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Derivation of Residual Radioactive Material Guidelines for Uranium in Soil at the Former Associate Aircraft Tool and Manufacturing Company Site, Fairfield, Ohio

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DISCLAIMER

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NOTATION

The following is a list of the acronyms, initialisms, abbreviations, and units of measure used in this document. Some notations used in tables or equations only are defined only in the respective tables or equations.

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
ALARA	as low as reasonably achievable
DOE	U.S. Department of Energy
FUSRAP	Formerly Utilized Sites Remedial Action Program
NLO	National Lead of Ohio
ORNL	Oak Ridge National Laboratory
RESRAD	*res*idual *rad*ioactive material guideline computer code

UNITS OF MEASURE

cm	centimeter(s)
cm^3	cubic centimeter(s)
d	day(s)
ft	foot (feet)
g	gram(s)
h	hour(s)
kg	kilogram(s)
L	liter(s)
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
mg	milligram(s)
mrem	millirem(s)
pCi	picocurie(s)
s	second(s)
yr	year(s)

DERIVATION OF RESIDUAL RADIOACTIVE MATERIAL GUIDELINES FOR URANIUM IN SOIL AT THE FORMER ASSOCIATE AIRCRAFT TOOL AND MANUFACTURING COMPANY SITE, FAIRFIELD, OHIO

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SUMMARY

Residual radioactive material guidelines for uranium in soil were derived for the former Associate Aircraft Tool and Manufacturing Company site[1] in Fairfield, Ohio. This site has been identified for remedial action under the U.S. Department of Energy's (DOE's) Formerly Utilized Sites Remedial Action Program (FUSRAP). Single-nuclide and total-uranium guidelines were derived on the basis of the requirement that, after remedial action, the 50-year committed effective dose equivalent to a hypothetical individual living or working in the immediate vicinity of the site should not exceed (1) 30 mrem/yr for the current-use and likely future-use scenarios or (2) 100 mrem/yr for less likely future-use scenarios (Yu et al. 1993a). The DOE residual radioactive material (RESRAD) computer code, which implements the methodology described in the DOE manual for establishing residual radioactive material guidelines, was used in this evaluation.

Three scenarios are considered in which it is assumed that the site will be used without radiological restrictions for a period of 1,000 years following remedial action. The three scenarios vary with regard to the type of site use, time spent at the site by the exposed individual, and sources of food and water consumed. The evaluation indicates that the dose constraint of 30 mrem/yr would 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 former Associate Aircraft site did not exceed 970 pCi/g for Scenario A (industrial worker: current-use scenario) or 280 pCi/g for Scenario B (resident: municipal water supply, a likely future-use scenario). The dose limit of 100 mrem/yr would not be exceeded at the site if the total uranium concentration of the soil did not exceed 790 pCi/g for Scenario C (subsistence farmer: on-site well water, a plausible but unlikely future-use scenario).

The uranium guidelines derived in this analysis apply 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). Consequently, if uranium-238 were measured as the indicator radionuclide, the respective soil concentration limits for Scenarios A, B, and C would be 470, 140, and 390 pCi/g. These guidelines were calculated

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[1] Referred to as the former Associate Aircraft site in the remainder of the document.

on the basis of a dose constraint of 30 mrem/yr for Scenarios A and B and a dose limit of 100 mrem/yr for Scenario C (Yu et al. 1993a). In setting the actual uranium guidelines for the former Associate Aircraft site, DOE will apply the as-low-as-reasonably-achievable (ALARA) policy to the decision-making process, along with other factors, such as whether a particular scenario is reasonable and appropriate.

1 INTRODUCTION

The former Associate Aircraft Tool and Manufacturing Company site[2] is located in Fairfield, Ohio (Figure 1). The site has been designated by the U.S. Department of Energy (DOE) as a candidate for remedial action under its Formerly Utilized Sites Remedial Action Program (FUSRAP). This designation was made after preliminary inspections by Oak Ridge National Laboratory (ORNL) in July and September 1992 indicated the presence of uranium contamination both inside and outside the building on the site. FUSRAP was established in 1974 by the U.S. Atomic Energy Commission (AEC), a predecessor of 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.

Remedial action activities at the former Associate Aircraft site will follow the guidelines established in DOE Order 5400.5 (DOE 1990). The RESRAD computer code (Yu et al. 1993a) is used to derive residual radionuclide guidelines on a site-specific basis. This report presents the uranium guidelines derived for the former Associate Aircraft site on the basis of a dose constraint of 30 mrem/yr for the current-use and likely future-use scenarios and a dose limit of 100 mrem/yr for less likely but plausible future-use scenarios (Yu et al. 1993a). The dose constraint of 30 mrem/yr is not currently required under DOE Order 5400.5 but is included in the proposed 10 CFR Part 834 rulemaking to account for additional dose contributions from other potential sources of radiation exposure.

1.1 SITE DESCRIPTION AND SETTING

The building on the former Associate Aircraft site previously housed an operation to machine uranium slugs (Figure 2). The site encompasses approximately 10,000 m^2, of which 3,700 m^2 is occupied by the building. At the time of the ORNL surveys, the current owner operated a multipurpose shop in the facility. The building faces vacant lots to the south and east and Ohio State Route 4 (Dixie Highway) to the west. Commercial properties are located north of the building.

The town of Fairfield is located in Butler County, Ohio, about 10 miles northwest of Cincinnati (Figure 1). The annual average precipitation rate in nearby Hamilton, Ohio (to the northwest), is 0.99 m/yr (Spieker 1965). The soil in the area of the site is predominantly sand and gravel (Spieker 1965). The site currently obtains water from municipal sources, and no wells have been dug on the property. The water table in the area ranges from as close as 2 m to more than 10 m below the soil surface (Sheets 1994; Spieker 1965). The distribution coefficient for uranium in a surface soil sample collected near the main entrance to the building was 100 cm^3/g (Orlandini 1994).

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[2] Hereafter referred to as the former Associate Aircraft site.

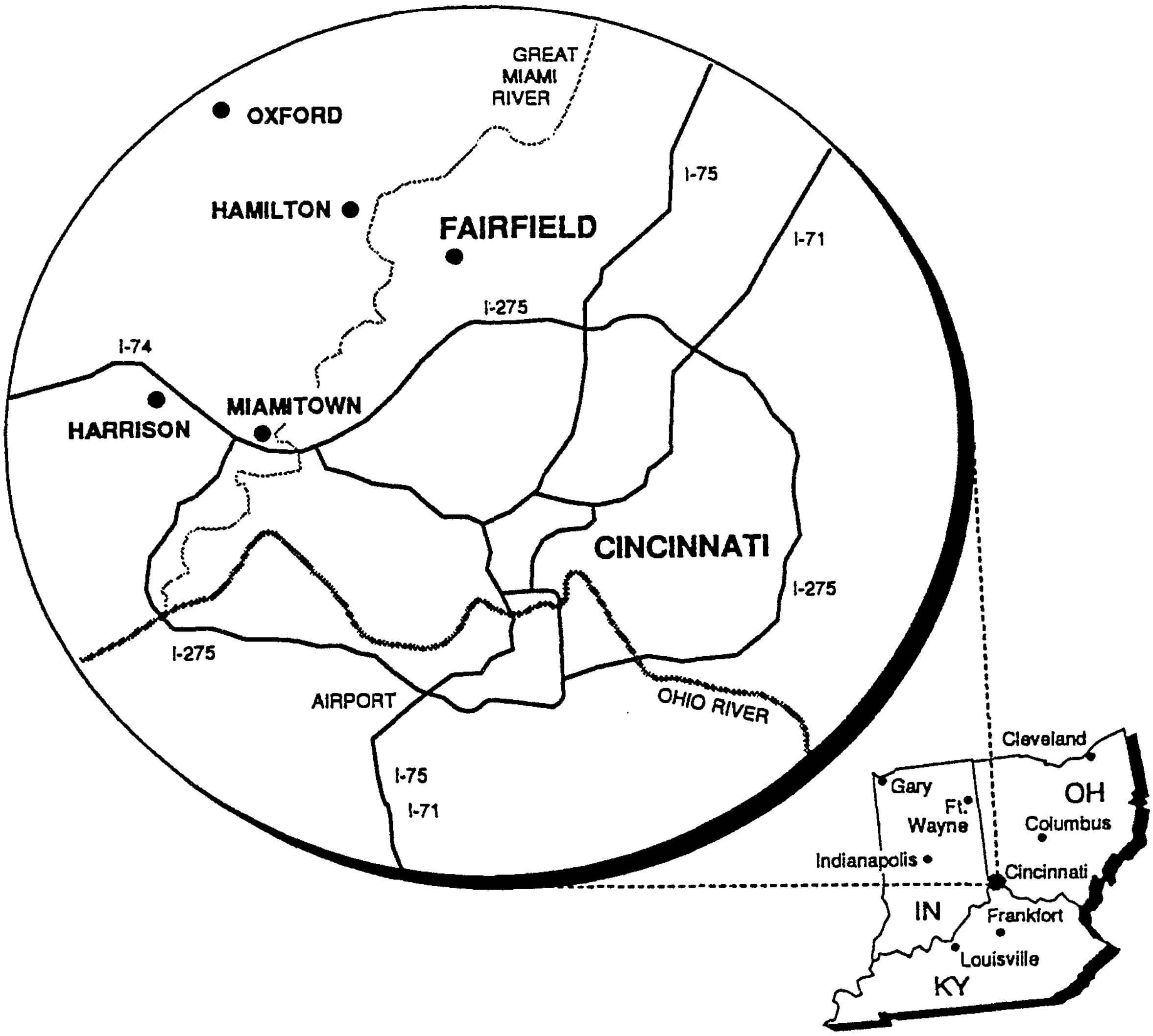

FIGURE 1 Map Showing Fairfield, Ohio, Location of the Former Associate Aircraft Site (Source: Murray et al. 1993)

1.2 SITE HISTORY

The Associate Aircraft Tool and Manufacturing Company was a subcontractor to National Lead of Ohio (NLO) from February to September 1956. Hollow uranium slugs were produced at the former Associate Aircraft site for NLO, which was a primary contractor for the AEC. Early operations conducted at the Fairfield site included hollow drilling, reaming, and turning slugs to a final outside diameter. Contractual records indicate that approximately 95,000 slugs were machined during the eight-month period of operation. During the last three months of the contract, Associate Aircraft production was maintained at a minimum operating level of 10,000 to 15,000 slugs per month (Murray et al. 1993).

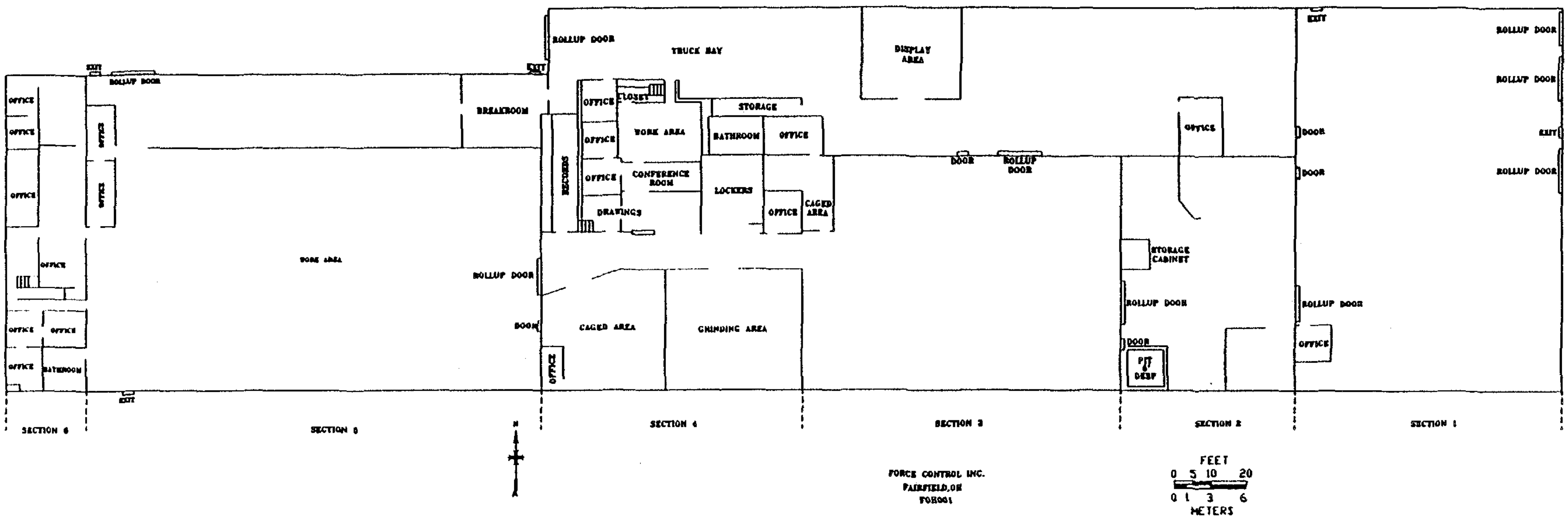

FIGURE 2 Layout of the Former Associate Aircraft Building (Source: Murray et al. 1993)

The present occupant of the site is Force Control Industries. An employee of that firm who had visited the site in the 1950s reports that no extensive remodeling of the sole building on the property had been performed before 1992 (Murray et al. 1993). However, the west entrance to the building (Figure 3) was remodeled soon after a radiological survey was performed in 1992. Debris from that construction project was placed behind the east end of the building.

The uranium-machining activities performed at the site in the 1950s contaminated equipment, the building, and land with low levels of radioactive materials. At contract termination, sites used by the contractor were decontaminated in accordance with the standards and survey methods in use at that time. However, since then, more stringent radiological criteria and guidelines have been implemented for the release of such sites for unrestricted use.

In the absence of substantial information regarding the current condition of the former Associate Aircraft site, DOE requested that ORNL personnel conduct a radiological survey of the facility under FUSRAP. The ground surface directly in front (west) of the building was thoroughly surveyed in July, before the front entrance was remodeled. A complete radiological characterization of the building and of a 25-ft-wide perimeter of ground surface around the other three sides of the building was performed in September 1992. The results indicated that residual uranium contamination from past AEC-related activities exceeds current DOE guidelines in the building and in isolated spots on the site outside the building (Murray et al. 1993).

1.3 DERIVATION OF CLEANUP GUIDELINES

Although most DOE cleanup guidelines applicable to remedial actions at FUSRAP sites are generic (DOE 1990), guidelines for uranium are derived on a site-specific basis. The purpose of this analysis was to derive the residual radioactive material guidelines for uranium (i.e., uranium-234, uranium-235, uranium-238, and total uranium) in soil applicable to remedial action at the former Associate Aircraft site. The derived guidelines represent 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 guideline for total uranium is derived by assuming that uranium-238, uranium-234, and uranium-235 are present in their natural activity concentration ratio of 1:1:0.046.

Site-specific uranium guidelines for the former Associate Aircraft site were derived on the basis of a dose constraint of 30 mrem/yr for the current-use and likely future-use scenarios and a dose limit of 100 mrem/yr for less likely but plausible future-use scenarios (Yu et al. 1993a). It was assumed that uranium is the only radionuclide present at an above-background concentration. The RESRAD computer code, version 5.41, was used to derive these guidelines. The RESRAD code is used to implement the methodology described in the DOE manual for establishing residual radioactive material guidelines (Yu et al. 1993a).

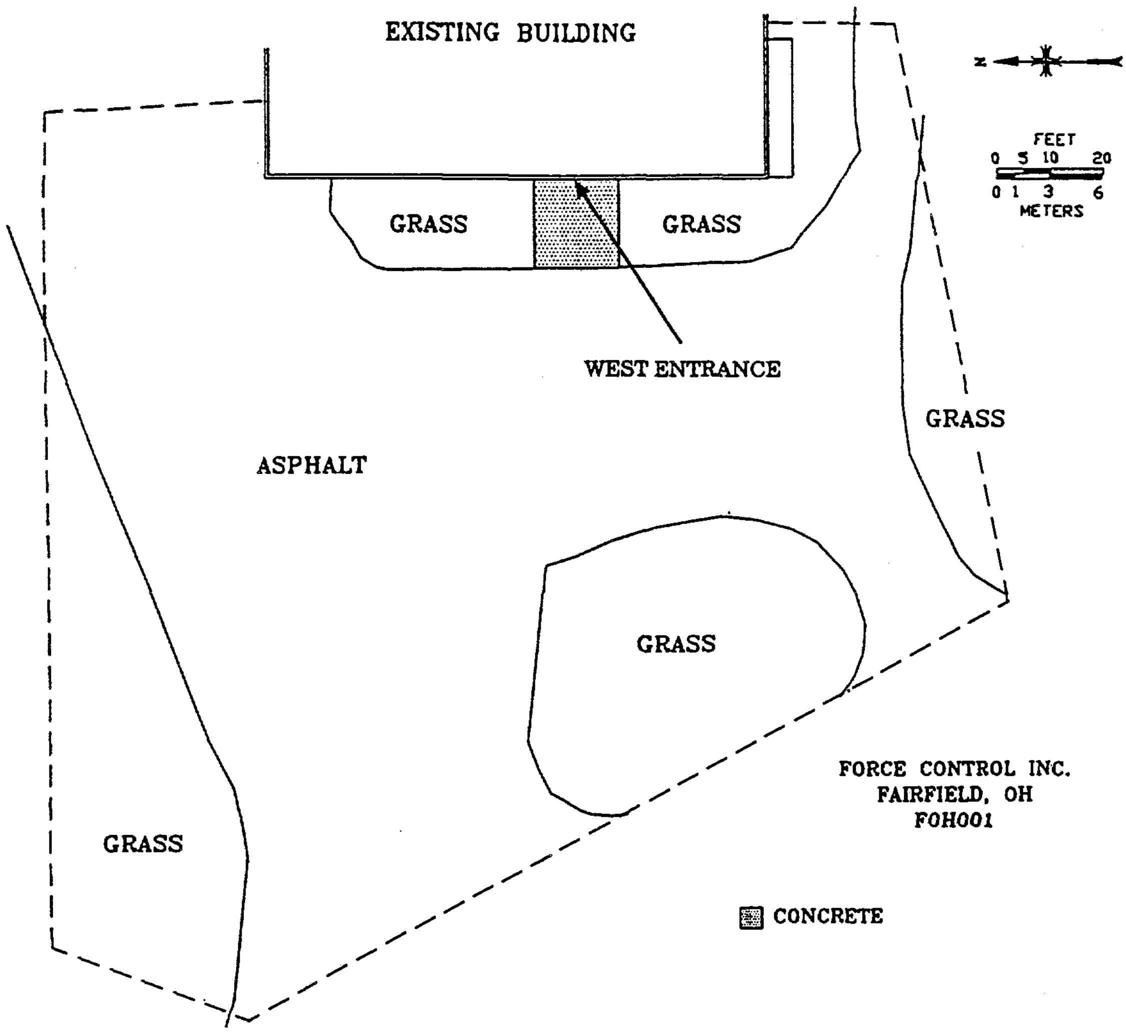

FIGURE 3 Diagram Showing the Area Surveyed (inside dashed line) in July 1992 West of the Building at the Former Associate Aircraft Site (Source: Adapted from Murray et al. 1993)

2 SCENARIO DEFINITIONS

Three potential exposure scenarios (Scenarios A, B, and C) were considered for this assessment of residual radioactivity guidelines for soil. The assumption was made that at some time within 1,000 years, the site will be released for use without radiological restrictions following remedial action (decontamination). Potential radiation doses resulting from nine exposure pathways were considered: (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 incidental ingestion of soil, (5) internal radiation from ingestion of plant foods grown in the decontaminated area and irrigated with water drawn from a well located at the downgradient edge of the decontaminated area, (6) internal radiation from ingestion of meat from livestock fed with fodder grown in the decontaminated area and irrigated with water drawn from an on-site well, (7) internal radiation from ingestion of milk from livestock fed with fodder grown in the decontaminated area and irrigated with water drawn from an on-site well, (8) internal radiation from the ingestion of fish from a pond downgradient from the decontaminated area, and (9) internal radiation from drinking of water drawn from the on-site well. All exposure pathways considered for the three scenarios are summarized in Table 1.

TABLE 1 Summary of Exposure Pathways for Scenarios A, B, and C at the Former Associate Aircraft 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	Yes	Yes
Ingestion of meat	No	No	Yes
Ingestion of milk	No	No	Yes
Ingestion of fish	No	No	Yes
Ingestion of soil	Yes	Yes	Yes
Ingestion of water	No	No	Yes

[a] Industrial worker: no consumption of water or foods obtained on the site.

[b] Resident: water used for drinking, household purposes, and irrigation is assumed to be from uncontaminated municipal sources.

[c] Subsistence farmer: water used for drinking, household purposes, livestock watering, and irrigation is assumed to be from an on-site well.

Scenario A (the current-use scenario) assumes continued industrial use of the site. Under this scenario, a hypothetical individual is assumed to spend 9 hours per day at the site (8 hours working indoors and 1 hour outdoors for lunch), 5 days per week, 50 weeks per year. It is also 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. The dose to the worker is assumed to be only from the decontaminated soil.

Scenario B (a likely future-use scenario) assumes residential use of the site. It is assumed that at some time in the future, the industrial activities at the site will be discontinued, the existing building will be removed, and the whole site will be transformed into a residential area. A hypothetical resident of the site is assumed to ingest plant foods grown in a garden on the site. All water used by the resident for drinking, household purposes, and irrigation is from municipal sources that are not radioactively contaminated. For this scenario, it is assumed that no livestock are raised on the site for the production of meat and milk and no pond is present to provide fish or other aquatic food.

Scenario C (a plausible but unlikely future-use scenario) is similar to Scenario B, in which a resident is assumed to ingest plant foods grown in the garden. However, under Scenario C, the resident is a subsistence farmer who is also assumed to ingest meat and milk from livestock fed with forage grown on-site and to consume fish and other aquatic organisms caught from an on-site pond. For this scenario, the groundwater drawn from a well located on-site is the only water source for drinking, household use, livestock watering, and irrigation. Currently no agricultural activity occurs at the site, and production of livestock or construction of a fishing pond in the decontaminated area is considered extremely unlikely. Agricultural use of the property would require removal of the current building and the paved areas at the site. For the purposes of this analysis, it is assumed that any residual soil contamination would not be removed during this process.

The RESRAD computer code (Yu et al. 1993a) was used to calculate the potential radiation doses for the hypothetical future industrial worker (Scenario A) and the resident and subsistence farmer (Scenarios B and C) on the basis of the following assumptions:

- During one year, the industrial worker (Scenario A) spends 2,000 hours (23% of the time) indoors at the decontaminated site, 250 hours (3%) outdoors at the site, and 6,510 hours (74%) away from the site. The resident and subsistence farmer (Scenarios B and C) during one year spend 4,380 hours (50%) indoors, 2,190 hours (25%) outdoors in the decontaminated area, and 2,190 hours (25%) away from the site (Yu et al. 1993a).

- The walls, floor, and foundation of the house (Scenarios B and C) or commercial building (Scenario A) on the site reduce external exposure by 30%; the indoor dust level is 40% of the outdoor dust level (Yu et al. 1993a).

- The outdoor airborne dust loading is 0.1 mg/m^3.

- 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 (Yu et al. 1993a).

- The size of the decontaminated area is sufficiently large that 10% and 50% of the plant food diet consumed by the resident and subsistence farmer for Scenarios B and C, respectively, is grown in a garden in the decontaminated area (Yu et al. 1993a). The industrial worker does not consume these plant foods.

- The size of the decontaminated area is sufficiently large to produce 50% of the forage used to feed livestock for meat and milk consumed by the subsistence farmer in Scenario C (Yu et al. 1993a). The industrial worker and the resident in Scenarios A and B do not consume these animal products.

- Half of the fish and other aquatic food consumed by the subsistence farmer in Scenario C is obtained from an on-site pond (Yu et al. 1993a).

- The current supply of water for the industrial building is from uncontaminated municipal sources, and this supply is assumed to be used under Scenarios A and B. However, for the plausible but unlikely scenario (Scenario C), the source of water for drinking, household uses, livestock watering, and irrigation is assumed to be an on-site well.

- The soil at the site is sand and gravel (Spieker 1965). Because of the lack of site-specific data, typical values for sandy soils tabulated in Yu et al. (1993a) are used for the density, total and effective porosities, soil "b" parameter, and hydraulic conductivity in the contaminated, unsaturated, and saturated zones.

- The uranium distribution coefficient was measured at 100 cm^3/g for surface soil (Orlandini 1994); this value is used for all uranium isotopes in the contaminated, unsaturated, and saturated zones. The distribution coefficients of the radioactive progeny are those for sandy soils tabulated in Yu et al. (1993b).

- No wells have been dug at the site. The water table in the area ranges from as close as 2 m to more than 10 m below the soil surface (Sheets 1994; Spieker 1965); a distance of 3.8 m to the water table is assumed on the basis of the average water table in area wells.

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

- No erosion of the contaminated material occurs.

- The thickness of the contaminated zone is based on conservative average values from ORNL measurements (Murray et al. 1993). The area of the former Associate Aircraft site (10,000 m^2) is assumed to be homogeneously contaminated to an average depth of 0.3 m. Of this area, approximately 3,700 m^2 is now occupied by the building.

3 DOSE/SOURCE CONCENTRATION RATIOS

To develop residual radioactivity guidelines for soil at the former Associate Aircraft site, the RESRAD computer code, version 5.41 (Yu et al. 1993a), 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 for 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, 3, and 4 for Scenarios A, B, and C, respectively. For all three scenarios, the maximum dose/source concentration ratios would occur at time zero (immediately after remedial action). The dose from natural uranium in soil in Scenarios A and B is contributed primarily by external exposure and inhalation of dust. In Scenario C, the dose from natural uranium is contributed almost equally by the external exposure, dust inhalation, and plant ingestion pathways.

The summation of $DSR_{ip}(t)$ for all pathways p is the $DSR_i(t)$ for the ith 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 in soil at the site for uranium-234, uranium-235, and uranium-238.

For this analysis, W_i is assumed to represent 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 in soil at the former Associate Aircraft site.

Uncertainty in the derivation of dose/source concentration ratios arises from the distribution of possible input parameter values, as well as uncertainty in the conceptual model used to represent the site. Depending on the scenario, different parameters may affect the results in each case. For Scenarios A and B, the external exposure and inhalation pathways contribute almost equally to most of the dose. Therefore, uncertainty in parameters affecting these pathways, such as the thickness of the contaminated zone and mass loading of dust in the air, will affect the results more than parameters affecting other

TABLE 2 Maximum Dose/Source Concentration Ratios for Scenario A (industrial worker: municipal water supply) at the Former Associate Aircraft Site

	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
Pathway	Uranium-234	Uranium-235	Uranium-238
External exposure	2.7×10^{-4}	1.8×10^{-1}	2.4×10^{-2}
Inhalation	1.3×10^{-2}	1.2×10^{-2}	1.2×10^{-2}
Radon	0	0	0
Ingestion of soil	2.5×10^{-3}	2.4×10^{-3}	2.4×10^{-3}

[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 (resident: municipal water supply) at the Former Associate Aircraft Site

	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
Pathway	Uranium-234	Uranium-235	Uranium-238
External exposure	8.5×10^{-4}	5.5×10^{-1}	7.7×10^{-2}
Inhalation	4.8×10^{-2}	4.4×10^{-2}	4.4×10^{-2}
Radon	0	0	0
Ingestion of plant foods	3.8×10^{-3}	3.7×10^{-3}	3.7×10^{-3}
Ingestion of soil	7.1×10^{-3}	6.8×10^{-3}	6.8×10^{-3}

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

TABLE 4 Maximum Dose/Source Concentration Ratios for Scenario C (subsistence farmer: on-site well water) at the Former Associate Aircraft Site

Pathway	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Uranium-234	Uranium-235	Uranium-238
External exposure	8.5×10^{-4}	5.5×10^{-1}	7.7×10^{-2}
Inhalation	4.8×10^{-2}	4.4×10^{-2}	4.4×10^{-2}
Radon	0	0	0
Ingestion of plant foods	1.9×10^{-2}	1.8×10^{-2}	1.8×10^{-2}
Ingestion of meat	1.6×10^{-3}	1.5×10^{-3}	1.5×10^{-3}
Ingestion of milk	3.9×10^{-3}	3.8×10^{-3}	3.8×10^{-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 Former Associate Aircraft Site

Radionuclide	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Scenario A[b]	Scenario B[c]	Scenario C[d]
Uranium-234	1.6×10^{-2}	5.9×10^{-2}	8.0×10^{-2}
Uranium-235	1.9×10^{-1}	6.1×10^{-1}	6.3×10^{-1}
Uranium-238	3.9×10^{-2}	1.3×10^{-1}	1.5×10^{-1}
Total uranium	3.1×10^{-2}	1.1×10^{-1}	1.3×10^{-1}

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

[b] Industrial worker (current-use scenario): no consumption of water or food obtained on the site.

[c] Resident: water used for drinking, household purposes, and irrigation is assumed to be from uncontaminated municipal sources (likely future-use scenario).

[d] Subsistence farmer: water used for drinking, household purposes, livestock watering, and irrigation is assumed to be from an on-site well (unlikely future-use scenario).

pathways. In addition, doses will depend strongly on the choice of occupancy factors selected for these two scenarios. In addition to the external gamma exposure and dust inhalation pathways, the plant ingestion pathway also contributes significantly to the dose calculated for Scenario C. Therefore, the guidelines for Scenario C will also be sensitive to parameters that affect this pathway, such as root uptake factors and plant ingestion rates.

Because the maximum dose occurs at time zero in all three scenarios, uncertainties in parameters that affect the leaching of radionuclides from the contaminated zone and their transport through unsaturated and saturated strata do not affect the results. It should be noted that the breakthrough time (the time it takes the uranium to reach the water table) is estimated to occur 600 years after remediation; however, the dose contribution from water-dependent pathways in Scenario C is smaller than the contribution of the water-independent pathways at the time of peak dose. Changing the depth to the water table only affects the breakthrough time, it does not significantly affect the magnitude of the dose contributed by water-dependent pathways.

The RESRAD default values were used in the calculations if no site-specific data were available. These defaults are based on national average or reasonable maximum values. In addition, the contaminated zone thickness of 0.3 m that was selected to derive the dose/source concentration ratios is based on the assumption that the soil is uniformly contaminated to that depth. In reality, the contamination occurs mostly in the top 15 cm of soil and is not dispersed uniformly throughout the site. For Scenario A, the thick concrete slab currently under the building would provide a significant amount of attenuation to external gamma radiation. In Scenarios B and C, it is likely that large amounts of potentially contaminated soil and demolition debris would be removed in preparing the site for residential or farming use. Therefore, the calculated dose/source ratios are conservative.

4 RESIDUAL RADIOACTIVE MATERIAL GUIDELINES

The residual radioactive material guideline is the concentration of residual radioactive material that can remain in the soil in a decontaminated area and still permit use of the area without radiological restrictions. Given a dose limit, DL, for an individual, the residual radioactive material guideline *G* for uranium at the former Associate Aircraft site can be calculated as

$$G = DL/DSR \ ,$$

where *DSR* is the total dose/source concentration ratio listed in Table 5. The dose limit, DL, used to derive the residual radioactive material guideline is 30 mrem/yr for the current-use and likely future-use scenarios and 100 mrem/yr for all other plausible future-use scenarios (Yu et al. 1993a). The calculated residual radioactive material guidelines for single radionuclides (uranium-234, uranium-235, and uranium-238) and total uranium are presented in Table 6.

For the calculations of the guidelines for total uranium, it was assumed that the activity concentration ratio of uranium-238, uranium-234, and uranium-235 is 1:1:0.046. The

TABLE 6 Residual Radioactive Material Guidelines for the Former Associate Aircraft Site

	Guideline[a] (pCi/g)		
Radionuclide	Scenario A[b]	Scenario B[c]	Scenario C[d]
Uranium-234	1,900	500	1,200
Uranium-235	160	50	160
Uranium-238	780	230	660
Total uranium	970	280	790

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

[b] Industrial worker: no consumption of water or food obtained on the site (current-use scenario, dose constraint = 30 mrem/yr).

[c] Resident: water used for drinking, household purposes, and irrigation is assumed to be from uncontaminated municipal sources (likely future-use scenario, dose constraint = 30 mrem/yr).

[d] Subsistence farmer: water used for drinking, household purposes, livestock watering, and irrigation is assumed to be from an on-site well (unlikely but plausible future-use scenario, dose limit = 100 mrem/yr).

derived guidelines for total uranium are 970, 280, and 790 pCi/g for Scenarios A, B, and C, respectively. If uranium-238 is measured as the indicator radionuclide, the uranium-238 limits for total uranium can be calculated by dividing the total uranium guidelines by 2.046. The resulting uranium-238 limits are 470, 140, and 390 pCi/g for Scenarios A, B, and C, respectively.

The law of sum of fractions applies when the derived radionuclide guidelines for decontamination of a site are implemented. That is, the summation of the radionuclide concentrations S_i remaining on-site (averaged over an area of 100 m^2 and a depth of 15 cm) 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 (a hot spot), the allowable concentration that can remain on-site may be higher than the homogeneous guideline, depending on the size of the contaminated area and in accordance with the ranges given in Table 7.

TABLE 7 Ranges for Hot-Spot Multiplication Factors

Area Range (m^2)	Factor (multiple of authorized limit)
<1	10[a]
1 - <3	6
3 - <10	3
10 - 25	2

[a] Areas less than 1 m^2 are to be averaged over a 1-m^2 area, and that average shall not exceed 10 times the authorized limit.

Source: Yu et al. (1993a).

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APPENDIX:

SCENARIOS AND PARAMETERS USED FOR THE ANALYSIS OF THE FORMER ASSOCIATE AIRCRAFT SITE

The following exposure scenarios were analyzed for the former Associate Aircraft site in Fairfield, Ohio:

- Scenario A: Industrial Use of the Site — Municipal Water Supply. A hypothetical person is assumed to work in the area of the site.

- Scenario B: Residential Use of the Site — Municipal Water Supply. A hypothetical resident is assumed to live in the decontaminated area and to use an uncontaminated municipal water supply for drinking, household purposes, and irrigation. The resident is assumed to ingest plant foods grown on-site; however, no livestock are raised on-site for the production of meat and milk, and no pond is present on-site to provide fish and other aquatic food.

- Scenario C: Subsistence Farming Use of the Site — On-Site Well Water. A hypothetical subsistence farmer is assumed to live in the decontaminated area and to use water from an on-site well for drinking, household purposes, livestock watering, and irrigation. The resident is assumed to ingest plant foods grown in the garden and meat and milk from livestock fed with forage grown on-site. The resident is assumed to catch and consume fish and other aquatic organisms from an on-site pond.

The parametric values used in the RESRAD code for the analysis of the former Associate Aircraft site are listed in Table A.1. These values are reported at up to three significant figures. Some parameters are specific to the former Associate Aircraft site; others are generic.

TABLE A.1 Parameters Used in the RESRAD Computer Code for the Analysis of the Former Associate Aircraft Site

Parameter	Unit	Value		
		Scenario A	Scenario B	Scenario C
Area of contaminated zone[a]	m^2	10,000	10,000	10,000
Thickness of contaminated zone[a]	m	0.3	0.3	0.3
Length parallel to aquifer flow[a]	m	Not used	Not used	100
Basic radiation dose limit[a,b]	mrem/yr	30	30	100
Cover depth[a]	m	0	0	0
Contaminated zone				
Density[b]	g/cm^3	1.5	1.5	1.5
Erosion rate[a]	m/yr	0	0	0
Total porosity[a]	—[c]	0.4	0.4	0.4
Effective porosity[a]	—[c]	0.3	0.3	0.3
Hydraulic conductivity[a]	m/yr	5,000	5,000	5,000
Soil-specific b parameter[a]	—[c]	4.05	4.05	4.05
Evapotranspiration coefficient[b]	—[c]	0.5	0.5	0.5
Precipitation[a]	m/yr	0.99	0.99	0.99
Irrigation[b]	m/yr	0.2	0.2	0.2
Irrigation mode[b]	—[c]	Overhead	Overhead	Overhead
Runoff coefficient[b]	—[c]	0.2	0.2	0.2
Watershed area for nearby pond[a,b]	m^2	Not used	Not used	1,000,000
Accuracy for water/soil computations[a,b]	—[c]	Not used	Not used	0.001
Saturated zone				
Density[a,b]	g/cm^3	Not used	Not used	1.5
Total porosity[a]	—[c]	Not used	Not used	0.4
Effective porosity[a]	—[c]	Not used	Not used	0.3
Hydraulic conductivity[a]	m/yr	Not used	Not used	5,000
Hydraulic gradient[a,b]	—[c]	Not used	Not used	0.02
Water table drop rate[a]	m/yr	Not used	Not used	0
Well pump intake depth (below water table)[a,b]	m	Not used	Not used	10
Model: nondispersion (ND) or mass balance (MB)[a,b]	—[c]	Not used	Not used	ND
Well pumping rate[a,b]	m^3/yr	Not used	Not used	250
Number of unsaturated zone strata[a]	—[c]	Not used	Not used	1
Unsaturated zone				
Thickness[a]	m	Not used	Not used	3.5
Soil density[a,b]	g/cm^3	Not used	Not used	1.5
Total porosity[a]	—[c]	Not used	Not used	0.4
Effective porosity[a]	—[c]	Not used	Not used	0.3
Soil-specific b parameter[a]	—[c]	Not used	Not used	4.05
Hydraulic conductivity[a,b]	m/yr	Not used	Not used	5,000
Distribution coefficient[a] (all zones)	cm^3/g			
Uranium-234		100	100	100
Uranium-235		100	100	100
Uranium-238		100	100	100
Actinium-227		450	450	450
Protactinium-231		550	550	550
Lead-210		270	270	270
Radium-226		500	500	500
Thorium-230		3,200	3,200	3,200
Inhalation rate[b]	m^3/yr	8,400	8,400	8,400
Mass loading for inhalation[a]	g/m^3	0.0001	0.0001	0.0001
Shielding factor, inhalation[b]	—[c]	0.4	0.4	0.4
Shielding factor, external gamma[b]	—[c]	0.7	0.7	0.7
Fraction of time indoors[a,b]	—[c]	0.23	0.5	0.5
Fraction of time outdoors[a,b]	—[c]	0.03	0.25	0.25

TABLE A.1 (Cont.)

Parameter	Unit	Value: Scenario A	Value: Scenario B	Value: Scenario C
Shape factor, external gamma[b]	—[c]	1	1	1
Dilution length for airborne dust, inhalation[b]	m	3	3	3
Food consumption				
Fruits, vegetables, and grain[a,b]	kg/yr	Not used	160	160
Leafy vegetables[a,b]	kg/yr	Not used	14	14
Milk[a,b]	L/yr	Not used	Not used	92
Meat and poultry[a,b]	kg/yr	Not used	Not used	63
Fish[a,b]	kg/yr	Not used	Not used	5.4
Other aquatic food[a,b]	kg/yr	Not used	Not used	0.9
Soil ingestion[b]	g/yr	36.5	36.5	36.5
Drinking water intake[a,b]	L/yr	Not used	Not used	510
Contaminated fraction of food and water	—[c]			
Drinking water[a,b]		Not used	Not used	1
Household water[a,b]		0	0	1
Livestock water[a,b]		Not used	Not used	1
Irrigation water[a,b]		Not used	0	1
Aquatic food[a,b]		Not used	Not used	0.5
Plant food[a]		Not used	0.1	0.5[d]
Meat[a]		Not used	Not used	0.5[d]
Milk[a]		Not used	Not used	0.5[d]
Livestock fodder intake for meat[a,b]	kg/d	Not used	Not used	68
Livestock fodder intake for milk[a,b]	kg/d	Not used	Not used	55
Livestock water intake for meat[a,b]	L/d	Not used	Not used	50
Livestock water intake for milk[a,b]	L/d	Not used	Not used	160
Livestock soil intake[a,b]	kg/d	Not used	Not used	0.5
Mass loading for foliar deposition[a,b]	g/m^3	Not used	0.0001	0.0001
Depth of soil mixing layer[b]	m	0.15	0.15	0.15
Depth of roots[a,b]	m	Not used	0.9	0.9
Groundwater fractional usage (balance from surface water)	—[c]			
Drinking water[a,b]		Not used	Not used	1
Household water[a,b]		Not used	Not used	1
Livestock water[a,b]		Not used	Not used	1
Irrigation[a,b]		Not used	Not used	1
Storage time of contaminated foodstuffs	days			
Fruits, non-leafy vegetables, and grain[a,b]		Not used	14	14
Leafy vegetables[a,b]		Not used	1	1
Fish[a,b]		Not used	Not used	7
Crustacea and mollusks[a,b]		Not used	Not used	7
Milk[a,b]		Not used	Not used	1
Meat and poultry[a,b]		Not used	Not used	20
Well water[a,b]		Not used	Not used	1
Livestock fodder[a,b]		Not used	Not used	45
Total porosity of the house or building foundation[b]	—[c]	0.1	0.1	0.1
Volumetric water content of the foundation[b]	—[c]	0.03	0.03	0.03
Diffusion coefficient for radon gas	m^2/s			
In foundation material[b]		3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}
In contaminated zone soil[b]		2.0×10^{-6}	2.0×10^{-6}	2.0×10^{-6}
Emanating power of radon-222[b]	—[c]	0.25	0.25	0.25
Radon vertical dimension of mixing[b]	m	2	2	2
Average annual wind speed[b]	m/s	2	2	2
Average building air exchange rate[b]	1/h	0.5	0.5	0.5
Height of building (room)[b]	m	2.5	2.5	2.5

TABLE A.1 (Cont.)

Parameter	Unit	Value		
		Scenario A	Scenario B	Scenario C
Building indoor area factor[b]	—[c]	0	0	0
Bulk density of house or building foundation[b]	g/cm^3	2.4	2.4	2.4
Thickness of house or building foundation[b]	m	0.15	0.15	0.15
Building depth below ground surface[b]	m	1	1	1

[a] Values based on site specifications, scenario assumptions, or Yu et al. (1993a,b).

[b] RESRAD default values.

[c] Parameter is dimensionless.

[d] Calculated with the RESRAD computer code.

Sources: Based on data from Murray et al. (1993); Orlandini (1994); Sheets (1994); Spieker (1965); Yu et al. (1993a,b).

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