02	2.04E-08	4.54E-08	2.31E-09	2.79E-10
		PGDP	4.30E-05	8.29E-11	1.85E-10	9.41E-12	1.13E-12
		PORTS	1.22E-01	2.35E-07	5.24E-07	2.67E-08	3.22E-09
		SRS	2.41E-02	4.66E-08	1.04E-07	5.29E-09	6.37E-10
		Oak Ridge	1.16E-02	2.23E-08	4.98E-08	2.54E-09	3.06E-10
		Max other	1.43E-02	2.76E-08	6.15E-08	3.13E-09	3.77E-10
	Seismic (direct release)	INEEL	6.35E-03	1.23E-08	2.73E-08	1.39E-09	1.68E-10
		PGDP	1.59E-04	3.07E-10	6.83E-10	3.48E-11	4.19E-12
		PORTS	4.14E-01	7.99E-07	1.78E-06	9.07E-08	1.09E-08
		SRS	2.69E-02	5.20E-08	1.16E-07	5.90E-09	7.11E-10
		Oak Ridge	1.27E-02	2.45E-08	5.46E-08	2.78E-09	3.35E-10
		Max other	5.28E-02	1.02E-07	2.27E-07	1.16E-08	1.39E-09
	Seismic (fire)	INEEL	6.91E-04	1.33E-09	2.97E-09	1.51E-10	1.82E-11
		PGDP	1.07E-05	2.07E-11	4.62E-11	2.35E-12	2.83E-13
		PORTS	2.84E-02	5.48E-08	1.22E-07	6.22E-09	7.49E-10
		SRS	2.32E-03	4.48E-09	9.98E-09	5.08E-10	6.13E-11
		Oak Ridge	1.10E-03	2.12E-09	4.72E-09	2.41E-10	2.90E-11
		Max other	3.58E-03	6.91E-09	1.54E-08	7.84E-10	9.45E-11
Centralized storage at a single site	Storage area fire	All	2.49E-01	4.81E-07	1.07E-06	5.46E-08	6.58E-09
	Seismic (direct release)	All	7.16E-01	1.38E-06	3.08E-06	1.57E-07	1.89E-08
	Seismic (fire)	All	5.01E-02	9.67E-08	2.15E-07	1.10E-08	1.32E-09
Partially consolidated storage at several DOE sites	Storage area fire	INEEL	2.44E-02	4.71E-08	1.05E-07	5.35E-09	6.44E-10
		PGDP	3.65E-03	7.05E-09	1.57E-08	8.00E-10	9.64E-11
		PORTS	1.68E-01	3.24E-07	7.22E-07	3.68E-08	4.43E-09
		SRS	2.47E-02	4.76E-08	1.06E-07	5.41E-09	6.52E-10
		Oak Ridge	2.99E-02	5.76E-08	1.28E-07	6.54E-09	7.89E-10
	Seismic (direct release)	INEEL	2.32E-02	4.48E-08	9.99E-08	5.09E-09	6.13E-10
		PGDP	6.53E-03	1.26E-08	2.81E-08	1.43E-09	1.72E-10
		PORTS	5.76E-01	1.11E-06	2.48E-06	1.26E-07	1.52E-08
		SRS	2.91E-02	5.62E-08	1.25E-07	6.38E-09	7.69E-10
		Oak Ridge	8.02E-02	1.55E-07	3.45E-07	1.76E-08	2.12E-09
	Seismic (fire)	INEEL	2.10E-03	4.06E-09	9.04E-09	4.61E-10	5.55E-11
		PGDP	4.96E-04	9.58E-10	2.13E-09	1.09E-10	1.31E-11
		PORTS	3.92E-02	7.57E-08	1.69E-07	8.60E-09	1.04E-09
		SRS	2.46E-03	4.75E-09	1.06E-08	5.39E-10	6.50E-11
		Oak Ridge	5.65E-03	1.09E-08	2.43E-08	1.24E-09	1.49E-10
Partially consolidated storage at two sites	Storage area fire	East	2.25E-01	4.35E-07	9.69E-07	4.94E-08	5.95E-09
		West	2.52E-02	4.86E-08	1.08E-07	5.51E-09	6.65E-10
	Seismic (direct release)	East	6.90E-01	1.33E-06	2.97E-06	1.51E-07	1.82E-08
		West	2.61E-02	5.03E-08	1.12E-07	5.71E-09	6.88E-10
	Seismic (fire)	East	4.79E-02	9.24E-08	2.06E-07	1.05E-08	1.26E-09
		West	2.29E-03	4.43E-09	9.86E-09	5.02E-10	6.05E-11

Table C.17. Radiological consequences to ecological receptors due to deposition of uranium on soil under bounding accident scenarios (continued)

Alternative	Accident scenario	Site	Untilled soil activity (pCi/g)	HQ for ecological receptors			
				Plants	Soil invertebrates	Shrews	Robins
Partially consolidated storage based on physical form	Storage area fire	PORTS	1.08E-01	2.09E-07	4.65E-07	2.37E-08	2.85E-09
		SRS	6.10E-02	1.18E-07	2.62E-07	1.34E-08	1.61E-09
		INEEL	7.43E-03	1.43E-08	3.19E-08	1.63E-09	1.96E-10
	Seismic (direct release)	PORTS	6.73E-01	1.30E-06	2.89E-06	1.47E-07	1.78E-08
		SRS	3.37E-02	6.51E-08	1.45E-07	7.39E-09	8.91E-10
		INEEL	8.79E-03	1.70E-08	3.78E-08	1.92E-09	2.32E-10
	Seismic (fire)	PORTS	4.54E-02	8.77E-08	1.95E-07	9.95E-09	1.20E-09
		SRS	3.80E-03	7.34E-09	1.63E-08	8.33E-10	1.00E-10
		INEEL	7.43E-04	1.43E-09	3.19E-09	1.63E-10	1.96E-11
Transfer to research facility	Facility fire	Generic	8.79E-04	1.70E-09	3.78E-09	1.92E-10	2.32E-11
	Seismic (direct release)	Generic	2.84E-04	5.48E-10	1.22E-09	6.22E-11	7.49E-12
	Seismic (fire)	Generic	1.76E-04	3.40E-10	7.57E-10	3.85E-11	4.65E-12
Transfer to other government agencies	Facility fire	Generic	4.39E-02	8.48E-08	1.89E-07	9.62E-09	1.16E-09
	Seismic (direct release)	Generic	1.42E-02	2.73E-08	6.09E-08	3.10E-09	3.74E-10
	Seismic (fire)	Generic	8.79E-03	1.70E-08	3.78E-08	1.92E-09	2.32E-10
Foreign sales	Facility fire	Generic	8.69E-02	1.68E-07	3.74E-07	1.90E-08	2.29E-09
	Seismic (direct release)	Generic	3.06E-02	5.91E-08	1.32E-07	6.70E-09	8.08E-10
	Seismic (fire)	Generic	1.88E-02	3.62E-08	8.07E-08	4.11E-09	4.95E-10
			Max	1.38E-06	3.08E-06	1.57E-07	1.89E-08

DOE = U.S. Department of Energy.
HQ = hazard quotient.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

Table C.18. Chemical toxicity consequences to ecological receptors due to deposition of uranium on surface water under bounding accident scenarios

Alternative	Accident scenario	Site	Surface water concentration (mg/L)	HQ for ecological receptors	
				Aquatic biota	Herons
All	General container handling	All	2.94E-05	1.13E-05	1.17E-08
No Action	Storage area fire	INEEL	7.81E-05	3.01E-05	3.12E-08
		PGDP	3.18E-07	1.22E-07	1.27E-10
		PORTS	9.02E-04	3.47E-04	3.61E-07
		SRS	1.78E-04	6.87E-05	7.14E-08
		Oak Ridge	8.56E-05	3.30E-05	3.42E-08
		Max other	1.06E-04	4.07E-05	4.23E-08
	Seismic (direct release)	INEEL	4.70E-05	1.81E-05	1.88E-08
		PGDP	1.17E-06	4.52E-07	4.70E-10
		PORTS	3.06E-03	1.18E-03	1.22E-06
		SRS	1.99E-04	7.67E-05	7.97E-08
		Oak Ridge	9.40E-05	3.62E-05	3.76E-08
		Max other	3.90E-04	1.50E-04	1.56E-07
	Seismic (fire)	INEEL	5.11E-06	1.97E-06	2.04E-09
		PGDP	7.94E-08	3.06E-08	3.18E-11
		PORTS	2.10E-04	8.08E-05	8.40E-08
		SRS	1.72E-05	6.60E-06	6.86E-09
		Oak Ridge	8.12E-06	3.13E-06	3.25E-09
		Max other	2.65E-05	1.02E-05	1.06E-08
Centralized storage at a single site	Storage area fire	All	1.84E-03	7.10E-04	7.37E-07
	Seismic (direct release)	All	5.30E-03	2.04E-03	2.12E-06
	Seismic (fire)	All	3.70E-04	1.43E-04	1.48E-07
Partially consolidated storage at several DOE sites	Storage area fire	INEEL	1.80E-04	6.95E-05	7.22E-08
		PGDP	2.70E-05	1.04E-05	1.08E-08
		PORTS	1.24E-03	4.78E-04	4.96E-07
		SRS	1.83E-04	7.03E-05	7.30E-08
		Oak Ridge	2.21E-04	8.50E-05	8.83E-08
	Seismic (direct release)	INEEL	1.72E-04	6.61E-05	6.87E-08
		PGDP	4.83E-05	1.86E-05	1.93E-08
		PORTS	4.26E-03	1.64E-03	1.70E-06
		SRS	2.15E-04	8.29E-05	8.62E-08
		Oak Ridge	5.93E-04	2.28E-04	2.37E-07
	Seismic (fire)	INEEL	1.55E-05	5.99E-06	6.22E-09
		PGDP	3.67E-06	1.41E-06	1.47E-09
		PORTS	2.90E-04	1.12E-04	1.16E-07
		SRS	1.82E-05	7.01E-06	7.28E-09
		Oak Ridge	4.18E-05	1.61E-05	1.67E-08
Partially consolidated storage at two sites	Storage area fire	East	1.67E-03	6.42E-04	6.67E-07
		West	1.86E-04	7.17E-05	7.45E-08
	Seismic (direct release)	East	5.10E-03	1.96E-03	2.04E-06
		West	1.93E-04	7.42E-05	7.71E-08
	Seismic (fire)	East	3.54E-04	1.36E-04	1.42E-07
		West	1.70E-05	6.53E-06	6.78E-09

Table C.18. Chemical toxicity consequences to ecological receptors due to deposition of uranium on surface water under bounding accident scenarios (continued)

Alternative	Accident scenario	Site	Surface water concentration (mg/L)	HQ for ecological receptors	
				Aquatic biota	Herons
Partially consolidated storage based on physical form	Storage area fire	PORTS	7.99E-04	3.08E-04	3.20E-07
		SRS	4.51E-04	1.74E-04	1.80E-07
		INEEL	5.49E-05	2.11E-05	2.20E-08
	Seismic (direct release)	PORTS	4.97E-03	1.91E-03	1.99E-06
		SRS	2.49E-04	9.60E-05	9.98E-08
		INEEL	6.50E-05	2.50E-05	2.60E-08
	Seismic (fire)	PORTS	3.36E-04	1.29E-04	1.34E-07
		SRS	2.81E-05	1.08E-05	1.12E-08
		INEEL	5.49E-06	2.11E-06	2.20E-09
Transfer to research facility	Facility fire	Generic	6.50E-06	2.50E-06	2.60E-09
	Seismic (direct release)	Generic	2.10E-06	8.08E-07	8.40E-10
	Seismic (fire)	Generic	1.30E-06	5.01E-07	5.21E-10
Transfer to other government agencies	Facility fire	Generic	3.25E-04	1.25E-04	1.30E-07
	Seismic (direct release)	Generic	1.05E-04	4.03E-05	4.19E-08
	Seismic (fire)	Generic	6.50E-05	2.50E-05	2.60E-08
Foreign sales	Facility fire	Generic	6.42E-04	2.47E-04	2.57E-07
	Seismic (direct release)	Generic	2.26E-04	8.71E-05	9.05E-08
	Seismic (fire)	Generic	1.39E-04	5.34E-05	5.55E-08
				2.04E-03	2.12E-06

DOE = U.S. Department of Energy.
HQ = hazard quotient.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

Table C.19. Radiological consequences to ecological receptors due to deposition of uranium on surface water under bounding accident scenarios

Alternative	Accident scenario	Site	Surface water activity (pCi/L)	HQ for ecological receptors		
				Aquatic biota	Sediment invertebrates	Herons
All	General container handling	All	2.06E-02	8.32E-08	2.43E-06	2.05E-09
No Action	Storage area fire	INEEL	5.47E-02	2.21E-07	6.45E-06	5.45E-09
		PGDP	2.22E-04	9.00E-10	2.62E-08	2.22E-11
		PORTS	6.31E-01	2.56E-06	7.45E-05	6.29E-08
		SRS	1.25E-01	5.06E-07	1.47E-05	1.25E-08
		Oak Ridge	5.99E-02	2.43E-07	7.07E-06	5.97E-09
		Max other	7.40E-02	3.00E-07	8.73E-06	7.37E-09
	Seismic (direct release)	INEEL	3.29E-02	1.33E-07	3.88E-06	3.28E-09
		PGDP	8.22E-04	3.33E-09	9.70E-08	8.20E-11
		PORTS	2.14E+00	8.68E-06	2.53E-04	2.14E-07
		SRS	1.39E-01	5.65E-07	1.65E-05	1.39E-08
		Oak Ridge	6.58E-02	2.66E-07	7.76E-06	6.56E-09
		Max other	2.73E-01	1.11E-06	3.22E-05	2.72E-08
	Seismic (fire)	INEEL	3.58E-03	1.45E-08	4.22E-07	3.57E-10
		PGDP	5.56E-05	2.25E-10	6.56E-09	5.54E-12
		PORTS	1.47E-01	5.95E-07	1.73E-05	1.46E-08
		SRS	1.20E-02	4.86E-08	1.42E-06	1.20E-09
		Oak Ridge	5.69E-03	2.30E-08	6.71E-07	5.67E-10
		Max other	1.85E-02	7.50E-08	2.19E-06	1.85E-09
Centralized storage at a single site	Storage area fire	All	1.29E+00	5.23E-06	1.52E-04	1.29E-07
	Seismic (direct release)	All	3.71E+00	1.50E-05	4.38E-04	3.70E-07
	Seismic (fire)	All	2.59E-01	1.05E-06	3.06E-05	2.59E-08
Partially consolidated storage at several DOE sites	Storage area fire	INEEL	1.26E-01	5.12E-07	1.49E-05	1.26E-08
		PGDP	1.89E-02	7.66E-08	2.23E-06	1.89E-09
		PORTS	8.69E-01	3.52E-06	1.03E-04	8.66E-08
		SRS	1.28E-01	5.17E-07	1.51E-05	1.27E-08
		Oak Ridge	1.55E-01	6.26E-07	1.82E-05	1.54E-08
	Seismic (direct release)	INEEL	1.20E-01	4.87E-07	1.42E-05	1.20E-08
		PGDP	3.38E-02	1.37E-07	3.99E-06	3.37E-09
		PORTS	2.98E+00	1.21E-05	3.52E-04	2.97E-07
		SRS	1.51E-01	6.11E-07	1.78E-05	1.50E-08
		Oak Ridge	4.15E-01	1.68E-06	4.90E-05	4.14E-08
	Seismic (fire)	INEEL	1.09E-02	4.41E-08	1.28E-06	1.09E-09
		PGDP	2.57E-03	1.04E-08	3.03E-07	2.56E-10
		PORTS	2.03E-01	8.23E-07	2.40E-05	2.03E-08
		SRS	1.27E-02	5.16E-08	1.50E-06	1.27E-09
		Oak Ridge	2.93E-02	1.18E-07	3.45E-06	2.92E-09
Partially consolidated storage at two sites	Storage area fire	East	1.17E+00	4.72E-06	1.38E-04	1.16E-07
		West	1.30E-01	5.28E-07	1.54E-05	1.30E-08
	Seismic (direct release)	East	3.57E+00	1.45E-05	4.21E-04	3.56E-07
		West	1.35E-01	5.46E-07	1.59E-05	1.35E-08
	Seismic (fire)	East	2.48E-01	1.00E-06	2.92E-05	2.47E-08
		West	1.19E-02	4.81E-08	1.40E-06	1.18E-09

Table C.19. Radiological consequences to ecological receptors due to deposition of uranium on surface water under bounding accident scenarios (continued)

Alternative	Accident scenario	Site	Surface water activity (pCi/L)	HQ for ecological receptors		
				Aquatic biota	Sediment invertebrates	Herons
Partially consolidated storage based on physical form	Storage area fire	PORTS	5.60E-01	2.27E-06	6.60E-05	5.58E-08
		SRS	3.16E-01	1.28E-06	3.72E-05	3.15E-08
		INEEL	3.85E-02	1.56E-07	4.54E-06	3.83E-09
	Seismic (direct release)	PORTS	3.48E+00	1.41E-05	4.11E-04	3.47E-07
		SRS	1.75E-01	7.07E-07	2.06E-05	1.74E-08
		INEEL	4.55E-02	1.84E-07	5.37E-06	4.53E-09
	Seismic (fire)	PORTS	2.35E-01	9.52E-07	2.77E-05	2.34E-08
		SRS	1.97E-02	7.97E-08	2.32E-06	1.96E-09
		INEEL	3.85E-03	1.56E-08	4.54E-07	3.83E-10
Transfer to research facility	Facility fire	Generic	4.55E-03	1.84E-08	5.37E-07	4.53E-10
	Seismic (direct release)	Generic	1.47E-03	5.95E-09	1.73E-07	1.46E-10
	Seismic (fire)	Generic	9.11E-04	3.69E-09	1.07E-07	9.08E-11
Transfer to other government agencies	Facility fire	Generic	2.27E-01	9.21E-07	2.68E-05	2.27E-08
	Seismic (direct release)	Generic	7.33E-02	2.97E-07	8.65E-06	7.31E-09
	Seismic (fire)	Generic	4.55E-02	1.84E-07	5.37E-06	4.53E-09
Foreign sales	Facility fire	Generic	4.50E-01	1.82E-06	5.31E-05	4.48E-08
	Seismic (direct release)	Generic	1.58E-01	6.42E-07	1.87E-05	1.58E-08
	Seismic (fire)	Generic	9.71E-02	3.93E-07	1.15E-05	9.68E-09
				1.50E-05	4.38E-04	3.70E-07

DOE = U.S. Department of Energy.
HQ = hazard quotient.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

The highest risk from radiation exposure in soil (Table C.17) is an HQ of 3.1×10^{-6} for exposure of earthworms as a result of a direct seismic release under centralized storage at a single site. Because all other risks are below this level, there is no unacceptable risk from radiation exposure of terrestrial receptors.

C.4.5.2 Surface water and sediment

Tables C.18 and C.19 show that no alternative resulted in unacceptable risks to aquatic biota, benthic invertebrates, and predators of aquatic biota and benthic invertebrates. The highest chemical risk was an HQ of 2.0×10^{-3} for exposure of aquatic biota as a result of a direct seismic release under centralized storage at a single site (Table C.18). Because all other risks are below this level, there is no unacceptable risk from chemical exposure of receptors of uranium deposited in surface water.

The highest risk of radiation exposure from uranium deposited in surface water is an HQ of 3.0×10^{-3} for exposure of great blue herons as a result of a direct seismic release under centralized storage at a single site (Table C.19). Because all other risks are below this level, there is no unacceptable risk from radiation exposure of receptors of uranium deposited in surface water.

C.4.6 OVERALL RISK EVALUATION

The overall risk from each alternative was evaluated by combining the predicted frequency of accidents with the consequences of those accidents as shown in Appendix A, Fig. A.1. The predicted frequency of each accident is shown in Appendix A, Table A.13. Ecological consequences were assigned categories as follows: HQ <0.1, negligible; HQ between 0.1 and 1, low; HQ between 1 and 10, moderate; and HQ greater than 10, high. Overall risks are shown in Tables C.20 (terrestrial receptors) and C.21 (receptors of uranium deposited in surface water). These tables show that overall risks under all alternatives are negligible.

C.5 SUMMARY

Airborne uranium released after potential accidents would be deposited downwind onto soil and surface water. Humans and ecological receptors would be exposed to the chemical toxicity of uranium and to the effects of radiation from contact, inhalation, and ingestion of contaminated soil, water, sediment, and food. This analysis calculates the concentrations of uranium in soil, surface water, and sediment that would result from each of the accident scenarios described in Appendix A.

Risks to EM workers, industrial workers, and residents who live on, and are surrounded by, contaminated soil were evaluated. Cancer risk, chronic radiation dose, and chronic chemical toxicity were assessed. Under all alternatives, all three types of consequences were negligible or low.

Table C.20. Summary of chronic risks to ecological receptors due to deposition of uranium on soil under bounding accident scenarios

Alternative	Accident scenario	Site	Frequency	Chemical exposure			Radiation exposure		
				Maximum HQ	Consequence level	Risk	Maximum HQ	Consequence level	Risk
All	General container handling	All	Anticipated	1.2E-03	Negligible	Negligible	1.7E-08	Negligible	Negligible
No Action	Storage area fire	INEEL	Extremely unlikely	3.0E-03	Negligible	Negligible	4.5E-08	Negligible	Negligible
		PGDP		1.2E-05	Negligible	Negligible	1.8E-10	Negligible	Negligible
		PORTS		3.5E-02	Negligible	Negligible	5.2E-07	Negligible	Negligible
		SRS		6.9E-03	Negligible	Negligible	1.0E-07	Negligible	Negligible
		Oak Ridge		3.3E-03	Negligible	Negligible	5.0E-08	Negligible	Negligible
		Max other		4.1E-03	Negligible	Negligible	6.1E-08	Negligible	Negligible
	Seismic (direct release)	INEEL	Extremely unlikely	1.8E-03	Negligible	Negligible	2.7E-08	Negligible	Negligible
		PGDP		4.5E-05	Negligible	Negligible	6.8E-10	Negligible	Negligible
		PORTS		1.2E-01	Low	Low	1.8E-06	Negligible	Negligible
		SRS		7.7E-03	Negligible	Negligible	1.2E-07	Negligible	Negligible
		Oak Ridge		3.6E-03	Negligible	Negligible	5.5E-08	Negligible	Negligible
		Max other		1.5E-02	Negligible	Negligible	2.3E-07	Negligible	Negligible
	Seismic (fire)	INEEL	Extremely unlikely	2.0E-04	Negligible	Negligible	3.0E-09	Negligible	Negligible
		PGDP		3.1E-06	Negligible	Negligible	4.6E-11	Negligible	Negligible
		PORTS		8.1E-03	Negligible	Negligible	1.2E-07	Negligible	Negligible
		SRS		6.6E-04	Negligible	Negligible	1.0E-08	Negligible	Negligible
		Oak Ridge		3.1E-04	Negligible	Negligible	4.7E-09	Negligible	Negligible
		Max other		1.0E-03	Negligible	Negligible	1.5E-08	Negligible	Negligible
Centralized storage at a single site	Storage area fire	All	Extremely unlikely	7.1E-02	Negligible	Negligible	1.1E-06	Negligible	Negligible
	Seismic (direct release)	All	Extremely unlikely	2.0E-01	Low	Low	3.1E-06	Negligible	Negligible
	Seismic (fire)	All	Extremely unlikely	1.4E-02	Negligible	Negligible	2.2E-07	Negligible	Negligible
Partially consolidated storage at several DOE sites	Storage area fire	INEEL	Extremely unlikely	7.0E-03	Negligible	Negligible	1.0E-07	Negligible	Negligible
		PGDP		1.0E-03	Negligible	Negligible	1.6E-08	Negligible	Negligible
		PORTS		4.8E-02	Negligible	Negligible	7.2E-07	Negligible	Negligible
		SRS		7.1E-03	Negligible	Negligible	1.1E-07	Negligible	Negligible
		Oak Ridge		8.5E-03	Negligible	Negligible	1.3E-07	Negligible	Negligible

Table C.20. Summary of chronic risks to ecological receptors due to deposition of uranium on soil under bounding accident scenarios (continued)

Alternative	Accident scenario	Site	Frequency	Chemical exposure			Radiation exposure		
				Maximum HQ	Consequence level	Risk	Maximum HQ	Consequence level	Risk
	Seismic (direct release)	INEEL	Extremely unlikely	6.6E-03	Negligible	Negligible	1.0E-07	Negligible	Negligible
		PGDP		1.9E-03	Negligible	Negligible	2.8E-08	Negligible	Negligible
		PORTS		1.6E-01	Low	Low	2.5E-06	Negligible	Negligible
		SRS		8.3E-03	Negligible	Negligible	1.3E-07	Negligible	Negligible
		Oak Ridge		2.3E-02	Negligible	Negligible	3.4E-07	Negligible	Negligible
	Seismic (fire)	INEEL	Extremely unlikely	6.0E-04	Negligible	Negligible	9.0E-09	Negligible	Negligible
		PGDP		1.4E-04	Negligible	Negligible	2.1E-09	Negligible	Negligible
		PORTS		1.1E-02	Negligible	Negligible	1.7E-07	Negligible	Negligible
		SRS		7.0E-04	Negligible	Negligible	1.1E-08	Negligible	Negligible
		Oak Ridge		1.6E-03	Negligible	Negligible	2.4E-08	Negligible	Negligible
Partially consolidated storage at two sites	Storage area fire	East	Extremely unlikely	6.4E-02	Negligible	Negligible	9.7E-07	Negligible	Negligible
		West		7.2E-03	Negligible	Negligible	1.1E-07	Negligible	Negligible
	Seismic (direct release)	East	Extremely unlikely	2.0E-01	Low	Low	3.0E-06	Negligible	Negligible
		West		7.4E-03	Negligible	Negligible	1.1E-07	Negligible	Negligible
	Seismic (fire)	East	Extremely unlikely	1.4E-02	Negligible	Negligible	2.1E-07	Negligible	Negligible
		West		6.6E-04	Negligible	Negligible	9.9E-09	Negligible	Negligible
Partially consolidated storage based on physical form	Storage area fire	PORTS	Extremely unlikely	3.1E-02	Negligible	Negligible	4.6E-07	Negligible	Negligible
		SRS		1.7E-02	Negligible	Negligible	2.6E-07	Negligible	Negligible
		INEEL		2.1E-03	Negligible	Negligible	3.2E-08	Negligible	Negligible
	Seismic (direct release)	PORTS	Extremely unlikely	1.9E-01	Low	Low	2.9E-06	Negligible	Negligible
		SRS		9.6E-03	Negligible	Negligible	1.5E-07	Negligible	Negligible
		INEEL		2.5E-03	Negligible	Negligible	3.8E-08	Negligible	Negligible
	Seismic (fire)	PORTS	Extremely unlikely	1.3E-02	Negligible	Negligible	2.0E-07	Negligible	Negligible
		SRS		1.1E-03	Negligible	Negligible	1.6E-08	Negligible	Negligible
		INEEL		2.1E-04	Negligible	Negligible	3.2E-09	Negligible	Negligible
Transfer to research facility	Facility fire	Generic	Extremely unlikely	2.5E-04	Negligible	Negligible	3.8E-09	Negligible	Negligible
	Seismic (direct release)	Generic		8.1E-05	Negligible	Negligible	1.2E-09	Negligible	Negligible
	Seismic (fire)	Generic		5.0E-05	Negligible	Negligible	7.6E-10	Negligible	Negligible

Table C.20. Summary of chronic risks to ecological receptors due to deposition of uranium on soil under bounding accident scenarios (continued)

				Chemical exposure			Radiation exposure		
Alternative	Accident scenario	Site	Frequency	Maximum HQ	Consequence level	Risk	Maximum HQ	Consequence level	Risk
Transfer to other government Agencies	Facility fire	Generic	Extremely unlikely	1.3E-02	Negligible	Negligible	1.9E-07	Negligible	Negligible
	Seismic (direct release)	Generic		4.0E-03	Negligible	Negligible	6.1E-08	Negligible	Negligible
	Seismic (fire)	Generic		2.5E-03	Negligible	Negligible	3.8E-08	Negligible	Negligible
Foreign sales	Facility fire	Generic	Extremely unlikely	2.5E-02	Negligible	Negligible	3.7E-07	Negligible	Negligible
	Seismic (direct release)	Generic		8.7E-03	Negligible	Negligible	1.3E-07	Negligible	Negligible
	Seismic (fire)	Generic		5.4E-03	Negligible	Negligible	8.1E-08	Negligible	Negligible

DOE = U.S. Department of Energy.
HQ = hazard quotient.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

Table C.21. Summary of chronic risks to ecological receptors due to deposition of uranium on surface water under bounding accident scenarios

Alternative	Accident scenario	Site	Frequency	Chemical exposure			Radiation exposure		
				Maximum HQ	Consequence level	Risk	Maximum HQ	Consequence level	Risk
All	General container handling	All	Anticipated	1.1E-05	Negligible	Negligible	2.4E-06	Negligible	Negligible
No Action	Storage area fire	INEEL	Extremely unlikely	3.0E-05	Negligible	Negligible	6.5E-06	Negligible	Negligible
		PGDP		1.2E-07	Negligible	Negligible	2.6E-08	Negligible	Negligible
		PORTS		3.5E-04	Negligible	Negligible	7.4E-05	Negligible	Negligible
		SRS		6.9E-05	Negligible	Negligible	1.5E-05	Negligible	Negligible
		Oak Ridge		3.3E-05	Negligible	Negligible	7.1E-06	Negligible	Negligible
		Max other		4.1E-05	Negligible	Negligible	8.7E-06	Negligible	Negligible
	Seismic (direct release)	INEEL	Extremely unlikely	1.8E-05	Negligible	Negligible	3.9E-06	Negligible	Negligible
		PGDP		4.5E-07	Negligible	Negligible	9.7E-08	Negligible	Negligible
		PORTS		1.2E-03	Negligible	Negligible	2.5E-04	Negligible	Negligible
		SRS		7.7E-05	Negligible	Negligible	1.6E-05	Negligible	Negligible
		Oak Ridge		3.6E-05	Negligible	Negligible	7.8E-06	Negligible	Negligible
		Max other		1.5E-04	Negligible	Negligible	3.2E-05	Negligible	Negligible
	Seismic (fire)	INEEL	Extremely unlikely	2.0E-06	Negligible	Negligible	4.2E-07	Negligible	Negligible
		PGDP		3.1E-08	Negligible	Negligible	6.6E-09	Negligible	Negligible
		PORTS		8.1E-05	Negligible	Negligible	1.7E-05	Negligible	Negligible
		SRS		6.6E-06	Negligible	Negligible	1.4E-06	Negligible	Negligible
		Oak Ridge		3.1E-06	Negligible	Negligible	6.7E-07	Negligible	Negligible
		Max other		1.0E-05	Negligible	Negligible	2.2E-06	Negligible	Negligible
Centralized storage at a single site	Storage area fire	All	Extremely unlikely	7.1E-04	Negligible	Negligible	1.5E-04	Negligible	Negligible
	Seismic (direct release)	All	Extremely unlikely	2.0E-03	Negligible	Negligible	4.4E-04	Negligible	Negligible
	Seismic (fire)	All	Extremely unlikely	1.4E-04	Negligible	Negligible	3.1E-05	Negligible	Negligible
Partially consolidated storage at several DOE sites	Storage area fire	INEEL	Extremely unlikely	6.9E-05	Negligible	Negligible	1.5E-05	Negligible	Negligible
		PGDP		1.0E-05	Negligible	Negligible	2.2E-06	Negligible	Negligible
		PORTS		4.8E-04	Negligible	Negligible	1.0E-04	Negligible	Negligible
		SRS		7.0E-05	Negligible	Negligible	1.5E-05	Negligible	Negligible
		Oak Ridge		8.5E-05	Negligible	Negligible	1.8E-05	Negligible	Negligible

Table C.21. Summary of chronic risks to ecological receptors due to deposition of uranium on surface water under bounding accident scenarios (continued)

Alternative	Accident scenario	Site	Frequency	Chemical exposure			Radiation exposure		
				Maximum HQ	Consequence level	Risk	Maximum HQ	Consequence level	Risk
	Seismic (direct release)	INEEL	Extremely unlikely	6.6E-05	Negligible	Negligible	1.4E-05	Negligible	Negligible
		PGDP		1.9E-05	Negligible	Negligible	4.0E-06	Negligible	Negligible
		PORTS		1.6E-03	Negligible	Negligible	3.5E-04	Negligible	Negligible
		SRS		8.3E-05	Negligible	Negligible	1.8E-05	Negligible	Negligible
		Oak Ridge		2.3E-04	Negligible	Negligible	4.9E-05	Negligible	Negligible
	Seismic (fire)	INEEL	Extremely unlikely	6.0E-06	Negligible	Negligible	1.3E-06	Negligible	Negligible
		PGDP		1.4E-06	Negligible	Negligible	3.0E-07	Negligible	Negligible
		PORTS		1.1E-04	Negligible	Negligible	2.4E-05	Negligible	Negligible
		SRS		7.0E-06	Negligible	Negligible	1.5E-06	Negligible	Negligible
		Oak Ridge		1.6E-05	Negligible	Negligible	3.5E-06	Negligible	Negligible
Partially consolidated storage at two sites	Storage area fire	East	Extremely unlikely	6.4E-04	Negligible	Negligible	1.4E-04	Negligible	Negligible
		West		7.2E-05	Negligible	Negligible	1.5E-05	Negligible	Negligible
	Seismic (direct release)	East	Extremely unlikely	2.0E-03	Negligible	Negligible	4.2E-04	Negligible	Negligible
		West		7.4E-05	Negligible	Negligible	1.6E-05	Negligible	Negligible
	Seismic (fire)	East	Extremely unlikely	1.4E-04	Negligible	Negligible	2.9E-05	Negligible	Negligible
		West		6.5E-06	Negligible	Negligible	1.4E-06	Negligible	Negligible
Partially consolidated storage based on physical form	Storage area fire	PORTS	Extremely unlikely	3.1E-04	Negligible	Negligible	6.6E-05	Negligible	Negligible
		SRS		1.7E-04	Negligible	Negligible	3.7E-05	Negligible	Negligible
		INEEL		2.1E-05	Negligible	Negligible	4.5E-06	Negligible	Negligible
	Seismic (direct release)	PORTS	Extremely unlikely	1.9E-03	Negligible	Negligible	4.1E-04	Negligible	Negligible
		SRS		9.6E-05	Negligible	Negligible	2.1E-05	Negligible	Negligible
		INEEL		2.5E-05	Negligible	Negligible	5.4E-06	Negligible	Negligible
	Seismic (fire)	PORTS	Extremely unlikely	1.3E-04	Negligible	Negligible	2.8E-05	Negligible	Negligible
		SRS		1.1E-05	Negligible	Negligible	2.3E-06	Negligible	Negligible
		INEEL		2.1E-06	Negligible	Negligible	4.5E-07	Negligible	Negligible
Transfer to research facility	Facility fire	Generic	Extremely unlikely	2.5E-06	Negligible	Negligible	5.4E-07	Negligible	Negligible
	Seismic (direct release)	Generic		8.1E-07	Negligible	Negligible	1.7E-07	Negligible	Negligible
	Seismic (fire)	Generic		5.0E-07	Negligible	Negligible	1.1E-07	Negligible	Negligible
Transfer to other government agencies	Facility fire	Generic	Extremely unlikely	1.3E-04	Negligible	Negligible	2.7E-05	Negligible	Negligible
	Seismic (direct release)	Generic		4.0E-05	Negligible	Negligible	8.7E-06	Negligible	Negligible
	Seismic (fire)	Generic		2.5E-05	Negligible	Negligible	5.4E-06	Negligible	Negligible

Table C.21. Summary of chronic risks to ecological receptors due to deposition of uranium on surface water under bounding accident scenarios (continued)

Alternative	Accident scenario	Site	Frequency	Chemical exposure			Radiation exposure		
				Maximum HQ	Consequence level	Risk	Maximum HQ	Consequence level	Risk
Foreign sales	Facility fire	Generic	Extremely unlikely	2.5E-04	Negligible	Negligible	5.3E-05	Negligible	Negligible
	Seismic (direct release)	Generic		8.7E-05	Negligible	Negligible	1.9E-05	Negligible	Negligible
	Seismic (fire)	Generic		5.3E-05	Negligible	Negligible	1.1E-05	Negligible	Negligible

DOE = U.S. Department of Energy.
HQ = hazard quotient.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

Risks to terrestrial plants, soil invertebrates, and consumers of contaminated soil, plants, and invertebrates were evaluated. The indicator receptors for these groups were plants, earthworms, and short-tailed shrews and American robins, respectively. Chronic chemical toxicity and radiation dose were assessed. The consequences of chemical toxicity to plants were negligible or low; consequences of chemical toxicity to other receptors and of radiation dose to all receptors were negligible.

Risks to terrestrial aquatic biota, benthic invertebrates, and animal consumers of contaminated surface water, sediment, aquatic biota, and benthic invertebrates were evaluated. The indicator receptor animal was the great blue heron. Chronic chemical toxicity and radiation dose were assessed. Under all alternatives, all types of consequences were negligible for all receptors.

Consequence levels were combined with the expected frequency of occurrence of the associated accidents to determine the overall risk to ecological receptors from each alternative. Overall risks were negligible or low for all alternatives.

C.6 REFERENCES

Baes, C. F., III, Sharp, R. D., Sjoren, A. L., and Shor, R. W. 1984. *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture,* ORNL-5786, Oak Ridge National Laboratory, Oak Ridge, TN.

Blaylock, B. G., Frank, M. L., and O'Neal, B. R. 1993. *Methodology for Estimating Radiation Dose Rates to Freshwater Biota Exposed to Radionuclides in the Environment,* ES/ER/TM-78, Oak Ridge National Laboratory, Oak Ridge, TN.

DOE (U.S. Department of Energy). 1988. *Health Physics Manual of Good Practices for Uranium Facilities*, EGG-2530, U.S. Department of Energy, prepared by Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID.

DOE (U.S. Department of Energy). 1997. *Report on the Remedial Investigation of Bear Creek Valley at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee,* DOE/OR/01-1455/V6&D2, U.S. Department of Energy, Office of Environmental Management, Oak Ridge, TN.

Efroymson, R. A., Will, M. E., Suter II, G. W., and Wooten, A. C. 1997. *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision,* ES/ER/TM-85/R3, Lockheed Martin Energy Systems, Oak Ridge National Laboratory, Oak Ridge, TN.

Efroymson, R. A., Will, M. E., and Suter II, G. W. 1997, *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process: 1997 Revision,* ES/ER/TM-126/R2, Lockheed Martin Energy Systems, Oak Ridge National Laboratory, Oak Ridge, TN.

EPA (U.S. Environmental Protection Agency). 1988. *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, Federal Guidance Report No. 11, EPA-520/1-88-020, U.S. Environmental Protection Agency, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1989. *Risk Assessment Guidance Part A. for Superfund Volume I: Human Health Evaluation Manual*, EPA/540/1-89/002, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1993a. *External Exposure to Radionuclides in Air, Water, and Soil*, Federal Guidance Report No. 12, EPA-402-R-93-081, U.S. Environmental Protection Agency, Washington, D.C.

EPA. (U.S. Environmental Protection Agency). 1993b. *Wildlife Exposure Factors Handbook*, Vol. I of II, EPA/600/R-93/187a U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Office of Research and Development, Washington, D.C.

EPA. (U.S. Environmental Protection Agency). 1999. *Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (Peer Review Draft), EPA 530-D-99-001A, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

Hanna, S. R., Briggs, G. A., and Hosker Jr., R. P. 1982. *Handbook on Atmospheric Diffusion,* DOE/TIC-11223, U.S. Department of Energy , Office of Health and Environmental Research, Office of Energy Research, Washington, D.C.

IAEA (International Atomic Energy Agency). 1992. *Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards,* IAEA Technical Report Series 332, Vienna, Austria.

Jones, D. S., Suter II, G. W., and Hull, R. N. 1997. *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Sediment-Associated Biota: 1997 Revision,* ES/ER/TM-95/R4, Lockheed Martin Energy Systems, Oak Ridge National Laboratory, Oak Ridge, TN.

NRC (Nuclear Regulatory Commission). 1992. *Residual Radioactive Contamination from Decommissioning,* NUREG/CR-5512. U.S. Nuclear Regulatory Commission, Washington, D.C.

Pasquill, F. 1974. *Atmospheric Diffusion,* John Wiley, New York.

Sample, B. E., Opresko, D. M., and Suter II, G.W. 1996. *Toxicological Benchmarks for Wildlife: 1996 Revision,* ES/ER/TM-86/R3, Lockheed Martin Energy Systems, Oak Ridge National Laboratory, Oak Ridge, TN.

Sample, B. E., Aplin, M. S., Efroymson, R. A., Suter II, G. W., and Welsh, C. J. E. 1997. *Methods and Tools for Estimation of the Exposure of Terrestrial Wildlife to Contaminants,* ORNL/TM-13391, Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN.

Suter, G. W. II, and Tsao, C. L. 1996. *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision,* ES/ER/TM-96/R2, Lockheed Martin Energy Systems, Oak Ridge National Laboratory, Oak Ridge, TN.