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Argonne National Laboratory
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DERIVATION OF URANIUM RESIDUAL RADIOACTIVE MATERIAL GUIDELINES FOR THE VENTRON SITE

by

C. Loureiro, C. Yu, and L. Jones
Environmental Assessment and Information Sciences Division

March 1992

work sponsored by

U.S. Department of Energy
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SUMMARY

Residual radioactive material guidelines for uranium were derived for the Ventron site in Beverly, Massachusetts. This site has been identified for remedial action under the Formerly Utilized Sites Remedial Action Program of the U.S. Department of Energy (DOE). The derivations for the single radionuclides and the total uranium guidelines were 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 Ventron site should not exceed a dose of 100 mrem/yr following remedial action.

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. Three potential scenarios were considered for the site; the scenarios were developed on the assumption that for a period of 1,000 years following remedial action, the site will be used without radiological restrictions. The scenarios vary with regard to use of the site, time spent at the site, and sources of food consumed. In all three scenarios, it is assumed that the water consumed at the site is transported from an area far away from the decontaminated area. The results of the evaluation indicate that the basic dose limit of 100 mrem/yr will not be exceeded for uranium (including uranium-234, uranium-235, and uranium-238) within 1,000 years, provided that the soil concentration of total combined uranium (uranium-234, uranium-235, and uranium-238) at the Ventron site does not exceed the following levels: 1,800 pCi/g for Scenario A (industrial worker: the expected scenario), 3,100 pCi/g for Scenario B (recreationist: a plausible scenario), and 480 pCi/g for Scenario C (resident farmer ingesting food produced in the decontaminated area: a possible but unlikely scenario).

The uranium guidelines derived in this report apply to the combined 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, and C would be 880, 1,500, and 230 pCi/g, respectively. These guidelines were calculated on the basis of a dose of 100 mrem/yr. In setting the actual uranium guidelines for the Ventron site, DOE will apply the as-low-as-reasonably-achievable policy to the decision-making process, along with other factors, such as 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 Ventron Division of Morton International (here referred to as the Ventron site) is located in Beverly, Massachusetts (Figure 1). It was designated by DOE as a candidate for remedial action under FUSRAP after Oak Ridge National Laboratory (ORNL) conducted radiological surveys of the site in 1980 and 1982 (Bechtel National, Inc. 1986). The proposed remedial action for the site will follow the guidelines established in DOE Order 5400.5 (DOE 1990). The RESRAD computer code (Gilbert et al. 1989) is used to derive residual radionuclide guidelines on a site-specific basis. This report presents the uranium guidelines derived for the Ventron site on the basis of a dose limit of 100 mrem/yr.

1.1 SITE DESCRIPTION AND SETTING

The Ventron site is located in Beverly, Massachusetts, about 24 km (15 mi) northeast of Boston, on Massachusetts Bay, at the confluence of the Bass and Danvers rivers (Figure 1). The property on the site consists of approximately 1.21 ha (3 acres). The site is bounded on the south by the Danvers River, on the west by the Bass River, on the north by Congress Street, and on the east by the Boston and Maine Railroad (Figure 2).

To study Massachusetts water and related land resources, the U.S. Department of Agriculture (USDA) and the Massachusetts Water Resources Commission divided the state into several regions. The Ventron site is located in the coastal region, which consists of 127 cities or towns in eastern Massachusetts in an area of approximately 6,700 km^2 (2,600 mi^2). The 1990 population of the region was estimated to be about 3,100,000. Approximately 75% of the land area is devoted to forest and urban uses. About 6% of the area is in agricultural use, with the balance in wetland, water, and other land uses (USDA 1978).

Currently the site is occupied by an operating chemical manufacturing facility composed of four groups of buildings, two large chemical storage tanks, two office buildings, and three other buildings used for storage and operations (Bechtel National, Inc. 1991) (Figure 2). Residential areas are nearby, including north of Congress Street.

The site soil is characterized by imported fill material with a predominance of coarse gravel and sand. At the top layer, the soil is formed by fine to medium sand and a small percentage of quartz. Underneath the site, granitic bedrock slopes sharply from a depth of approximately 1.5 m (5 ft) beneath the office buildings to approximately 7.6 to 9.1 m (25 to

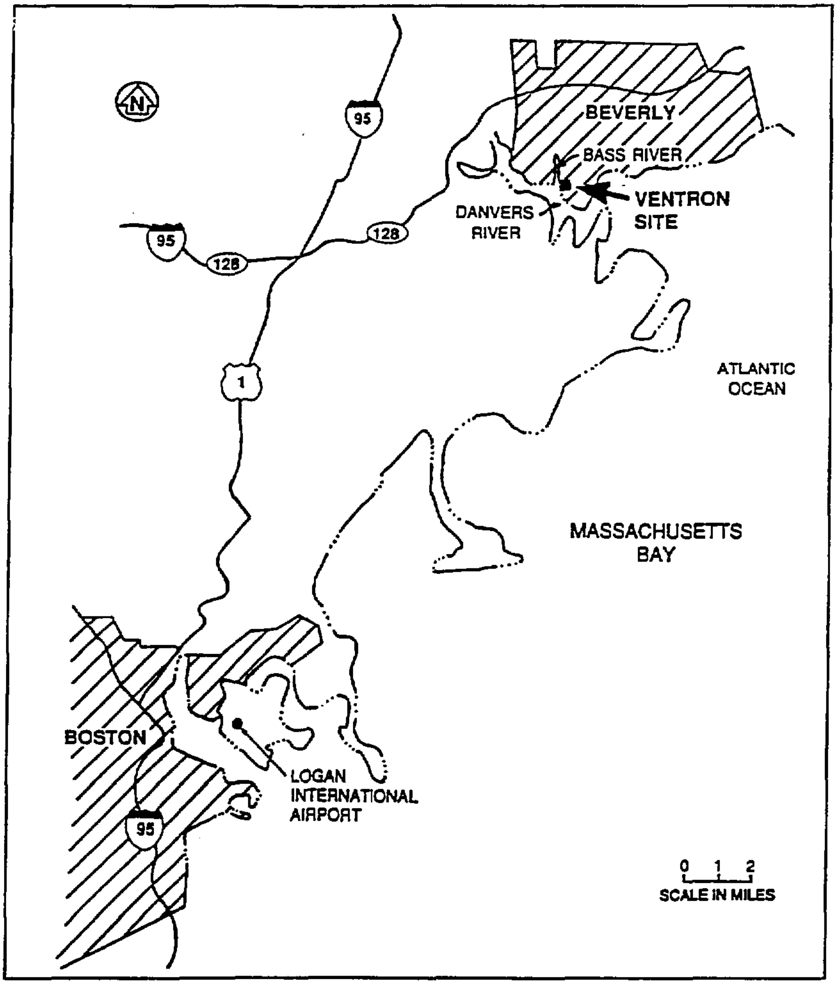

FIGURE 1 Location of the Ventron Site

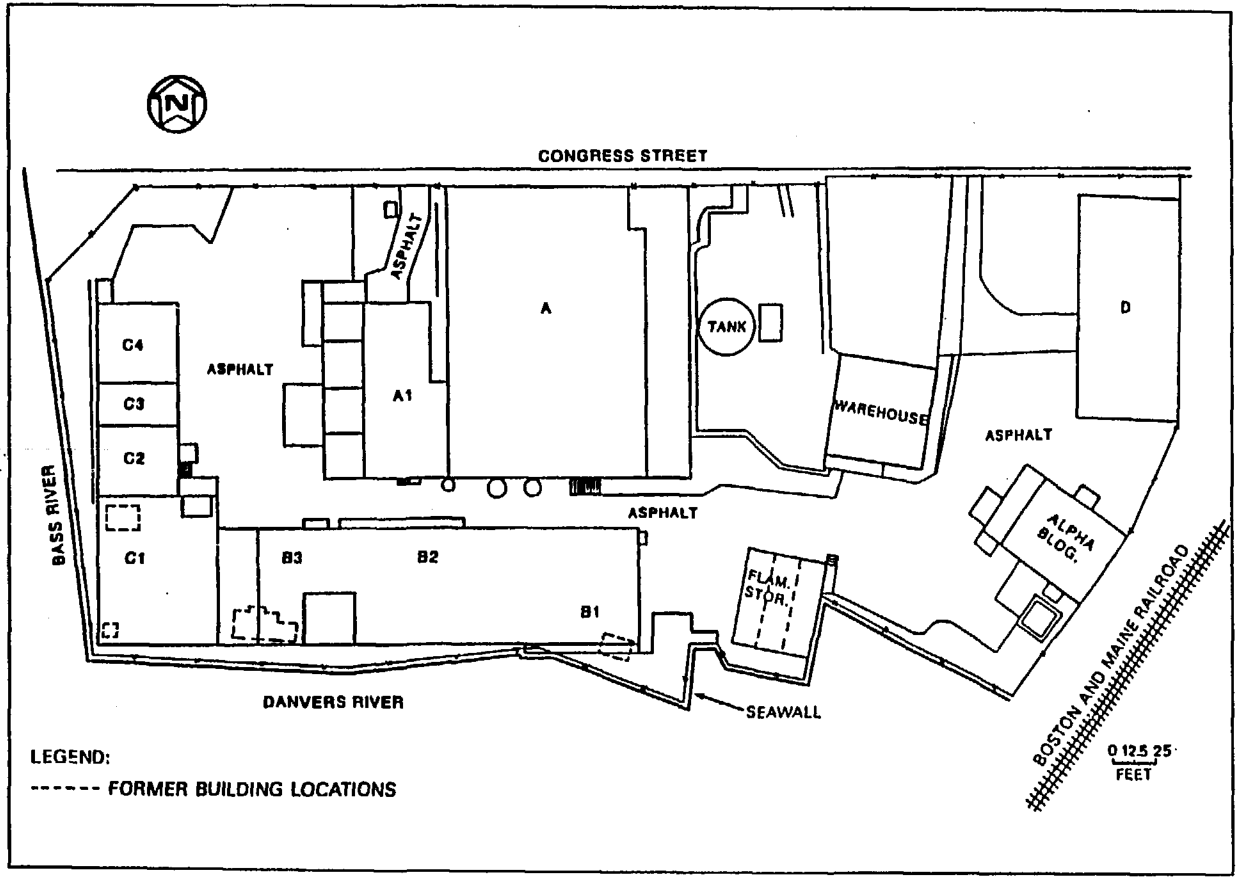

FIGURE 2 Map of the Ventron Site

30 ft) at the sea wall. The surface soil and fill have a low water retention capacity and, therefore, the groundwater level at the site is controlled by the tide. Groundwater at the site is salty and unsuited for drinking and agricultural consumption (Bechtel National, Inc. 1991).

The average ambient air temperature is approximately 10°C (50°F), with an average of about -1°C (30°F) in January and an average of about 22°C (71°F) in July. The length of the growing season (above 0°C [32°F] threshold) is about 200 days in the immediate coastal areas. Mean annual precipitation is about 112 cm (44 in.). The average annual runoff is about 56 cm (22 in.), which is more than 50% above the average precipitation level (USDA 1978).

1.2 SITE HISTORY

Metal Hydrides Corporation, a predecessor of the Ventron Division of Morton International, operated the facility from 1942 to 1948 under contract to the MED and AEC to convert uranium oxide to uranium metal powder. Later operations involved the recovery of uranium from scrap uranium and turnings from the fuel fabrication plant at Hanford, Washington. All these activities were conducted at the foundry site in Beverly, Massachusetts. Three buildings were used for the uranium work. Two of these buildings, which were used to house the foundry facilities, were demolished sometime between 1948 and 1950. Two new buildings have since been erected at these locations. The remaining original building contains (1) the furnace and leaching facilities, (2) a mixing room, (3) a drying room, and (4) an analytical laboratory.

In addition to the uranium-related work, some non-MED-related work with thorium was also conducted at the site. Details of these thorium-related activities are not known, but it is believed that they involved purification of thorium compounds and uranium. Thorium-232 was the primary contaminant resulting from the non-MED activities (Bechtel National, Inc. 1991).

In 1965, Metal Hydrides Corporation became the Ventron Corporation; in late 1976, Morton Thiokol, Inc., acquired control of the company. In 1982, Ventron became a division of Morton Thiokol, Inc., which was renamed Morton International in 1990 (Bechtel National, Inc. 1991).

In 1947 and 1948, the AEC conducted radiation surveys of the facility. The two wooden foundry buildings and various pieces of equipment were found to be contaminated, and cleaning was recommended. Specific cleaning recommendations included (1) sandblasting painted surfaces, (2) removing concrete floors and platforms, and (3) dumping the contaminated equipment and rubble into the ocean (Bechtel National, Inc. 1986). It is unknown whether the ocean dumping was ever carried out (Noey et al. 1987).

In 1977, the Oak Ridge office of DOE and ORNL conducted a screening survey of the site and recommended a comprehensive radiological survey of the entire site.

In 1980, the Health and Safety Research Division of ORNL conducted a comprehensive radiological designation survey of the outdoor portion of the site. Measurements included uranium, radium, and thorium concentrations in surface and subsurface soil, both outdoors and beneath buildings. The buildings and other structures on the site were surveyed in 1982. The results from these surveys demonstrated the presence of radioactive contamination in excess of guidelines and led to the recommendation to DOE for remedial action (Bechtel National, Inc. 1986).

The ORNL surveys indicated the presence of residual radioactive contamination, primarily uranium-238, with lesser amounts of thorium-232 and radium-226 in outdoor soil and fill material beneath Buildings B1, B2, B3, and C1 (Figure 2). The maximum concentration of uranium-238 found on-site was 71,000 pCi/g, which was measured in the subsurface soil underneath Building B2. The highest concentration of uranium-238 found in on-site surface soil was 44,000 pCi/g. The highest concentration of thorium-232 measured in on-site soil was 3,900 pCi/g. The depth of the contamination extended to 2.5 m (8.25 ft) beneath the buildings but appeared to be greater than 3 m (9.9 ft) in the southeast outer portion of the site (Cottrell and Carrier 1987).

1.3 DERIVATION OF CLEANUP GUIDELINES

Although most DOE cleanup guidelines applicable to remedial actions at FUSRAP sites are generic in nature (DOE 1990), guidelines for uranium are derived on a site-specific basis. The purpose of this report is to present the derivation of the residual radioactive material guidelines for uranium (i.e., uranium-234, uranium-235, and uranium-238) that are applicable to remedial action at the Ventron 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 site-specific uranium guidelines for the Ventron site were derived on the basis of a dose limit of 100 mrem/yr (DOE 1990) and the assumption 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.

2 SCENARIO DEFINITIONS

Three potential exposure scenarios were considered for the Ventron site. In all scenarios it is assumed that, at some time within 1,000 years, the site will be released for use without radiological restrictions following remedial action.

Scenario A (the expected scenario) assumes continuing industrial use of the site. Under this scenario, a hypothetical individual 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. Therefore, in one year, the industrial worker is assumed to spend 17% of his or her time working outdoors at the site, 6% working indoors at the site, and 77% away from the site. It is assumed that the worker does not ingest water, plant foods, or fish obtained from the decontaminated area, or meat or milk from livestock raised in the decontaminated area.

Scenario B (a plausible scenario) assumes recreational use of the site. Under this scenario, it is assumed that at some time in the future, the industry presently located at the site will be deactivated, and the whole site will be transformed into a public recreational park. It is also assumed that a hypothetical individual spends 15 hours per week, 50 weeks per year in the decontaminated area of the park. Therefore, in one year, this generic recreationist is assumed to spend 9% of his or her time in the decontaminated area and 91% away from the site. It is assumed that the recreationist does not ingest water or plant foods obtained from the decontaminated area, or meat or milk from livestock raised in the decontaminated area. Fish and other aquatic food consumed by the recreationist are assumed to be obtained solely from nearby rivers.

Scenario C (a possible but unlikely scenario) assumes that the site is used as a farm. Under this scenario, it is assumed that at some time in the future, the industry presently located at the site will be deactivated, and the whole site will be transformed into a farm. It is also assumed that, in one year, a hypothetical 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 site.

The resident farmer is assumed to ingest plant foods grown in the garden and fish and other aquatic food obtained solely from nearby rivers. The individual also ingests meat and milk from livestock raised in the decontaminated area. Because of the site's proximity to the sea, it is assumed that water obtained from the area is not used for drinking, feeding livestock, or irrigating.

Potential radiation doses resulting from the following eight exposure pathways are analyzed:

- Direct exposure to external radiation from the decontaminated soil material,

- Internal radiation from inhalation of contaminated dust,

- Internal radiation from inhalation of emanating radon-222,
- Internal radiation from ingestion of plant foods grown in the decontaminated area but not irrigated with water from local groundwater wells,
- Internal radiation from ingestion of meat from livestock fed with fodder grown in the decontaminated area but given water drawn from outside the area,
- Internal radiation from ingestion of milk from livestock fed with fodder grown in the decontaminated area but given water drawn from outside the area,
- Internal radiation from ingestion of fish and other aquatic food from nearby rivers, and
- Internal radiation from ingestion of on-site soil.

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

TABLE 1 Summary of Pathways for Scenarios A, B, and C at the Ventron Site

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

[a] Industrial worker.

[b] Recreationist.

[c] Resident farmer.

[d] Water used for drinking, feeding livestock, or irrigating is assumed to be transported from off-site because of the proximity of the sea.

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 following assumptions were made concerning the previously mentioned scenarios:

- During one year, the industrial worker spends 1,500 hours (17%) outdoors at the site, 500 hours (6%) indoors at the site, and 6,760 hours (77%) away from the decontaminated area. The recreationist spends 750 hours (9%) per year on-site. The resident farmer spends 4,380 hours (50%) indoors, 2,190 hours (25%) outdoors in the decontaminated area, and 2,190 hours (25%) away from the site.

- 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 (3 ft) below ground surface, with an effective radon diffusion coefficient of 2×10^{-8} m^2/s.

- The size of the decontaminated area is large enough 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 the recreationist does not consume these plant foods.

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

- All the fish and other aquatic food consumed by the recreationist and the farmer are obtained solely from nearby rivers. The industrial worker does not consume aquatic food obtained from the site.

- The consumption rates for fish (50 kg/yr) and other aquatic food (10 kg/yr) used in the aquatic food pathway of Scenarios B and C are conservative values obtained from the upper part of the range recommended by the U.S. Environmental Protection Agency (1990).

- Because of the proximity of the sea, site water is not used for drinking, feeding livestock, or irrigating. All the water consumed in the decontaminated area would come from somewhere outside the area.

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

- The thickness of the contaminated zone is a conservative average value from ORNL measurements (Cottrell and Carrier 1987). The whole area of the Ventron site (12,140 m^2 [14,519 yd^2]) was assumed to be homogeneously contaminated with an average thickness of 3.0 m (10 ft).

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 remedial action. The time frame considered in this analysis was 1,000 years. Radioactive decay and ingrowth were considered in deriving the dose/source concentration ratios. 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 4 for Scenarios A, B, and C, respectively. For Scenarios A and C, the maximum dose/source concentration ratios would occur at time zero (immediately after remedial action); for Scenario B, the maximum dose/source concentration ratio would occur at 660 years following remedial action. The primary pathway for Scenarios A and C would be inhalation; for Scenario C, the external exposure and ingestion of plant foods are comparable to the inhalation pathway. The primary pathway for Scenario B would be the consumption of fish and other aquatic food.

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-234, uranium-235, and uranium-238.

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 radionuclides and total uranium are provided in Table 5. These ratios were used to determine the allowable residual radioactivity for uranium at the Ventron site.

TABLE 2 Maximum Dose/Source Concentration Ratios for Scenario A (Industrial Worker) at the Ventron Site

Pathway	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Uranium-234	Uranium-235	Uranium-238
External exposure	2.7×10^{-4}	1.9×10^{-1}	2.7×10^{-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 soil	0	0	0
Ingestion of water	0	0	0

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

TABLE 3 Maximum Dose/Source Concentration Ratios for Scenario B (Recreationist) at the Ventron Site

Pathway	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Uranium-234	Uranium-235	Uranium-238
External exposure	6.8×10^{-4}	3.2×10^{-2}	4.4×10^{-3}
Inhalation	7.6×10^{-3}	1.3×10^{-2}	6.9×10^{-3}
Radon	6.0×10^{-7}	0	3.4×10^{-10}
Ingestion of plant foods	0	0	0
Ingestion of meat	0	0	0
Ingestion of milk	0	0	0
Ingestion of fish	5.0×10^{-3}	7.0×10^{-1}	4.8×10^{-3}
Ingestion of soil	3.5×10^{-4}	7.5×10^{-4}	3.2×10^{-4}
Ingestion of water	0	0	0

[a] Maximum dose/source concentration ratios would occur at 660 years following remedial action; all values are reported to two significant figures.

TABLE 4 Maximum Dose/Source Concentration Ratios for Scenario C (Farmer Resident) at the Ventron Site

Pathway	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Uranium-234	Uranium-235	Uranium-238
External exposure	7.7×10^{-4}	5.3×10^{-1}	7.6×10^{-2}
Inhalation	9.6×10^{-2}	8.8×10^{-2}	8.8×10^{-2}
Radon	0	0	0
Ingestion of plant foods	5.7×10^{-2}	5.5×10^{-2}	5.5×10^{-2}
Ingestion of meat	8.5×10^{-3}	8.2×10^{-3}	8.2×10^{-3}
Ingestion of milk	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}
Ingestion of fish	0	0	0
Ingestion of soil	7.1×10^{-3}	6.8×10^{-3}	6.8×10^{-3}
Ingestion of water	0	0	0

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

TABLE 5 Total Dose/Source Concentration Ratios for Uranium at the Ventron Site

Radionuclide	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Scenario A	Scenario B	Scenario C
Uranium-234	4.1×10^{-2}	1.4×10^{-2}	1.7×10^{-1}
Uranium-235	2.3×10^{-1}	7.5×10^{-1}	6.9×10^{-1}
Uranium-238	6.5×10^{-2}	1.6×10^{-2}	2.3×10^{-1}
Total uranium	5.7×10^{-2}	3.2×10^{-2}	2.1×10^{-1}

[a] All values are reported to two significant figures.

4 RESIDUAL RADIOACTIVE MATERIAL GUIDELINES

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

$$G = 100/DSR$$

where DSR is the total dose/source concentration ratio listed in Table 5. The calculated residual radioactive material guidelines for single radionuclides (uranium-234, uranium-235, and uranium-238) and total uranium are presented in Table 6.

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 1,800, 3,100, and 480 pCi/g for Scenarios A, B, and C, 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 uranium-238 limits would be 880, 1,500, and 230 pCi/g for Scenarios A, B, and C, 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 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 their guidelines G_i, should not be greater than unity, that is,

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

The derived guidelines listed in Table 6 are for a large, homogeneously contaminated area. For a small, isolated 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.

TABLE 6 Residual Radioactive Material Guidelines for the Ventron Site

	Guideline (pCi/g)[a]		
Radionuclide	Scenario A[b]	Scenario B[c]	Scenario C[d]
Uranium-234	2,400	7,100	590
Uranium-235	430	130	140
Uranium-238	1,500	6,300	430
Total uranium	1,800	3,100	480

[a] All values are reported to two significant figures.

[b] Industrial worker.

[c] Recreationist.

[d] Resident farmer.

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APPENDIX:

PARAMETERS USED IN THE ANALYSIS OF THE VENTRON SITE

Exposure Scenarios:

Scenario A: Continuing industrial use of the site.
A hypothetical person is assumed to work in the area of the site.

Scenario B: Recreational use of the site.
A hypothetical recreationist is assumed to spend some time during the year at a public park constructed on the decontaminated area.

Scenario C: Residential use of the site.
A hypothetical resident farmer is assumed to live in the decontaminated area.

The parametric values used in the RESRAD code for the analysis of the Ventron site are listed in Table A.1. All parametric values are reported at three significant figures. Some parameteric values are specific to the Ventron site; other values are generic.

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

		Value		
Parameter	Unit	Scenario A	Scenario B	Scenario C
Area of contaminated zone[a]	m^2	12,100	12,100	12,100
Thickness of contaminated zone[a]	m	3	3	3
Length parallel to aquifer flow[a]	m	not used	140	140
Cover depth[a]	m	0	0	0
Density of contaminated zone[a]	g/cm^3	1.76	1.76	1.76
Contaminated zone erosion rate[b]	m/yr	0.001	0.001	0.001
Contaminated zone total porosity[b]	-	0.4	0.4	0.4
Contaminated zone effective porosity[b]	-	0.2	0.2	0.2
Contaminated zone hydraulic conductivity[b]	m/yr	10	10	10
Contaminated zone b parameter[b]	-	5.3	5.3	5.3
Evapotranspiration coefficient[b]	-	0.6	0.6	0.6
Precipitation[a]	m/yr	1.12	1.12	1.12
Irrigation[b]	m/yr	0.2	0.2	0.2
Irrigation mode[b]	-	overhead	overhead	overhead
Runoff coefficient[b]	-	0.2	0.2	0.2
Watershed area for nearby pond[b]	m^2	not used	1,000,000	1,000,000
Density of saturated zone[b]	g/cm^3	1.6	1.6	1.6
Saturated zone total porosity[b]	-	not used	0.4	0.4
Saturated zone effective porosity[b]	-	not used	0.2	0.2
Saturated zone hydraulic conductivity[b]	m/yr	not used	100	100
Saturated zone hydraulic gradient[b]	-	not used	0.02	0.02
Saturated zone b parameter[b]	-	5.3	5.3	5.3
Water table drop rate[b]	m/yr	not used	0.001	0.001

TABLE A.1 (Cont'd)

Parameter	Unit	Value		
		Scenario A	Scenario B	Scenario C
Well pump intake depth (below water table)[b]	m	not used	10	10
Model: nondispersion (ND) or mass-balance (MB)[b]	-	ND	ND	ND
Number of unsaturated zone strata[a]	-	not used	1	1
Unsaturated zone 1, thickness[b]	m	not used	4.0	4.0
Unsaturated zone 1, soil density[b]	g/cm^3	not used	1.6	1.6
Unsaturated zone 1, total porosity[b]	-	not used	0.4	0.4
Unsaturated zone 1, effective porosity[b]	-	not used	0.2	0.2
Unsaturated zone 1, soil-specific b parameter[b]	-	not used	5.3	5.3
Unsaturated zone 1, hydraulic conductivity[b]	m/yr	not used	100	100
Distribution coefficient[b]	cm^3/g			
Contaminated zone				
Radium-226		70	70	70
Thorium-232		60,000	60,000	60,000
Uranium-238		50	50	50
Lead-210		100	100	100
Radium-228		70	70	70
Thorium-228		60,000	60,000	60,000
Thorium-230		60,000	60,000	60,000
Uranium-234		50	50	50
Distribution coefficient[b]	cm^3/g			
Unsaturated zone				
Radium-226		70	70	70
Thorium-232		60,000	60,000	60,000
Uranium-238		50	50	50
Lead-210		100	100	100
Radium-228		70	70	70
Thorium-228		60,000	60,000	60,000
Thorium-230		60,000	60,000	60,000
Uranium-234		50	50	50
Distribution coefficient[b]	cm^3/g			
Saturated zone				
Radium-226		70	70	70
Thorium-232		60,000	60,000	60,000
Uranium-238		50	50	50
Lead-210		100	100	100
Radium-228		70	70	70
Thorium-228		60,000	60,000	60,000
Thorium-230		60,000	60,000	60,000
Uranium-234		50	50	50
Inhalation rate[b]	m^3/yr	8,400	8,400	8,400
Mass loading for inhalation[b]	g/m^3	0.0002	0.0002	0.0002
Occupancy and shielding factor, external gamma[a]	-	0.211	0.086	0.6
Occupancy factor, inhalation[a]	-	0.194	0.086	0.45
Shape factor, external gamma[b]	-	1	1	1
Dilution length for airborne dust, inhalation[b]	m	3	3	3
Fruit, vegetable, and grain consumption[b]	kg/yr	not used	not used	160.0
Leafy vegetable consumption[b]	kg/yr	not used	not used	14.0
Milk consumption[b]	L/yr	not used	not used	92.0
Meat and poultry consumption[b]	kg/yr	not used	not used	63.0
Fish consumption[a]	kg/yr	not used	50	50
Other seafood consumption[a]	kg/yr	not used	10	10
Soil ingestion[b]	kg/yr	not used	36.5	36.5
Drinking water intake[b]	L/yr	not used	not used	not used

TABLE A.1 (Cont'd)

Parameter	Unit	Value: Scenario A	Scenario B	Scenario C
Fraction of drinking water from site[a]	-	not used	not used	not used
Fraction of aquatic food from site[a]	-	not used	1.0	1.0
Livestock fodder intake for meat[b]	kg/d	not used	not used	68.0
Livestock fodder intake for milk[b]	kg/d	not used	not used	55.0
Livestock water intake for meat[b]	L/d	not used	not used	50.0
Livestock water intake for milk[b]	L/d	not used	not used	160.0
Mass loading for foliar deposition[b]	g/m^3	not used	not used	0.0001
Depth of soil mixing layer[b]	m	0.15	0.15	0.15
Depth of roots[b]	m	not used	not used	0.9
Groundwater fractional usage (balance from surface water):				
Drinking water[a]	-	not used	not used	not used
Livestock water[a]	-	not used	not used	not used
Irrigation[a]	-	not used	not used	not used
Total porosity of the cover material[a]	-	not used	not used	not used
Total porosity of the house or building foundation[a,b]	-	0.1	not used	0.1
Volumetric water content of the cover material[a]	-	not used	not used	not used
Volumetric water content of the foundation[b]	-	0.01	0.01	0.01
Diffusion coefficient for radon gas:	m^2/s			
in cover material[a]		not used	not used	not used
in foundation material[b]		2.0×10^{-8}	not used	2.0×10^{-8}
in contaminated zone soil[b]		2.0×10^{-6}	2.0×10^{-6}	2.0×10^{-6}
Emanating power of radon-222[b]	-	0.2	0.2	0.2
Emanating power of radon-220[a]	-	not used	not used	not used
Radon vertical dimension of mixing[b]	m	2.0	2.0	2.0
Average annual wind speed[b]	m/s	2.0	2.0	2.0
Average building air exchange rate[a,b]	1/h	1.0	not used	1.0
Height of the building (room)[a,b]	m	5.0	not used	2.5
Building indoor area factor[a,b]	-	1.0	not used	1.0
Bulk density of house or building foundation[a,b]	g/cm^3	2.4	not used	2.4
Thickness of house or building foundation[b]	m	0.15	not used	0.15
Building depth below ground surface[a,b]	m	1.0	not used	1.0
Fraction of time spent indoors[a]	-	0.057	0.0	0.5
Fraction of time spent outdoors[a]	-	0.171	0.086	0.25

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

[b] RESRAD default values.