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Derivation of Uranium Residual Radioactive Material Guidelines for the Elza Gate Site

by

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Summary

Residual radioactive material guidelines for uranium were derived for a large, homogeneously contaminated area at the Elza Gate Site in Oak Ridge, Tennessee. This site has been identified for remedial action under the Formerly Utilized Sites Remedial Action Program (FUSRAP) of the U.S. Department of Energy (DOE). The derivation of the single-nuclide and total uranium guidelines was based on the requirement that the 50-year committed effective dose equivalent to a hypothetical individual who lives or works in the immediate vicinity of the Elza Gate Site should not exceed a dose of 100 mrem/yr following decontamination. The DOE residual radioactive material guideline computer code, RESRAD, which implements the methodology described in the DOE manual for implementing residual radioactive material guidelines, was used in this evaluation. Four potential scenarios were considered for the site; the scenarios vary with regard to time spent at the site, sources of water used, and sources of food consumed. The results of the evaluation indicate that the basic dose limit of 100 mrem/yr will not be exceeded for uranium within 1000 years, provided that the soil concentration of uranium at the Elza Gate Site does not exceed the following levels: 1800 pCi/g for Scenario A (industrial worker: the expected scenario); 4000 pCi/g for Scenario B (recreationist: a plausible scenario); 470 pCi/g for Scenario C (resident farmer using pond water as the only water source: a possible but unlikely scenario); and 120 pCi/g for Scenario D (resident farmer using well water as the only water source: a possible but unlikely scenario). The uranium guideline applies to the total activity concentration of uranium isotopes (i.e., uranium-238, uranium-234, and uranium-235 present in their natural activity concentration ratio of 1:1:0.046). Therefore, if uranium-238 is measured as the indicator radionuclide, the respective limits for Scenarios A, B, C, and D would be 880, 2000, 230, and 59 pCi/g. These guidelines are calculated on the basis of a dose of 100 mrem/yr. In setting the actual uranium guideline for the Elza Gate Site, the DOE will apply the as low as reasonably achievable (ALARA) policy to the decision-making process, along with other factors, such as determining whether a particular scenario is reasonable and appropriate.

1 Introduction and Brief History

The Formerly Utilized Sites Remedial Action Program (FUSRAP) was established in 1974 by the U.S. Atomic Energy Commission (AEC), a predecessor of the U.S. Department of Energy (DOE). The mandate of the program is to identify, evaluate, and, if necessary, decontaminate sites previously used by the AEC or its predecessor, the Manhattan Engineer District (MED).

The Elza Gate Site is located in Oak Ridge, Tennessee (Figure 1). The proposed remedial action for the site will include the excavation of contaminated soil and concrete according to DOE guidelines for residual radioactive material, as established in DOE Order 5400.5 (DOE 1990a), and the transport and long-term management of waste at the DOE's Oak Ridge Reservation. The RESRAD computer code (Gilbert et al. 1989) is used to derive uranium guidelines on a site-specific basis. This report presents the uranium guideline derived for the Elza Gate Site.

1.1 Site Description and Setting

The Elza Gate Site covers an area of about 7 ha (17 acres) and is located in the southeastern part of the city of Oak Ridge, Tennessee, near the intersection of Melton Lake Drive and Oak Ridge Turnpike (Figure 1). The site became contaminated with radioactive materials when the MED, during the early 1940s, and subsequently the AEC, used it to store uranium ore and ore-processing residues. The site is currently also known as the Melton Lake Industrial Park and is owned by MECO Development, a real-estate development company. The site is being developed for use as an industrial park.

The Oak Ridge region is characterized by a ridge and valley topography, with a series of northeast-southwest trending ridges and intervening valleys. The ridges are breached at irregular intervals by stream channels that otherwise follow the trend of the valleys. The ridges in the area reach elevations of approximately 300 m (1000 ft) above mean sea level (MSL). The Elza Gate Site is at an elevation of approximately 250 m (820 ft) above MSL and is about 150 m (500 ft) from the western shore of a tributary of the Clinch River. The Clinch River, which eventually discharges into the Tennessee River, is the source of most of the water used in the Oak Ridge area. A partially stagnant body of water lies to the south of the site. The flood insurance rate map indicates that the site lies outside the 100-year floodplain (Poligone 1990). The soils in the site area are sandy loams.

The climate at Oak Ridge is warm and humid. The summers are dominated by warm, moist air from the Gulf of Mexico. In the winter, cold, dry air masses from Canada are warmed as the air crosses the Cumberland Mountains and moves down the eastern slopes to the Oak Ridge area. Precipitation averages 140 cm (55 in.) annually; the relative humidity averages 70%. The maximum 24-hour rainfall is about 20 cm (8 in.) Approximately 70% of the average annual

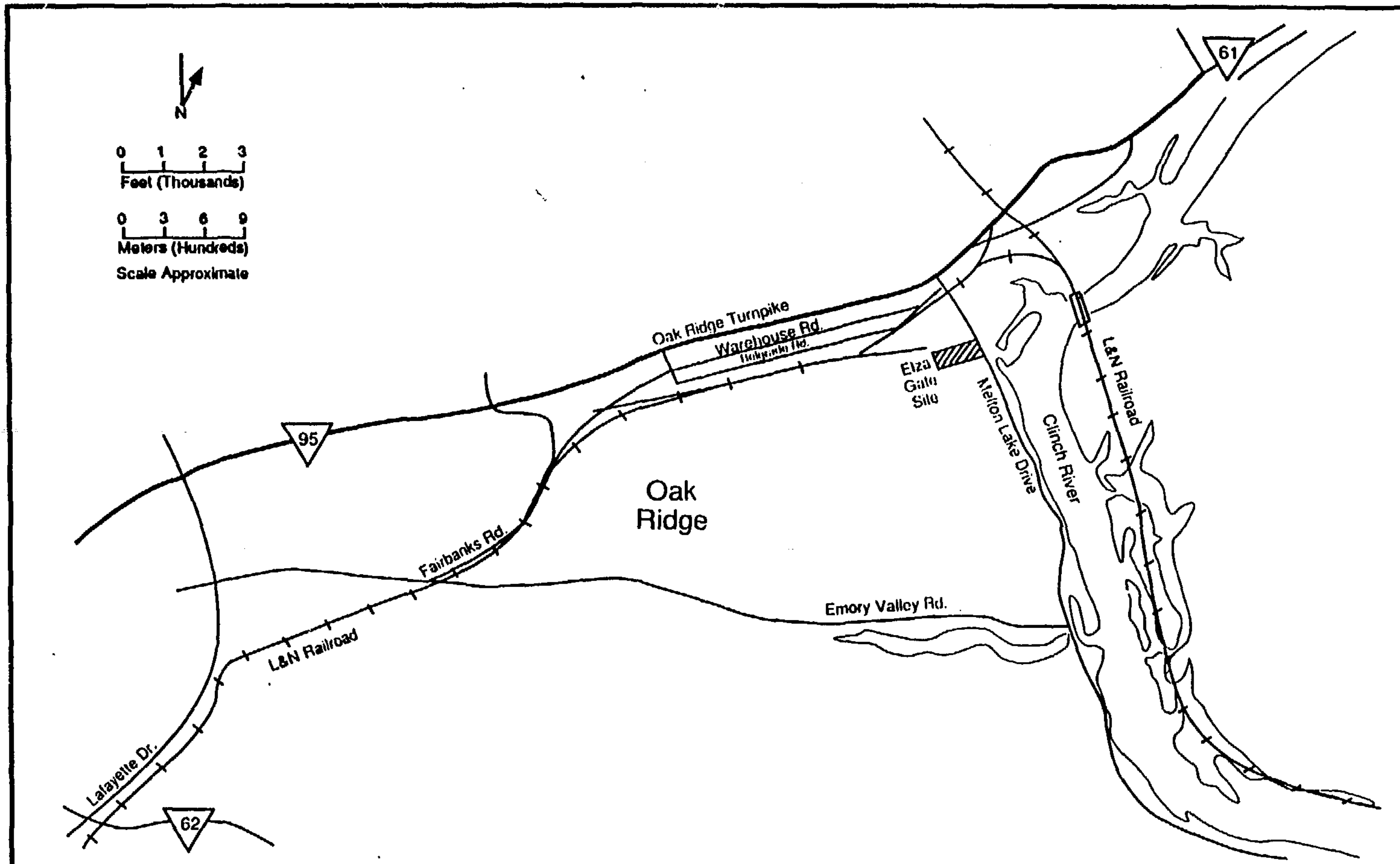

FIGURE 1 Location of the Elza Gate Site (Source: Modified from Bechtel National, Inc. 1990)

precipitation is lost through evapotranspiration, and the rest becomes runoff to surface waters and recharge to the groundwater. Snow is infrequent but sometimes occurs in sufficient quantity to hinder traffic and outdoor activities.

Winds on the ridges blow predominately from the southwest, although winds from the northeast are also frequent. Remnants of hurricanes and tropical storms occasionally affect the area.

1.2 Site History

During the 1940s, the MED used the Elza Gate Site to store pitchblende (a high-grade uranium ore from Africa), residue from ore processing, and other radioactive material. Originally five warehouses were on the site, at least three of which were used for storing radioactive material. One warehouse was used principally for storing uranium slag that was intended for reprocessing. Another held the pitchblende, uranium oxide residues, and tailings. A third warehouse held low-grade ore, which was initially stored in burlap bags. The ore was rebagged on-site. During the MED era, the complex was accessed by a railroad spur located to the southeast of the site and a road that entered from what is now Melton Lake Drive. The railroad has since been removed and has been replaced by an access road between the site and Melton Lake Drive.

In 1946, ownership of the site passed to the AEC, which used the warehouses for storage until they were vacated in 1972.

After a radiological survey and appropriate decontamination by Oak Ridge National Laboratory (ORNL) in 1972, the site was recommended for use without radiological restrictions (Sapirie 1972). The property was then relinquished by the AEC in 1972, and title to the property was assumed by the city of Oak Ridge. That same year, the city sold the property to Jet Air, Inc., which in turn sold it to MECO Development in 1988. The site is divided into nine parcels (Figure 2). The concrete pads from MED warehouses remain on parcels 1 through 4.

In 1987, at the request of the Tennessee Department of Health and Environment, Oak Ridge Associated Universities (ORAU) (Egli 1988) conducted a survey at the site because of the possibility of contamination from Jet Air, Inc.'s metal plating facility. The survey confirmed the presence of heavy metal contamination. In addition, uranium was discovered in concentrations above background level in the soil in some areas.

In 1988, MECO Development added offices to the structure built by Jet Air, Inc., and constructed a new access road along the south side of the concrete pads for the purpose of developing the property for lease and sale as an industrial park. In October 1988, a preliminary radiological survey of the site was conducted by ORNL. Parcels 1 through 4 and the original site access road were found to exceed the criteria (Cottrell et al. 1989) for declaring the site eligible for remediation consideration under FUSRAP. As a result, on November 30, 1988, the entire Melton Lake Industrial Park was authorized for inclusion in FUSRAP (Fiore 1988).

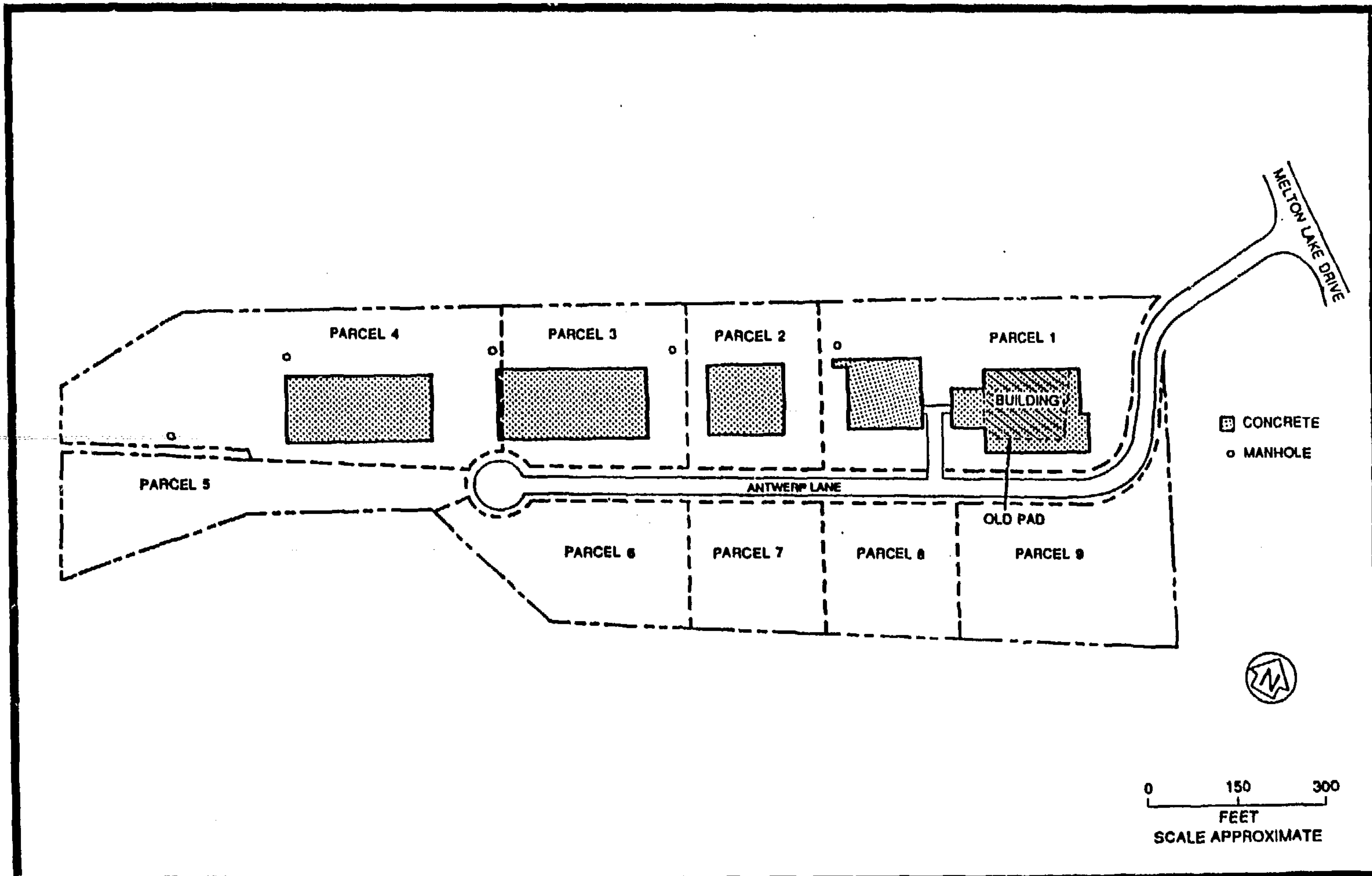

FIGURE 2 Plan View of the Elza Gate Site (Source: Bechtel National, Inc. 1988)

Radiologically contaminated soil areas at the site are shown in Figure 3. The total site area of 70,600 m^2 (84,400 yd^2) is used in the analysis to derive homogeneous soil guidelines for uranium.

The only on-site structure is currently occupied by a company that manufactures storage containers for low-level radioactive waste. Modification of the property can be expected to continue as it is sold or leased. Previous remedial action activities and the present site conditions are described in the environmental documentation being prepared for the site (DOE 1990b).

1.3 Derivation of Cleanup Guidelines

Although most DOE cleanup guidelines applicable to remedial actions at FUSRAP sites are generic in nature (DOE 1990a), guidelines for uranium are derived on a site-specific basis. The purpose of this report is to derive the residual radioactive material guidelines for uranium (i.e., uranium-234, uranium-235, or uranium-238) that are applicable to remedial action at the Elza Gate Site; that is, the residual concentration of uranium in a homogeneously contaminated area that must not be exceeded if the site is to be released for use without radiological restrictions. The total uranium guideline is also derived by assuming that uranium-238, uranium-234, and uranium-235 are present in their natural activity concentration ratio of 1:1:0.046. The derivation of site-specific uranium guidelines for the Elza Gate Site is based on a dose limit of 100 mrem/yr (DOE 1990a), assuming that uranium is the only radionuclide present at an above-background concentration. The RESRAD computer code, which implements the methodology described in the DOE manual for implementing residual radioactive material guidelines (Gilbert et al. 1989), was used to derive these guidelines.

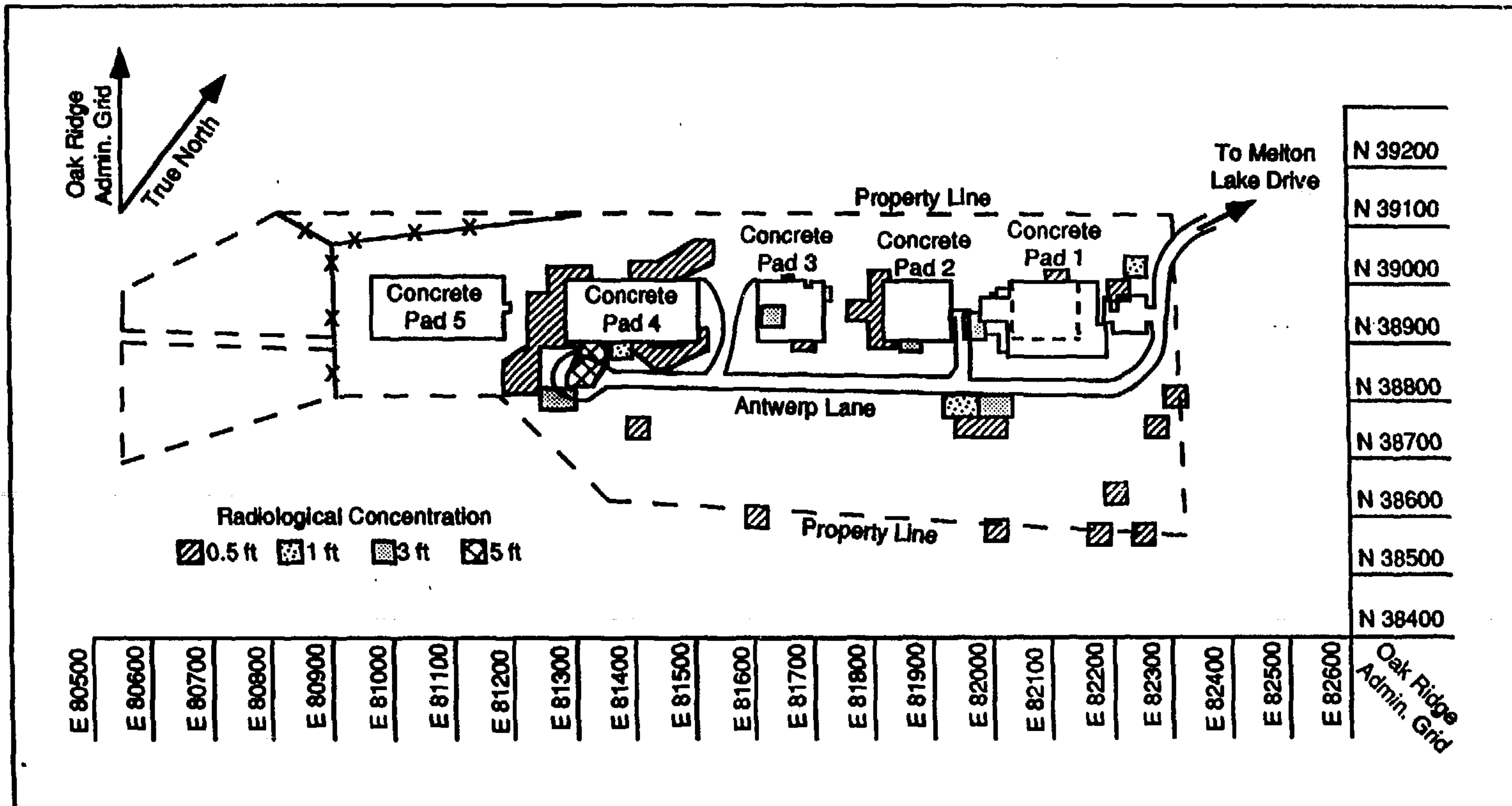

FIGURE 3 Radiologically Contaminated Soil Areas at the Elza Gate Site (Source: Modified from Liedle 1990

2 Scenario Definition

Four potential exposure scenarios are considered for the Elza Gate Site. All scenarios assume that, at some time within 1000 years, the site will be released for use without radiological restrictions following decontamination.

Scenario A (the expected scenario) assumes industrial use of the site. A hypothetical person is assumed to work in the area of the site for 8 hours per day (6 hours outdoors and 2 hours indoors), 5 days per week, 50 weeks per year. The industrial worker does not ingest drinking water, plant foods, or fish from the decontaminated area, or ingest meat or milk from livestock raised in the decontaminated area.

Scenario B (a plausible scenario) assumes recreational use of the site. It is assumed that, at some time in the future, the site will be used as a public park. A hypothetical person spends 15 hours per week, 50 weeks per year in the decontaminated area of the park. The recreationist does not ingest drinking water, plant foods, or fish from the decontaminated area, or ingest meat or milk from livestock raised in the decontaminated area.

Scenario C (a possible but unlikely scenario) assumes a resident farmer in the immediate vicinity of the site who drinks water obtained from a pond adjacent to and downstream of the decontaminated area, ingests plant foods grown in a garden in the decontaminated area, and ingests meat and milk from livestock raised in the decontaminated area. All water used by the farmer is drawn from the pond adjacent to the decontaminated area. The individual also ingests fish taken from the pond.

Scenario D (a possible but unlikely scenario) also assumes a resident farmer, except that groundwater drawn from a well located at the downgradient edge of the contaminated zone is the only water source for drinking, irrigation, and raising livestock.

Potential radiation doses resulting from eight exposure pathways are analyzed: (1) direct exposure to external radiation from the decontaminated soil material, (2) internal radiation from inhalation of contaminated dust, (3) internal radiation from inhalation of emanating radon-222, (4) internal radiation from ingestion of plant foods grown in the decontaminated area and irrigated with water drawn from the pond or well adjacent to the decontaminated area on the downgradient side, (5) internal radiation from ingestion of meat from livestock fed with fodder grown in the decontaminated area and water drawn from the pond or well, (6) internal radiation from ingestion of milk from livestock fed with fodder grown in the decontaminated area and water drawn from the pond or well, (7) internal radiation from ingestion of aquatic food (fish) from the pond, and (8) internal radiation from drinking water drawn from the pond or well.

The following assumptions were made in using the RESRAD computer code (Gilbert et al. 1989) to calculate the potential radiation doses to the hypothetical future industrial worker, recreationist, or resident farmer.

- The resident farmer spends 50% of his or her time indoors in the decontaminated area, 25% outdoors in the decontaminated area, and 25% away from the decontaminated area. The industrial worker spends 2000 hours per year on-site (25% indoors and 75% outdoors). The recreationist spends 750 hours per year on-site, all outdoors.

- The walls, floor, and foundation of the house or office building reduce external exposure by 30%; the indoor dust level is 40% of the outdoor dust level (Gilbert et al. 1989).

- The depth of the house or building foundation is 1 m below ground surface with an effective radon diffusion coefficient of 2×10^{-8} m^2/s.

- The size of the decontaminated area is sufficiently large such that 50% of the plant food diet consumed by the resident farmer is grown in a garden in the decontaminated area. The industrial worker or recreationist does not consume these plant foods.

- The size of the decontaminated area is large enough to provide sufficient meat and milk for the resident farmer from livestock raised (i.e., foraging) in the decontaminated area. The industrial worker or recreationist does not consume this meat or milk.

- Vegetables are irrigated by and livestock are provided with water drawn from the pond or well located adjacent to the decontaminated area.

- The adjacent pond provides 50% of the aquatic food consumed by the resident farmer. The industrial worker or recreationist does not consume any aquatic food from the decontaminated area.

- The adjacent pond or well provides 100% of the drinking water consumed by the resident farmer. The industrial worker or recreationist does not consume this drinking water.

- After remedial action, no cover material is placed over the decontaminated area.

All pathways considered for Scenarios A, B, C, and D are summarized in Table 1.

TABLE 1 Summary of Pathways for Scenarios A, B, C, and D at the Elza Gate Site[a]

Pathway	Scenario A	Scenario B	Scenario C	Scenario D
External exposure	Yes	Yes	Yes	Yes
Inhalation	Yes	Yes	Yes	Yes
Radon	Yes	Yes	Yes	Yes
Ingestion of plant foods	No	No	Yes	Yes
Ingestion of meat	No	No	Yes	Yes
Ingestion of milk	No	No	Yes	Yes
Ingestion of fish	No	No	Yes	Yes
Ingestion of water[b]	No	No	Yes	Yes

[a]Scenario A, industrial worker; Scenario B, recreationist; Scenarios C and D, resident farmer.

[b]Source of water used: 100% pond water for drinking, irrigation, and livestock for Scenario C; 100% well water for Scenario D.

3 Dose/Source Concentration Ratios

The RESRAD computer code (Gilbert et al. 1989) was used to calculate the dose/source concentration ratio $DSR_{ip}(t)$ for uranium isotope i and pathway p at time t after decontamination. The time frame considered in this analysis was 1000 years. Radioactive decay and ingrowth were considered in deriving the dose/source concentration ratio. The various parameters used in the RESRAD code for this analysis are listed in the Appendix. The calculated maximum dose/source concentration ratios for all pathways are presented in Tables 2 through 5 for Scenarios A, B, C, and D, respectively. For Scenarios A, B, and C, the maximum dose/source concentration ratios would occur at time zero (immediately after decontamination). For Scenario D, the maximum dose/source concentration ratio for uranium isotopes would occur at time 790 years following decontamination. The primary pathway for Scenarios A, B, and C would be inhalation; for Scenario D, the primary pathway would be ingestion of drinking water from the well.

The summation of $DSR_{ip}(t)$ for all pathways p is the $DSR_i(t)$ for the i^{th} isotope, that is,

$$DSR_i(t) = \sum_p DSR_{ip}(t)$$

The total dose/source concentration ratio for total uranium can be calculated as

$$DSR(t) = \sum_i W_i \; DSR_i(t)$$

where W_i is the existing activity concentration fraction at the site for uranium-238, uranium-234, and uranium-235. For this analysis, W_i is assumed to be present in the natural activity concentration ratios of 1/2.046, 1/2.046, and 0.046/2.046 for uranium-238, uranium-234, and uranium-235, respectively. The total dose/source concentration ratios for single nuclides and total uranium are provided in Table 6. These ratios were used to determine the allowable residual radioactivity for uranium at the Elza Gate Site.

TABLE 2 Maximum Dose/Source Concentration Ratios for Scenario A at the Elza Gate Site

Pathway	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Uranium-234	Uranium-235	Uranium-238
External exposure	2.6×10^{-4}	1.9×10^{-1}	2.6×10^{-2}
Inhalation	4.1×10^{-2}	3.8×10^{-2}	3.8×10^{-2}
Radon	0	0	0
Ingestion of plant foods	0	0	0
Ingestion of meat	0	0	0
Ingestion of milk	0	0	0
ingestion of fish	0	0	0
Ingestion of water	0	0	0

[a]Dose/source concentration ratios would occur at time zero (immediately following decontamination); all values are reported to two significant figures.

TABLE 3 Maximum Dose/Source Concentration Ratios for Scenario B at the Elza Gate Site

Pathway	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Uranium-234	Uranium-235	Uranium-238
External exposure	1.1×10^{-4}	7.6×10^{-2}	1.1×10^{-2}
Inhalation	1.9×10^{-2}	1.7×10^{-2}	1.7×10^{-2}
Radon	0	0	0
Ingestion of plant foods	0	0	0
Ingestion of meat	0	0	0
Ingestion of milk	0	0	0
Ingestion of fish	0	0	0
Ingestion of water	0	0	0

[a]Dose/source concentration ratios would occur at time zero (immediately following decontamination); all values are reported to two significant figures.

TABLE 4 Maximum Dose/Source Concentration Ratios for Scenario C at the Elza Gate Site

Pathway	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Uranium-234	Uranium-235	Uranium-238
External exposure	7.5×10^{-4}	5.3×10^{-1}	7.5×10^{-2}
Inhalation	9.7×10^{-2}	9.0×10^{-2}	9.0×10^{-2}
Radon	0	0	0
Ingestion of plant foods	5.7×10^{-2}	5.5×10^{-2}	5.5×10^{-2}
Ingestion of meat	1.4×10^{-2}	1.4×10^{-2}	1.4×10^{-2}
Ingestion of milk	2.0×10^{-3}	1.9×10^{-3}	1.9×10^{-3}
Ingestion of fish	0	0	0
Ingestion of water	0	0	0

[a]Dose/source concentration ratios would occur at time zero (immediately following decontamination); all values are reported to two significant figures.

TABLE 5 Maximum Dose/Source Concentration Ratios for Scenario D at the Elza Gate Site

Pathway	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Uranium-234	Uranium-235	Uranium-238
External exposure	4.2×10^{-3}	2.0×10^{-1}	2.8×10^{-2}
Inhalation	3.7×10^{-2}	5.2×10^{-2}	3.4×10^{-2}
Radon	1.8×10^{-3}	0	1.3×10^{-6}
Ingestion of plant foods	1.3×10^{-1}	2.7×10^{-1}	1.1×10^{-1}
Ingestion of meat	1.0×10^{-1}	2.4×10^{-1}	9.9×10^{-2}
Ingestion of milk	2.3×10^{-2}	2.2×10^{-2}	2.2×10^{-2}
Ingestion of fish	6.2×10^{-4}	1.3×10^{-2}	6.0×10^{-4}
Ingestion of water	5.3×10^{-1}	1.3×10^{0}	5.1×10^{-1}

[a]Dose/source concentration ratios would occur at time 790 years following decontamination; all values are reported to two significant figures.

TABLE 6 Total Dose/Source Concentration Ratios for Uranium at the Elza Gate Site

	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)			
Radionuclide	Scenario A	Scenario B	Scenario C	Scenario D
Uranium-234	4.1×10^{-2}	1.9×10^{-2}	1.7×10^{-1}	8.3×10^{-1}
Uranium-235	2.2×10^{-1}	9.3×10^{-2}	6.9×10^{-1}	2.1×10^{0}
Uranium-238	6.4×10^{-2}	2.8×10^{-2}	2.4×10^{-1}	8.1×10^{-1}
Total uranium	5.7×10^{-2}	2.5×10^{-2}	2.1×10^{-1}	8.5×10^{-1}

[a]All values reported to two significant figures.

4 Residual Radioactive Material Guidelines

The residual radioactive material guideline is defined as the concentration of residual radioactive material that can remain in the decontaminated area and still allow for use of that area without radiological restrictions. Given the DOE annual radiation dose limit of 100 mrem/yr for an individual (DOE 1990a), the residual radioactive material guideline, G, for uranium at the Elza Gate Site can be calculated as

$$G = 100/DSR$$

where DSR is the total dose/source concentration ratio listed in Table 6. The calculated residual radioactive material guidelines for both single radionuclides (uranium-234, uranium-235, and uranium-238) and total uranium are presented in Table 7.

In calculating the total uranium guidelines (reported to two significant figures), it was assumed that the activity concentration ratio of uranium-238, uranium-234, and uranium-235 is 1:1:0.046. The derived guidelines for total uranium would be 1800, 4000, 470, and 120 pCi/g for Scenarios A, B, C, and D, respectively. If uranium-238 is measured as the indicator radionuclide, then the uranium-238 limits for total uranium can be calculated by dividing the total uranium guidelines by 2.046. The resulting limits would be 880, 2000, 230, and 59 pCi/g for Scenarios A, B, C, and D, respectively.

When implementing the derived radionuclide guidelines for decontamination of a site, the law of sum of fractions applies. That is, the summation of the fractions of radionuclide

TABLE 7 Residual Radioactive Material Guidelines for the Elza Gate Site

	Guideline (pCi/g)[a]			
Radionuclide	Scenario A	Scenario B	Scenario C	Scenario D
Uranium-234	2400	5400	590	120
Uranium-235	450	1100	150	47
Uranium-238	1600	3600	430	120
Total uranium	1800	4000	470	120

[a]All values reported to two significant figures.

concentrations S_i remaining on-site, averaged over an area of 100 m^2 (120 yd^2) and a depth of 15 cm (6 in.) and divided by its guideline G_i, should not be greater than unity; that is,

$$\sum_i S_i/G_i \leq 1$$

The derived guidelines listed in Table 7 are for a large, homogeneously contaminated area. For an isolated small area of contamination, the allowable concentration that can remain on-site may be higher than the homogeneous guideline, depending on the size of the area of contamination.

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Appendix:

Parameters Used in the Analysis of the Elza Gate Site

Appendix:

Parameters Used in the Analysis of the Elza Gate Site

The parametric values used in the RESRAD code for the analysis of the Elza Gate Site are listed in Table A.1. All parametric values are reported at up to three significant figures. Some parameters are specific to the Elza Gate Site; other values are generic.

TABLE A.1 Parameters Used in the RESRAD Code for the Analysis of the Elza Gate Site

		Value			
Parameter	Unit	Scenario A	Scenario B	Scenario C	Scenario D
Area of contaminated zone[a]	m^2	70,600	70,600	70,600	70,600
Thickness of contaminated zone	m	1.5	1.5	1.5	1.5
Length parallel to aquifer flow[a]	m	265	265	265	265
Cover depth	m	0	0	0	0
Density of contaminated zone	g/cm^3	1.8	1.8	1.8	1.8
Contaminated zone erosion rate	m/yr	0.0004	0.0004	0.0004	0.0004
Contaminated zone total porosity	-[b]	0.4	0.4	0.4	0.4
Contaminated zone effective porosity	-[b]	0.3	0.3	0.3	0.3
Contaminated zone hydraulic conductivity	m/yr	18.7	18.7	18.7	18.7
Contaminated zone b parameter	-[b]	7.12	7.12	7.12	7.12
Evapotranspiration coefficient	-[b]	0.7	0.7	0.7	0.7
Precipitation	m/yr	1.4	1.4	1.4	1.4
Irrigation	m/yr	0.3	0.3	0.3	0.3
Irrigation mode	-[b]	not used	not used	overhead	overhead
Runoff coefficient	-[b]	0.3	0.3	0.3	0.3
Watershed area for nearby pond	m^2	not used	not used	7,560,000	7,560,000
Density of saturated zone	g/cm^3	2.0	2.0	2.0	2.0
Saturated zone total porosity	-[b]	not used	not used	0.4	0.4
Saturated zone effective porosity	-[b]	not used	not used	0.3	0.3
Saturated zone hydraulic conductivity	m/yr	not used	not used	192	192
Saturated zone hydraulic gradient	-[b]	not used	not used	0.084	0.084
Saturated zone b parameter	-[b]	7.75	7.75	7.75	7.75
Water table drop rate	m/yr	not used	not used	0.0004	0.0004

TABLE A.1 (Cont'd)

Parameter	Unit	Value: Scenario A	Scenario B	Scenario C	Scenario D
Well pump intake depth (below water table)[c]	m	not used	not used	10	10
Model: nondispersion (ND) or mass-balance (MB)	-[b]	not used	not used	ND	ND
Number of unsaturated zone strata	-[b]	not used	not used	2	2
Unsaturated zone 1, thickness	m	not used	not used	1.4	1.4
Unsaturated zone 1, soil density	g/cm^3	not used	not used	1.8	1.8
Unsaturated zone 1, total porosity	-[b]	not used	not used	0.4	0.4
Unsaturated zone 1, effective porosity	-[b]	not used	not used	0.3	0.3
Unsaturated zone 1, soil-specific b parameter	-[b]	not used	not used	7.12	7.12
Unsaturated zone 1, hydraulic conductivity	m/yr	not used	not used	18.7	18.7
Unsaturated zone 2, thickness	m	not used	not used	1.7	1.7
Unsaturated zone 2, soil density	g/cm^3	not used	not used	2.0	2.0
Unsaturated zone 2, total porosity	-[b]	not used	not used	0.4	0.4
Unsaturated zone 2, effective porosity	-[b]	not used	Not used	0.3	0.3
Unsaturated zone 2, soil-specific b parameter	-[b]	not used	not used	7.75	7.75
Unsaturated zone 2, hydraulic conductivity	m/yr	not used	not used	192	192
Distribution coefficient	cm^3/g				
Contaminated zone					
Uranium-234		114	114	114	114
Uranium-235		114	114	114	114
Uranium-238		114	114	114	114
Actinium-227[c,d]		20	20	20	20
Protactinium-231[c,d]		50	50	50	50
Lead-210[c,d]		100	100	100	100
Radium-226[c,d]		70	70	70	70
Thorium-230[d]		276	276	276	276
Unsaturated zone 1					
Uranium-234		114	114	114	114
Uranium-235		114	114	114	114
Uranium-238		114	114	114	114
Actinium-227[c,d]		20	20	20	20

TABLE A.1 (Cont'd)

Parameter	Unit	Value: Scenario A	Scenario B	Scenario C	Scenario D
Protactinium-231[c,d]		50	50	50	50
Lead-210[c,d]		100	100	100	100
Radium-226[c,d]		70	70	70	70
Thorium-230[d]		276	276	276	276
Unsaturated zone 2					
Uranium-234		6.8	6.8	6.8	6.8
Uranium-235		6.8	6.8	6.8	6.8
Uranium-238		6.8	6.8	6.8	6.8
Actinium-227[c,d]		20	20	20	20
Protactinium-231[c,d]		50	50	50	50
Lead-210[c,d]		100	100	100	100
Radium-226[c,d]		70	70	70	70
Thorium-230[d]		276	276	276	276
Saturated zone					
Uranium-234		6.8	6.8	6.8	6.8
Uranium-235		6.8	6.8	6.8	6.8
Uranium-238		6.8	6.8	6.8	6.8
Actinium-227[c,d]		20	20	20	20
Protactinium-231[c,d]		50	50	50	50
Lead-210[c,d]		100	100	100	100
Radium-226[c,d]		70	70	70	70
Thorium-230[d]		276	276	276	276
Inhalation rate[c]	m^3/yr	8400	8400	8400	8400
Mass loading for inhalation[c]	g/m^3	0.0002	0.0002	0.0002	0.0002
Occupancy and shielding factor, external gamma[a]	-[b]	0.21	0.086	0.6	0.6
Occupancy factor, inhalation[a]	-[b]	0.19	0.086	0.45	0.45
Shape factor, external gamma[c]	-[b]	1	1	1	1
Dilution length for airborne dust, inhalation[c]	m	3	3	3	3
Fruit, vegetable, and grain consumption[c]	kg/yr	not used	not used	160	160
Leafy vegetable consumption[c]	kg/yr	not used	not used	14	14
Milk consumption[c]	L/yr	not used	not used	92	92
Meat and poultry consumption[c]	kg/yr	not used	not used	63	63
Fish consumption[c]	kg/yr	not used	not used	5.4	5.4
Other seafood consumption[c]	kg/yr	not used	not used	0.9	0.9
Drinking water intake[c]	L/yr	not used	not used	410	410

TABLE A.1 (Cont'd)

Parameter	Unit	Value: Scenario A	Scenario B	Scenario C	Scenario D
Fraction of drinking water from site[a]	-[b]	not used	not used	1	1
Fraction of aquatic food from site[a]	-[b]	not used	not used	0.5	0.5
Livestock fodder intake for meat[c]	kg/d	not used	not used	68	68
Livestock fodder intake for milk[c]	kg/d	not used	not used	55	55
Livestock water intake for meat[c]	L/d	not used	not used	50	50
Livestock water intake for milk[c]	L/d	not used	not used	160	160
Mass loading for foliar deposition[c]	g/m^3	not used	not used	0.0001	0.0001
Depth of soil mixing layer[c]	m	0.15	0.15	0.15	0.15
Depth of roots[c]	m	not used	not used	0.9	0.9
Groundwater fractional usage (balance from surface water)[a]	-[b]				
Drinking water		not used	not used	0	1
Livestock water		not used	not used	0	1
Irrigation		not used	not used	0	1
Total porosity of the cover material[c]	-[b]	0.4	0.4	0.4	0.4
Total porosity of the house or building foundation[c]	-[b]	0.1	0.1	0.1	0.1
Volumetric water content of the cover material[c]	-[b]	0.05	0.05	0.05	0.05
Volumetric water content of the foundation[c]	-[b]	0.01	0.01	0.01	0.01
Diffusion coefficient for radon gas[c]	m/s				
in cover material		2.0×10^{-6}	2.0×10^{-6}	2.0×10^{-6}	2.0×10^{-6}
in foundation material		2.0×10^{-8}	2.0×10^{-8}	2.0×10^{-8}	2.0×10^{-8}
in contaminated zone soil		2.0×10^{-6}	2.0×10^{-6}	2.0×10^{-6}	2.0×10^{-6}
Emanating power of radon gas[c]	-[b]	0.2	0.2	0.2	0.2
Radon vertical dimension of mixing[c]	m	2.0	2.0	2.0	2.0
Average annual wind speed[c]	m/s	2.0	2.0	2.0	2.0
Average building air exchange rate[c]	1/h	1.0	1.0	1.0	1.0

TABLE A.1 (Cont'd)

Parameter	Unit	Value			
		Scenario A	Scenario B	Scenario C	Scenario D
Height of the building (room)[c]	m	2.5	2.5	2.5	2.5
Bulk density of house or building foundation[c]	g/cm^3	2.4	2.4	2.4	2.4
Thickness of house or building foundation[c]	m	0.15	0.15	0.15	0.15
Building depth below ground surface[c]	m	1.0	1.0	1.0	1.0
Fraction of time spent indoors[a]	-[b]	0.057	0	0.5	0.5
Fraction of time spent outdoors[a]	-[b]	0.171	0.086	0.25	0.25

[a]Values based on site specifications or scenario assumptions.

[b]Parameter is dimensionless.

[c]RESRAD default values.

[d]Radionuclide is a decay product.

Source: Liedle, S.D., 1990, letter from S.D. Liedle (Project Manager-FUSRAP, Bechtel National, Inc., Oak Ridge, Tenn.) to J.S. Devgun (Argonne National Laboratory), Sept. 20, except where indicated by footnotes "a" or "c."