APPENDIX C

ANALYSIS OF ACCIDENT IMPACTS TO NATURAL RESOURCES

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APPENDIX C

ANALYSIS OF ACCIDENT IMPACTS TO NATURAL RESOURCES

C.1 INTRODUCTION

This appendix describes the methods that were used to analyze impacts to natural resources resulting from an evaluation-basis earthquake (EBE) under the preferred and no action alternatives. The EBE scenario was selected for analysis because it would result in the most catastrophic contaminant release of the three bounding accidents described in Section 4.1.3. Additionally, the EBE accident scenario under the proposed action and the no action alternative would be the same. Therefore a single analysis was performed for both alternatives.

C.2 SURFACE WATER ANALYSIS METHODOLOGY

Impacts to surface water were evaluated by estimating the amounts of radiological and non-radiological constituents that would be introduced into the water bodies described in the affected environment (Chap. 3). Using estimated amounts of released constituents from the various waste streams (provided to Science Applications International Corporation) and activities (such as on-site accidents, on-site treatment, and on-site storage activities) estimated concentrations of the constituents in the receiving surface water were calculated and compared to existing water quality benchmarks. The first choice for water quality benchmarks was Commonwealth of Kentucky water quality criteria [401 *Kentucky Administrative Regulations* (*KAR*) 5:031. Surface water standards], followed by National Water Quality Criteria [U.S. Environmental Protection Agency (EPA) 1999]. If benchmarks were not available from either of these sources, the third choice for a benchmark was EPA Tier II Secondary Chronic Values (Suter and Tsao 1996). The discussion of the quantitative approach to this method is contained in the following section describing the analysis method for aquatic biota. In addition to this quantitative approach, qualitative estimates of water quality were performed for any activities that could result in soil erosion and runoff with subsequent impacts on sedimentation and siltation.

C.3 AQUATIC BIOTA ANALYSIS METHODOLOGY

Aquatic biota may be exposed to external radiation from radionuclides dissolved in surface water or attached to sediments, or by internal radiation from ingested radionuclides. Aquatic biota are exposed to non radionuclides by direct uptake from the surface water and sediment via direct contact, or by ingestion of contaminants. In the aquatic scenario, it is assumed that all of the liquid released travels into the Ohio River, where it is diluted by one day's flow of water. The evaluation of impacts to aquatic biota is restricted to potential consequences of the exposure scenarios.

C.3.1 Radionuclide Content of Wastes

The composition of wastes in the various storage containers varies. For this evaluation, it is assumed that equal proportions of each waste stream would be released. Under the earthquake scenario, it is assumed that 5% of the radioactivity in liquid waste is released. The total volume, mass, and activity of the seven radionuclides reported in the waste are presented in Table C.1, along with the activity of each that is assumed to be discharged by an earthquake-related spill.

Table C.1. Analysis of radionuclide exposure to aquatic and terrestrial biota under the earthquake scenario for accidental release

	Radionuclides						
	Am-241	**Cs-137**	**Np237**	**Pu-239**	**Tc-99**	**Th-230**	**U**
Volume (m^3)	5.42E+02	5.08E+02	3.69E+01	5.45E+02	8.92E+02	3.40E+01	7.81E+02
Mass (g)	5.42E+08	5.08E+08	3.69E+07	5.45E+08	8.92E+08	3.40E+07	7.81E+08
Activity (pCi)	1.72E+09	5.49E+07	1.84E+11	6.40E+11	1.46E+13	7.92E+09	9.66E+10
Activity (Ci)	1.72E-03	5.49E-05	1.84E-01	6.40E-01	1.46E+01	7.92E-03	9.66E-02
pCi spilled (5%)	8.59E-05	2.74E-06	9.19E-03	3.20E-02	7.29E-01	3.96E-04	4.83E-03
Aquatic scenario							
River conc. (pCi/L)	1.83E-04	5.84E-06	1.95E-02	6.81E-02	1.55E+00	8.43E-04	1.03E-02
Benchmark (pCi/L)	1.17E+03	7.27E+03	1.34E+03	1.25E+03	1.94E+06	4.13E+02	4.00E+03
Ratio	1.56E-07	8.03E-10	1.46E-05	5.45E-05	7.99E-07	2.04E-06	2.57E-06
Terrestrial scenario							
Soil conc. (pCi/g)	8.26E-03	2.64E-04	8.83E-01	3.08E+00	7.01E+01	3.81E-02	4.64E-01
Paducah Site NFA benchmark (pCi/g)	9.75E+02	1.24E+03	1.68E+03	2.03E+03	6.57E+03	3.99E+03	1.06E+03
Ratio	1.60E-10	1.26E-10	9.29E-11	7.69E-11	2.38E-11	3.91E-11	1.47E-10
Small mammal benchmark (pCi/g)	2.84E+03	6.99E+02	9.84E+02	4.96E+04	1.45E+03	2.27E+04	3.84E+02
Ratio	2.91E-06	1.18E-05	8.39E-06	1.66E-07	5.69E-06	3.64E-07	2.15E-05
Songbird benchmarks (pCi/g)	5.47E+03	1.72E+03	4.40E+03	5.67E+06	2.40E+03	1.05E+06	3.42E+03
Ratio	5.31E-10	1.69E-09	6.61E-10	5.13E-13	1.21E-09	2.77E-12	8.50E-10

NFA = no further action

C.3.2 Radionuclide Exposure in Surface Water

The risk to aquatic receptors in the Ohio River was estimated by using screening benchmarks. For a comparison of potential impacts to the benchmarks, it was necessary to estimate the concentrations of radionuclides diluted in the river after the spill.

The estimated flow rate in the river is 4.7×10^{11} L/24 h [U.S. Geological Survey (USGS) 2000]. The total released activity of each radionuclide was divided by this volume. The resulting concentration of each radionuclide in the river is given in Table C.1. Although the vast majority of the waste released into the river would move downstream in a short time, a portion of this activity could be deposited in sediment and would remain at one location for longer than the water. To ensure a conservative evaluation of risks to aquatic biota in the Ohio River, benchmarks for chronic exposure of aquatic biota were used.

C.3.3 Radionuclide Effects Benchmarks for Surface Water

The International Council on Radiation Protection (ICRP 1977) recommended screening levels of 0.1 rad/day for terrestrial animals and 1 rad/day for aquatic receptors. The National Council on Radiation Protection and Measurement (NCRP) also recommends a screening level of 1 rad/day for aquatic biota (NCRP 1991). A screening level of 1 rad/d was used in the preparation of screening benchmarks. Screening benchmarks for radionuclides in water were prepared by the Oak Ridge National Laboratory for the U.S. Department of Energy (DOE) [Bechtell Jacobs Company, LLC (BJC) 1998]. These benchmarks include external exposure by immersion in water and resting on sediment as well as ingestion of water, sediment, and prey that have also been exposed. The benchmark values for most of the radionuclides (plus daughters) range from 1170 pCi/L to 7270 pCi/L (Table C.1).

C.3.4 Results of Radionuclide Exposure Screening for Surface Water

As shown in Table C.1, the ratios of modeled exposure concentrations to benchmark concentrations of individual radionuclides in the Ohio River are all below 6×10^{-5} . The sum of the ratios (the total risk) is about 7.5×10^{-5}. This value is far below any concentration that could cause chronic radiation damage. In addition, the benchmarks are for chronic exposure, and conditions for chronic exposure are not likely to occur. Therefore, the earthquake scenario is highly unlikely to cause harm to aquatic biota in the Ohio River as a result of exposure to radionuclides.

Aquatic receptors in Bayou and Little Bayou Creeks and other water conveyances by which the waste would reach the Ohio River would likely be killed by the caustic nature of the waste. Radiation exposure to any survivors would be of an acute nature; ecological risk models for acute radiation of biota are not available, but it has been estimated that an acute dose of 24 rad/d is unlikely to cause long-term damage to aquatic snails (NCRP 1991). Assuming that 5% of the waste inventory is released, approximately 30,000 L of liquid would proceed down the conveyances. The concentration of radionuclides in this liquid would be on the order of 25 million pCi/L, about four orders of magnitude above benchmarks for chronic exposure of aquatic biota and probably about 1000-fold above benchmarks for acute toxicity. Therefore, it is likely that a spill of waste that travels undiluted to the Ohio River would cause acute lethality to all aquatic biota in its path until it is diluted in the Ohio River.

C.3.5 Chemical Content of Wastes

The composition of wastes in the various storage containers varies. For this evaluation, it is assumed that equal proportions of each waste stream would be released. Under the earthquake scenario, it is assumed that 5% of the chemical in liquid waste is released. The total volume and mass of the nine chemicals (six organics and three inorganics) reported in the waste are presented in Table C.2 along with the amount of each that is assumed to be discharged by an earthquake-related spill.

C.3.6 Chemical Exposure in Surface Water

The risk to aquatic receptors in the Ohio River was estimated initially by using screening benchmarks. For a comparison of potential impacts to the benchmarks, it was necessary to estimate the chemical concentrations diluted in the river after the spill.

The estimated flow rate in the river is 4.7×10^{11} L/24 h (USGS 2000). The total released mass of each chemical was divided by this volume. The resulting concentration of each chemical in the river is given in Table C.2. Although the vast majority of the waste released into the river would move downstream in a short time, a portion of the constituents could be deposited in sediment and would remain at one location for longer than the water. To ensure a conservative evaluation of risks to aquatic biota in the Ohio River, benchmarks for chronic exposure of aquatic biota were used.

C.3.7 Chemical Effects Benchmarks for Surface Water

The first choice for water quality benchmarks was Commonwealth of Kentucky water quality criteria (401 *KAR* 5:031. Surface water standards), followed by National Water Quality Criteria (EPA 1999). If benchmarks were not available from either of these sources, the third choice for a benchmark was EPA Tier II Secondary Chronic Values (Suter and Tsao 1996). If the estimated concentrations of constituents in the surface water exceed the water quality benchmarks, aquatic biota would be assumed to be at potential risk and would be further scrutinized using a weight-of-evidence analysis by considering factors such as the quality and quantity of habitat, bioaccumulation potential of the constituent and its bioavailability, and magnitude of the exceedance of the benchmark to evaluate whether the potential for adverse impacts is credible. Thus, even though a constituent concentration might exceed the toxicity benchmark, the weight of evidence analysis might indicate that mitigating factors reduce the potential adverse impacts to levels below concern.

C.3.8 Results of Chemical Exposure Screening for Surface Water

As shown in Table C.2, the ratios of modeled exposure concentrations to benchmark concentrations of individual chemicals are all below 4.15×10^{-2} except for polychlorinated biphenyls (PCBs), which has a ratio of 2.08. The weight of evidence analysis indicates that the magnitude of this ratio barely exceeds 1. In addition, PCBs, especially those with higher percentages of chlorination (e.g., aroclors 1254 or 1260), have low solubilities in water. In addition, PCBs are strongly adsorbed to sediments and particulates (EPA 1980) so the total concentration in surface water most likely represents particle- or organic-bound fractions that are not very bioavailable for uptake. Thus, even though there is PCB in the surface water, the low amount relative to the conservative benchmark and likely unavailability of that PCB to aquatic biota makes it unlikely to present adverse concentration of the biota. Therefore, the earthquake scenario is highly unlikely to cause harm to aquatic biota in the Ohio River as a result of exposure to chemical constituents.

However, aquatic receptors in Big and Little Bayou Creeks and other water conveyances by which the waste would reach the Ohio River would likely suffer acute mortality due to the caustic nature of the waste. Assuming that 5% of the waste inventory is released, approximately 30,000 L of liquid would proceed down the conveyances. Therefore, it is likely that a spill of waste that travels undiluted to the Ohio River would cause acute lethality to all aquatic biota in its path until it is diluted. Recovery of the biota via recolonization from the Ohio River should be rapid (days to weeks), however, because the transient pH pulse would not leave contaminants in the water or sediment.

Table C.2. Chemical constituent concentrations released into aquatic and terrestrial ecosystems after the earthquake accident scenario at Paducah

	Organic constituents						Inorganic constituents		
	1,1,1-Tri-chloroethane	**1,2,4-Tri-chlorobenzene**	**Polychlorinated biphenyls**	**Trichloroethene**	**Total petroleum hydrocarbons**	**Xylene**	**Cadmium**	**Chromium**	**Lead**
Volume (m^3)	5.08E+02	5.08E+02	7.84E+02	1.03E+02	5.08E+02	5.08E+02	1.05E+02	1.05E+02	1.03E+02
Mass (g)	1.22E+05	5.08E+03	2.74E+05	0.00E+00	1.13E+08	8.64E+01	5.25E+05	5.25E+05	5.15E+05
g spilled (5%)	6.10E+03	2.54E+02	1.37E+04	0.00E+00	5.66E+06	4.32E+00	2.63E+04	2.63E+04	2.58E+04
Aquatic scenario									
River conc. (µg/L)	1.30E-02	5.40E-04	2.91E-02	0.00E+00	1.21E+01	9.19E-06	5.59E-02	5.59E-02	5.48E-02
Benchmark (µg/L)	5.28E+02	4.49E+01	1.40E-02	4.70E+01	None	1.80E+00	1.42E+00	1.10E+01	1.32E+00
Ratio	2.46E-05	1.20E-05	**2.08E+00**	0.00E+00	No benchmark	5.10E-06	3.93E-02	5.08E-03	4.15E-02
Terrestrial scenario									
Soil conc. (mg/kg)	5.86E-01	2.44E-02	1.32E+00	0.00E+00	5.45E+02	4.15E-04	2.52E+00	2.52E+00	2.48E+00
Paducah Site NFA benchmark (mg/kg)	None	1.00E-02	2.00E-02	1.00E-03	None	5.00E-02	1.10E-01	4.00E-02	2.00E+01
Ratio	No benchmark	**2.44E+00**	**6.58E+01**	0.00E+00	No benchmark	8.30E-03	**2.29E+01**	**6.31E+01**	1.24E-01

Ratios in **bold** exceed 1.0, and thus exceed toxicity benchmarks

Aquatic benchmarks are either *KAR* water quality standard (1st choice), National Ambient Water Quality Criteria (2nd choice), or US EPA Tier II secondary chronic values (3rd choice)

NFA = no further action

C.4 TERRESTRIAL BIOTA ANALYSIS METHODOLOGY

Terrestrial receptors are exposed to external radiation from soil and to internal radiation through the food chain. External exposure to beta- and gamma-radiation is evaluated because alpha particles rarely have the power to penetrate skin. Internal radiation results from retention in tissues of radionuclides taken up directly from soil or in food that has incorporated radioactivity. Potential risks to plants, soil-dwelling invertebrates (earthworms), soil-dwelling small mammals [short-tailed shrew (*Blarina brevicauda*), and songbirds such as American robin (*Turdus migratorius*)] were evaluated for the terrestrial exposure scenario. Shrews and robins were chosen because their high level of consumption of earthworms and other soil invertebrates, as well as the accompanying soil, gives them a relatively higher exposure to soil contaminants than most other receptors. All receptors were assumed to spend all of their time in the affected area, so their dietary intake in this evaluation comes solely from the affected soil. It was assumed that if this worst-case screening evaluation indicates no important radiological exposure of the biota, it is not necessary to do a detailed evaluation at other trophic levels.

C.4.1 Radionuclide Content of Wastes

The composition of wastes in the various storage containers varies. For this evaluation, it is assumed that equal proportions of each waste stream would be released. Under the earthquake scenario, it is assumed that 5% of the radioactivity in liquid waste is released. The total volume, mass, and activity of the seven radionuclides reported in the waste are presented in Table C.1, along with the activity of each that is assumed to be discharged by an earthquake-related spill.

C.4.2 Radionuclide Exposure in Soil

Terrestrial biota are exposed to both external radiation from the soil in which they live or on which they forage. External exposure for soil-dwelling biota can include both subsurface and surface exposure. External exposure to beta- and gamma-radiation is evaluated because alpha particles rarely have the power to penetrate skin. Internal radiation results from retention in tissues of radionuclides taken up directly from soil or in food that has incorporated radioactivity. All receptors were assumed to spend all of their time in the affected area, so their dietary intake in this evaluation comes solely from the affected soil.

To estimate soil concentrations under the earthquake conditions, it was assumed that all of the liquid, containing several radionuclides, is absorbed into the top 20 cm of the 180 m-square storage area. It was assumed that the soil density is 1.6 g/cc. The affected mass of soil would be 1.8×10^4 cm × 1.8×10^4 cm × 20 cm × 1.6 g/cc = 1.04×10^{10} g. Therefore, the average concentration of each radionuclide in soil could be calculated by dividing the total activity by the mass of soil in which it is assumed to be distributed. These values were used for the screening evaluation and are shown in table C.1.

C.4.3 Radionuclide Effects Benchmarks for Soil

The ICRP (1977) recommended screening levels of 0.1 rad/day for terrestrial animals and 1 rad/day for aquatic receptors. The NCRP also recommends a screening level of 1 rad/day for aquatic biota (NCRP 1991). The International Atomic Energy Agency has stated that a chronic dose of 0.1 rad/day is unlikely to be harmful to populations of terrestrial animals and a chronic dose of 1 rad/day is unlikely to be harmful to populations of terrestrial plants and invertebrates (IAEA 1992). Paducah Gaseous Diffusion Plant site (PGDP) no further action (NFA) levels for contaminants in soil have been calculated (DOE 2000). In the screening risk assessment method for radionuclides an upper limit of 0.1 rad/d for terrestrial biota was chosen. To be consistent with this document and NCRP recommendations, the chosen screening levels for whole-organism doses were 1 rad/d for aquatic organisms and 0.1 rad/day to all terrestrial organisms.

C.4.4 Results of Radionuclide Exposure Screening for Soils

To screen exposures to soil radionuclides, PGDP NFA levels for radionuclides in soil were used. These levels were assumed not to cause harm to ecological populations at Paducah (DOE 2000). Soil concentrations, screening benchmarks, and results for individual radionuclides are shown in Table C.1. The scenario for chronic radionuclide exposure as a result of the modeled worst-case spill indicated that the sum of chronic terrestrial exposures would be about 7×10^{-10} of the tolerable daily radiation dose as indicated by NFA levels. Therefore, in even this worst-case accident scenario, long-term radiation effects to soil biota would be negligible.

C.4.5 Chemical Exposure in Soil

Terrestrial biota are exposed to both external radiation from the soil in which they live or on which they forage. All receptors were assumed to spend all of their time in the affected area.

Just as with radionuclides, in order to estimate soil concentrations under the earthquake conditions it was assumed that all of the liquid, containing several radionuclides, is absorbed into the top 20 cm of the 180 m-square storage area. It was assumed that the soil density is 1.6 g/cc. The affected mass of soil would be 1.8×10^4 cm × 1.8×10^4 cm × 20 cm × 1.6 g/cc = 1.04×10^{10} g. Therefore, the average concentration of each radionuclide in soil could be calculated by dividing the total activity by the mass of soil in which it is assumed to be distributed. These values were used for the screening evaluation and are shown in table C.2.

C.4.6 Chemical Effects Benchmarks for Soil

To screen exposures to soil chemicals, PGDP NFA levels for chemicals in soil were used (Table C.2). These levels were assumed not to cause harm to ecological populations at Paducah (DOE 2000). Two of the chemicals, total petroleum hydrocarbons and 1,1,1-trichloroethane, did not have PGDP NFA values.

C.4.7 Results of Chemical Exposure Screening for Soils

Soil concentrations, screening benchmarks, and ratios of the soil concentrations to screening benchmarks are shown in Table C.2. Two organics (PCBs and 1,2,4-trichlorobenzene) and two inorganics (cadmium and chromium) had modeled concentrations that exceeded the PGDF NFA benchmarks. PCBs in soil exceed the PGDF NFA benchmark by the largest ratio (65.8), followed by chromium (63.1). The soil cadmium modeled concentration exceeded the PGDF NFA benchmark by a ratio of 22.9. These ratios indicate that these constituents potentially pose adverse impacts to soil biota if the worst case spill accident occurred and are candidates for further weight of evidence analysis.

Although the concentrations of four constituents in soil exceed the PGDP NFA concentrations, the lack of suitable habitat for terrestrial receptors within the fenced portion of the PGDP and the spill area diminish potential adverse impacts because receptors would essentially be absent. The lack of suitable habitat within the PGDP and its large contribution to minimal risks to terrestrial receptor is further enhanced by the abundance of suitable habitat surrounding the fenced portion of PGDP, thereby providing alternative habitat for receptors. Thus, even though PCBs, 1,2,4-trichlorobenzene, cadmium, and chromium concentrations in the soil could exceed the conservative PGDP NFA benchmarks, the lack of suitable habitat within the fenced PGDP makes it unlikely to present adverse impacts of the biota. Furthermore, it is assumed that the contaminated soils from the accident would be quickly cleaned up or removed to minimize any potential adverse impacts to biota. Therefore, the earthquake scenario is highly unlikely to cause harm to terrestrial biota as a result of exposure to chemical constituents.