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Derivation of Residual Radioactive Material Guidelines for Uranium in Soil at the Middlesex Sampling Plant Site, Middlesex, New Jersey

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

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
ALARA	as low as reasonably achievable
BNI	Bechtel National, Incorporated
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
FUSRAP	Formerly Utilized Sites Remedial Action Program
MED	Manhattan Engineer District
MML	Middlesex Municipal Landfill
MSL	mean sea level
MSP	Middlesex Sampling Plant
ORNL	Oak Ridge National Laboratory
RESRAD	*res*idual *rad*ioactive material guideline computer code
SAIC	Science Applications International Corporation

UNITS OF MEASURE

°C	degrees Celsius	L	liter(s)
cm	centimeter(s)	m	meter(s)
cm^3	cubic centimeter(s)	m^2	square meter(s)
d	day(s)	m^3	cubic meter(s)
°F	degrees Fahrenheit	mg	milligram(s)
ft	foot (feet)	mi	mile(s)
g	gram(s)	mph	mile(s) per hour
h	hour(s)	mrem	millirem(s)
ha	hectare(s)	pCi	picocurie(s)
in.	inch(es)	s	second(s)
kg	kilogram(s)	yd^3	cubic yard(s)
km	kilometer(s)	yr	year(s)

DERIVATION OF RESIDUAL RADIOACTIVE MATERIAL GUIDELINES FOR URANIUM IN SOIL AT THE MIDDLESEX SAMPLING PLANT SITE, MIDDLESEX, NEW JERSEY

by

D.E. Dunning

SUMMARY

Residual radioactive material guidelines for uranium in soil were derived for the Middlesex Sampling Plant (MSP) site in Middlesex, New Jersey. This site has been designated for remedial action under the Formerly Utilized Sites Remedial Action Program (FUSRAP) of the U.S. Department of Energy (DOE). The site became contaminated from operations conducted in support of the Manhattan Engineer District (MED) and the Atomic Energy Commission (AEC) between 1943 and 1967. Activities conducted at the site included sampling, storage, and shipment of uranium, thorium, and beryllium ores and residues. Uranium guidelines for single radioisotopes and total uranium were derived on the basis of the requirement that the 50-year committed effective dose equivalent to a hypothetical individual living or working in the immediate vicinity of the MSP site should not exceed a dose of 30 mrem/yr following remedial action for the current-use and likely future-use scenarios or a dose of 100 mrem/yr for less likely future-use scenarios.

The RESRAD computer code, which implements the methodology described in the DOE manual for establishing residual radioactive material guidelines, was used in this evaluation. Four scenarios were considered for the site. These scenarios vary regarding future land use at the site, sources of water used, and sources of food consumed. The evaluation indicates that the dose constraint of 30 mrem/yr would not be exceeded within 1,000 years if the soil concentrations of total combined uranium (i.e., uranium-234, uranium-235, and uranium-238) at the MSP site did not exceed 1,100 pCi/g for Scenario A (industrial worker) or 1,800 pCi/g for Scenario B (recreational user). The dose limit of 100 mrem/yr would not be exceeded at the site if the total uranium concentration did not exceed the level of 860 pCi/g for Scenario C (resident using only water sources not affected by site conditions) or 430 pCi/g for Scenario D (subsistence farmer using only water from an on-site well).

Uranium guidelines derived in this report apply to the combined activity concentration of uranium-234, uranium-235, and uranium-238 present in their natural activity concentration ratio of 1:1:0.046. Consequently, if uranium-238 is measured as the indicator radionuclide, the respective soil concentration guidelines would be 540 pCi/g for Scenario A, 880 pCi/g for Scenario B, 420 pCi/g for Scenario C, and 210 pCi/g for Scenario D. In setting the actual

uranium guidelines for this site, DOE will apply the as-low-as-reasonably-achievable (ALARA) policy to the decision-making process and will consider such other factors as whether a particular scenario is reasonable and appropriate and whether the contamination is isolated and localized.

1 INTRODUCTION

The Middlesex Sampling Plant (MSP) site is in the Borough of Middlesex, Middlesex County, New Jersey (Figure 1). This site was established in 1943 as part of the Manhattan Engineer District (MED) and was used for sampling, storing, and shipping uranium, thorium, and beryllium ores. The U.S. Department of Energy (DOE) has designated the site as a candidate for remedial action under DOE's Formerly Utilized Sites Remedial Action Program (FUSRAP). FUSRAP was established in 1974 by the U.S. Atomic Energy Commission (AEC), a predecessor agency of DOE. The mandate of the program is to identify, evaluate, and, if necessary, decontaminate sites previously used by the AEC or MED, or otherwise designated for FUSRAP responsibility.

Remedial actions at the MSP site will follow the guidelines established in DOE Order 5400.5 (DOE 1990). The DOE residual radioactive material computer code, RESRAD (Yu et al. 1993), is used to derive residual radionuclide guidelines on a site-specific basis. This report presents guidelines for residual uranium concentrations in soils at the MSP site. These guidelines were derived for 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. The dose constraint of 30 mrem/yr is not currently required under DOE Order 5400.5 but is specified in the proposed Title 10, Code of Federal Regulations, Part 834 (10 CFR Part 834) rulemaking (DOE 1993) to account for additional dose contributions from other potential sources of radiation exposure.

1.1 SITE DESCRIPTION AND SETTING

The MSP site is in a highly developed area of northern New Jersey, approximately 29 km (18 mi) from Newark, New Jersey. The site occupies 3.9 ha (9.6 acres), 3.2 ha (8 acres) of which was paved to provide a drum storage area. A 2.1-m- (7-ft-) high chain-link fence surrounds the site and the four buildings on it (Figure 2). Building A was used for administrative offices during active operation of the site. Building B was a garage. Building C was the process building, where the ore was weighed, assayed, and sampled. Building D was a boiler house that provided steam for the process building. The MSP site is currently used by DOE for storage of about 50,600 m^3 (66,300 yd^3) of contaminated soil excavated from vicinity properties during 1980-1981 and 1984-1986 (Bechtel National, Incorporated [BNI] 1991). No continuing commercial or industrial activities now occur at the MSP site.

The eastern side of the property borders fields and garden areas, and the western side borders an industrial site. The property to the south consists of marshy land and fields and includes the drainage ditch that carries runoff from the MSP site into Main Stream. The main entrance to the facility (Mountain Avenue) is on the northern side of the site, which also borders the Lehigh Valley Railroad right-of-way.

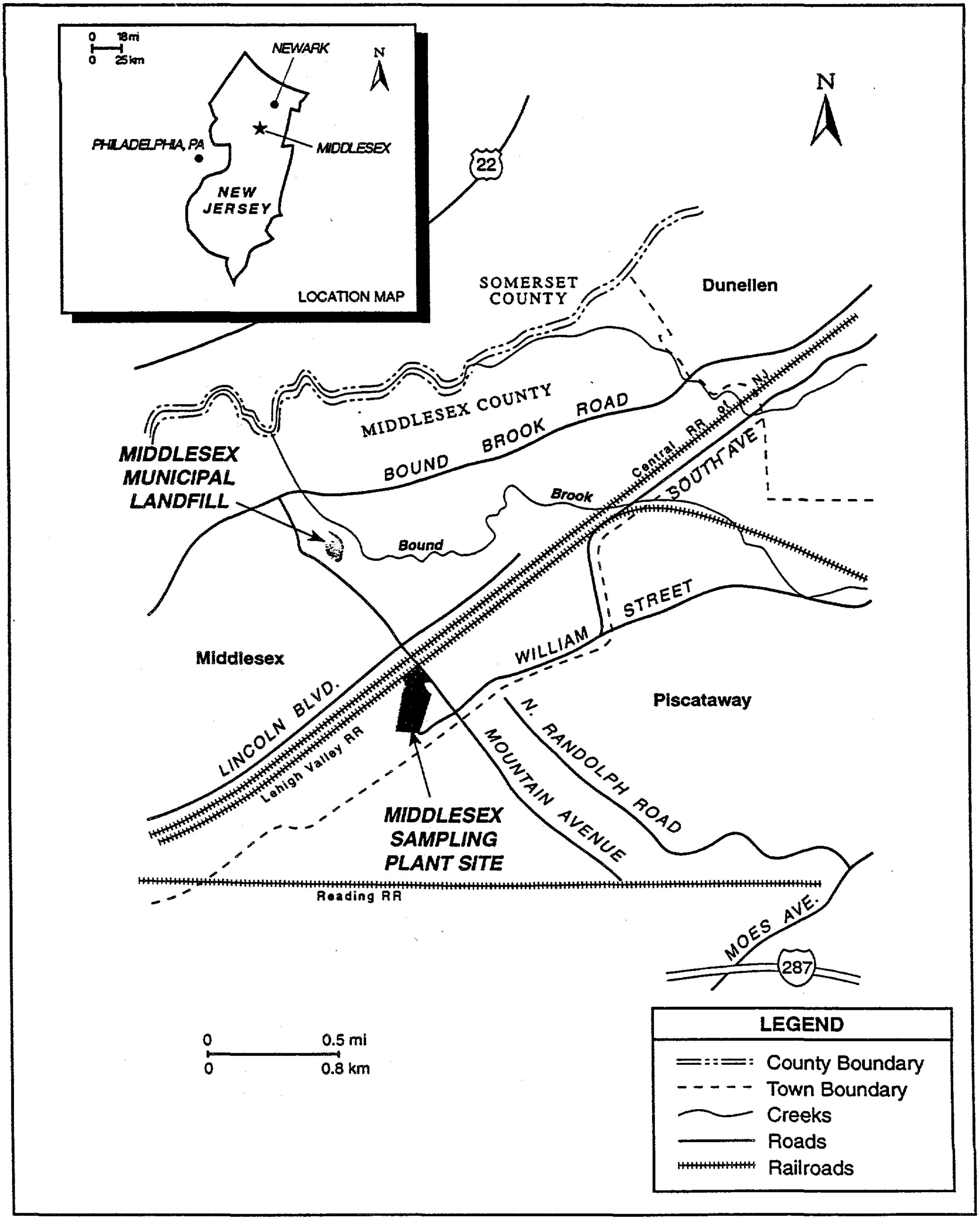

FIGURE 1 Location of the MSP Site (Source: SAIC 1995)

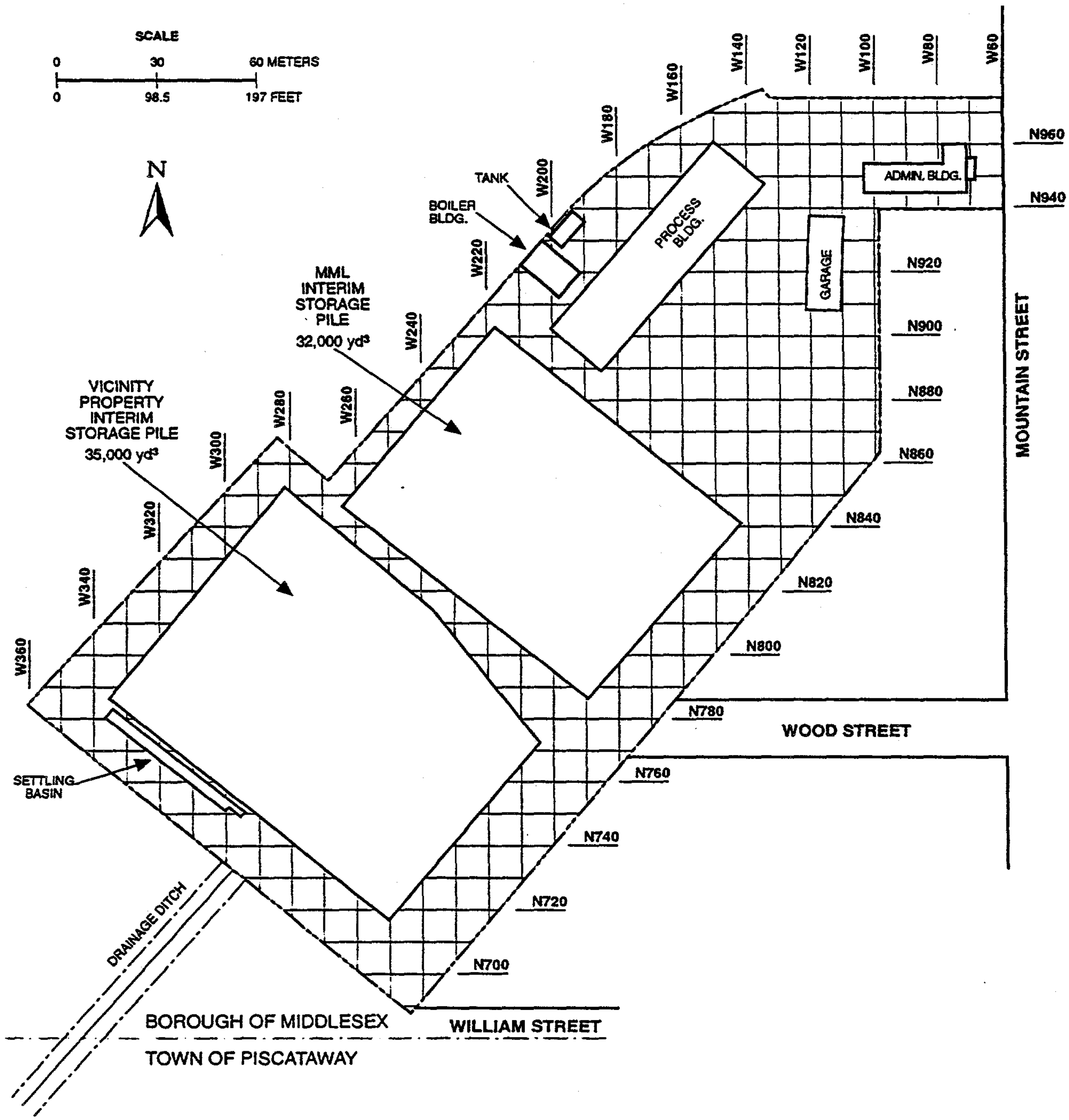

FIGURE 2 Major Features of the MSP Site (Source: SAIC 1995)

The site slopes gently from about 18 m (60 ft) above mean sea level (MSL) at the gate on the northern end to 15 m (50 ft) above MSL at the fence line on the southern end (BNI 1989b). The topography of Middlesex County varies from nearly level at some points to gently rolling at others. Maximum elevations are about 73 m (240 ft) above MSL in the southwestern part of South Brunswick Township; the lowest elevations approach sea level at the tidal areas on Raritan Bay and at the mouth of the Raritan River.

The regional climate is humid, with a mean annual precipitation of 1.1 m (42.1 in.). The annual daily maximum temperature for the Middlesex area is 16.9°C (62.5°F), and the average daily minimum is 7.3°C (45.2°F). Winds are predominantly from the west at a mean speed of 14 to 18.4 km/h (8.7 to 11.4 mph).

1.2 SITE HISTORY

The MSP was established in 1943 in support of MED activities. Uranium operations were conducted at the site under contract with United Lead Company between 1943 and 1955. Ores received at the facility were thawed (if necessary), dried, crushed, screened, and collected in hoppers, which were sampled for assay. These ores were then packaged, weighed, and shipped to processing facilities (BNI 1991).

During 1951 and 1952, MSP became the intermediate shipment point for uranium bars shipped from the Lake Ontario Ordnance Works to the American Machine and Foundry Company in Brooklyn, New York. At the Brooklyn facility, the bars were experimentally machined into slugs (Science Applications International Corporation [SAIC] 1995). Scrap from this operation was returned to MSP for shipment to a uranium recovery processor. Before closing, the MSP site also processed beryllium ore for shipment to Brush Beryllium in Luckey, Ohio (BNI 1989a).

The AEC ended most operations at MSP in 1955. However, the site continued to be used for storage and limited sampling of thorium residues. After all AEC activities at MSP ended in 1967, on-site structures were decontaminated, and the site was certified for unrestricted use under radiological release criteria then in effect. In 1968, the AEC returned the MSP to the General Services Administration, which transferred the property to the Department of the Navy. The site served as a U.S. Marine Corps reserve training center from 1969 to 1979 (BNI 1991).

In 1976, Oak Ridge National Laboratory (ORNL) conducted a radiological survey of MSP. That survey showed the presence of soil contamination. That contamination was primarily localized to near-surface soils throughout the site, with the area of highest incidence near the process building (ORNL 1980). Contamination was also identified within the on-site buildings and in the drainage ditch south of the property. An additional radiological survey was conducted for ORNL by Roy F. Weston, Inc., in 1980, with similar results (BNI 1989b).

In 1980, the MSP site was placed in DOE custody. During 1980-1981, DOE conducted a remedial action to clean up approximately 36 vicinity properties where residual radioactive contamination exceeded DOE guidelines. All but two of these properties were adjacent to the MSP site. Contaminated materials were apparently transported to the two remote properties for use as fill. Approximately 27,000 m^3 (35,000 yd^3) of contaminated soil was excavated during these remedial actions, transported to MSP, and placed in interim storage on an existing asphalt pad that was improved before waste emplacement (BNI 1991). This interim waste storage pile is labeled as the "vicinity property interim storage pile" in Figure 2.

A second interim waste storage pile (labeled as the "MML interim storage pile" in Figure 2) was constructed at the MSP site during 1984-1986 to hold material excavated from the Middlesex Municipal Landfill (MML). Operations at MML began in the mid-1940s. In 1948, soil contaminated with pitchblende (high-grade uranium ore) was removed from MSP and placed on top of the existing fill at MML. The contaminated material was covered to varying depths in later landfill operations. Excavation of the radioactively contaminated materials from the MML began in 1984, when approximately 11,500 m^3 (15,100 yd^3) of the contaminated soil was transported to MSP for interim storage; the MML interim storage pile was expanded in 1986 to hold the remaining 12,200 m^3 (16,000 yd^3) of contaminated material from the MML.

1.3 DERIVATION OF CLEANUP GUIDELINES

Because no generic cleanup guidelines for uranium applicable to remedial actions at FUSRAP sites are available, uranium guidelines 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, uranium-238, and total uranium) that are applicable to remedial action at the MSP 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 total uranium guideline 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.

The derivation of site-specific uranium guidelines for the MSP site was based on 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. 1993). The assumption was made that uranium is the only radionuclide present above background concentrations. The RESRAD computer code (version 5.41), which implements the methodology described in the DOE manual for establishing residual radioactive material guidelines (Yu et al. 1993), was used to derive these guidelines. The DOE will establish the final uranium guidelines for this site by applying the as-low-as-reasonably-achievable (ALARA) policy to the derived guidelines presented in this report and by considering such other factors as whether a particular scenario is reasonable and appropriate and whether the contamination is isolated and localized.

2 SCENARIO DEFINITIONS

Four potential exposure scenarios are considered for the MSP site. For all scenarios it is assumed that at some time within 1,000 years the site will be released for use without radiological restrictions following remediation.

Scenario A (the current-use scenario) assumes continued industrial use of the site. A hypothetical employee is assumed to work in the decontaminated area for 8 hours per day (7 hours indoors and 1 hour outdoors), 5 days per week, 50 weeks per year. The industrial worker does not ingest drinking water, plant foods, or fish from the decontaminated area and does not 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 is assumed to spend 15 hours per week, 50 weeks per year in the decontaminated area of the park. The recreational user does not ingest drinking water, plant foods, or fish from the decontaminated area and does not ingest meat or milk from livestock raised in the decontaminated area.

Scenario C (a plausible but unlikely scenario) assumes residential use of the site. The resident is assumed to spend 12 hours per day indoors and 6 hours per day outdoors in the decontaminated area. This hypothetical resident is assumed to obtain all water from a distant source not affected by site conditions. (The site is currently served by a municipal water supply.) The resident ingests plant foods grown in a garden in the decontaminated area but does not ingest meat or milk from livestock raised in the decontaminated area nor fish grown in a pond in the decontaminated area.

Scenario D (a plausible but unlikely scenario) assumes the presence of a subsistence farmer at the site. The farmer drinks water obtained from a well at the downgradient edge of the decontaminated area, ingests plant foods grown in a garden in the decontaminated area, ingests fish taken from a pond assumed to be constructed adjacent to and downgradient of the decontaminated area, and ingests meat and milk from livestock raised in the decontaminated area. Site occupancy assumptions are the same as for Scenario C. All water used for drinking, irrigating, and livestock watering is assumed to be drawn from the on-site well. (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 building structures and the paved areas at the site. For the purposes of this analysis, it is assumed that any residual soil contamination is not removed during this process.)

Potential radiation doses resulting from nine exposure pathways were 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 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 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 the 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 the on-site well, (8) internal radiation from 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.

The following assumptions were made in using the RESRAD code (Yu et al. 1993) to calculate the potential radiation doses to each of the hypothetical future receptors:

- The industrial worker spends 2,000 hours per year on-site (7 hours per day indoors and 1 hour per day outdoors for 250 days per year). The recreationist spends 750 hours per year on-site, all outdoors. The resident and subsistence farmer each spend 6,570 hours per year on-site in the decontaminated area (12 hours per day indoors and 6 hours per day outdoors for 365 days per year).

- The walls, floor, and foundation of the house or commercial building reduce external exposure by 30%, and the indoor dust level is 40% of the outdoor dust level (Yu et al. 1993).

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

- The house or building foundation is assumed to be built at the ground surface (i.e., foundation depth of 0 m below ground surface), with an effective radon diffusion coefficient of 3×10^{-7} m^2/s (Yu et al. 1993).

- The size of the decontaminated area is sufficiently large that 10% and 50% of the produce consumed by the resident (Scenario C) and subsistence farmer (Scenario D), respectively, is grown in a garden in the decontaminated area. Neither the industrial worker nor the recreationist consumes produce from an on-site garden.

- Ingestion of meat or milk from livestock raised in the decontaminated area is considered only for the subsistence farmer (Scenario D). The decontaminated area is sufficiently large to produce 50% of the forage used to feed livestock used for meat and milk consumed by the subsistence farmer in Scenario D. The industrial worker, recreationist, and resident do not consume meat or milk from livestock raised on-site.

- The current water supply for the MSP site is from uncontaminated municipal sources. However, under Scenario D, a well at the downgradient edge of the decontaminated area is assumed to provide all water for drinking, household purposes, livestock watering, and irrigation of the on-site garden. No such well is assumed to exist for Scenarios A, B, and C, so the industrial worker, recreational user, and resident would not use water from an on-site source.

- An adjacent pond provides 50% of the aquatic food (fish) consumed by the subsistence farmer (Scenario D). The industrial worker, recreationist, and resident do not consume any aquatic food from the decontaminated area.

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

- The entire area of the MSP site is assumed to be uniformly contaminated with residual uranium to a depth of 1 m. (This assumption is based on the observed depth of contamination before remediation [SAIC 1995]).

- Site-specific estimates of hydrogeologic properties for the MSP site are used for the following parameters: saturated/unsaturated zone total porosity, saturated/unsaturated zone effective porosity, saturated/unsaturated zone hydraulic conductivity, saturated zone hydraulic gradient, and unsaturated zone thickness (Redmon 1994a). In the absence of site-specific data for other parameters, site features are assumed to be adequately characterized by RESRAD default parameter values.

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

TABLE 1 Summary of Pathways Considered for Scenarios A, B, C, and D[a]

Pathway	Scenario A	Scenario B	Scenario C	Scenario D
External exposure	Yes	Yes	Yes	Yes
Particulate inhalation	Yes	Yes	Yes	Yes
Radon inhalation	Yes	Yes	Yes	Yes
Ingestion of soil	Yes	Yes	Yes	Yes
Ingestion of produce from on-site garden	No	No	Yes	Yes
Ingestion of meat from on-site livestock	No	No	No	Yes
Ingestion of milk from on-site livestock	No	No	No	Yes
Ingestion of fish from on-site pond	No	No	No	Yes
Ingestion of water from on-site well	No	No	No	Yes

[a] Scenario A, industrial worker; Scenario B, recreational user; Scenario C, resident using a distant water source unaffected by site conditions; and Scenario D, subsistence farmer using an on-site well as the only water source.

3 DOSE/SOURCE CONCENTRATION RATIOS

To compute the guidelines for the MSP site, the RESRAD computer code, version 5.41 (Yu et al. 1993), was used to calculate the dose/source concentration ratio $DSR_{ip}(t)$ for uranium isotope i and pathway p at time t after remediation. The period 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 5 for Scenarios A through D. For Scenarios A, B, and C, the maximum dose/source concentration ratios are predicted to occur at time zero (immediately after remediation); for Scenario D, the maximum dose/source concentration ratio is predicted to occur 1,000 years after the remedial action. In Scenarios A, B, and C, the dose from natural uranium in soil is primarily from the external exposure and particulate inhalation pathways, with smaller contributions from soil ingestion and ingestion of produce from an on-site garden (Scenario C only). In Scenario D, the primary exposure pathway is predicted to be ingestion of drinking water from an on-site well.

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

$$DRS_i(t) = \sum_p DSR_{ip}(t) \; .$$

The total dose/source concentration ratio for total uranium (enriched, depleted, or normal) can be calculated as

$$DRS(t) = \sum_i W_i \, DSR_i(t) \; .$$

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 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 uranium isotopes and total uranium are provided in Table 6. These ratios were used to determine the allowable residual radioactivity for uranium at the MSP 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 most strongly influence the results in each case. For Scenarios A, B, and C, the external exposure and

TABLE 2 Maximum Dose/Source Concentration Ratios for Scenario A (industrial worker)

	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
Pathway	Uranium-234	Uranium-235	Uranium-238
External exposure	2.4×10^{-4}	1.6×10^{-1}	2.2×10^{-2}
Particulate inhalation	1.2×10^{-2}	1.1×10^{-2}	1.1×10^{-2}
Radon inhalation	0	0	0
Ingestion of soil	2.2×10^{-3}	2.1×10^{-3}	2.1×10^{-3}
Ingestion of produce from on-site garden	0	0	0
Ingestion of meat from on-site livestock	0	0	0
Ingestion of milk from on-site livestock	0	0	0
Ingestion of fish from on-site pond	0	0	0
Ingestion of water from on-site well	0	0	0

[a] Maximum dose/source concentration ratios are predicted to 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 (recreational user)

	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
Pathway	Uranium-234	Uranium-235	Uranium-238
External exposure	1.2×10^{-4}	7.9×10^{-2}	1.1×10^{-2}
Particulate inhalation	9.3×10^{-3}	8.5×10^{-3}	8.5×10^{-3}
Radon inhalation	0	0	0
Ingestion of soil	8.2×10^{-4}	7.8×10^{-4}	7.8×10^{-4}
Ingestion of produce from on-site garden	0	0	0
Ingestion of meat from on-site livestock	0	0	0
Ingestion of milk from on-site livestock	0	0	0
Ingestion of fish from on-site pond	0	0	0
Ingestion of water from on-site well	0	0	0

[a] Maximum dose/source concentration ratios are predicted to 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 (resident)

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}	7.9×10^{-2}
Particulate inhalation	4.8×10^{-2}	4.5×10^{-2}	4.5×10^{-2}
Radon inhalation	0	0	0
Ingestion of soil	7.1×10^{-3}	6.8×10^{-3}	6.8×10^{-3}
Ingestion of produce from on-site garden	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}
Ingestion of meat from on-site livestock	0	0	0
Ingestion of milk from on-site livestock	0	0	0
Ingestion of fish from on-site pond	0	0	0
Ingestion of water from on-site well	0	0	0

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

TABLE 5 Maximum Dose/Source Concentration Ratios for Scenario D (subsistence farmer)

Pathway	Maximum Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)		
	Uranium-234	Uranium-235	Uranium-238
External exposure	0	0	0
Particulate inhalation	0	0	0
Radon inhalation	1.8×10^{-4}	0	4.1×10^{-7}
Ingestion of soil	0	0	0
Ingestion of produce from on-site garden	1.5×10^{-2}	7.1×10^{-2}	1.4×10^{-2}
Ingestion of meat from on-site livestock	1.5×10^{-3}	2.0×10^{-3}	1.4×10^{-3}
Ingestion of milk from on-site livestock	5.5×10^{-3}	5.8×10^{-3}	5.5×10^{-3}
Ingestion of fish from on-site pond	1.0×10^{-3}	1.7×10^{-2}	7.7×10^{-3}
Ingestion of water from on-site well	2.0×10^{-1}	9.2×10^{-1}	1.9×10^{-1}

[a] Maximum dose/source concentration ratios are predicted to occur 1,000 years following remedial action; all values are reported to two significant figures.

TABLE 6 Total Dose/Source Concentration Ratios for Uranium for Scenarios A-D

	Total Dose/Source Concentration Ratio[a] (mrem/yr)/(pCi/g)			
Radionuclide	Scenario A	Scenario B	Scenario C	Scenario D
Uranium-234	1.4×10^{-2}	1.0×10^{-2}	6.8×10^{-2}	2.2×10^{-1}
Uranium-235	1.7×10^{-1}	8.9×10^{-2}	6.2×10^{-1}	1.0×10^{-0}
Uranium-238	3.5×10^{-2}	2.1×10^{-2}	1.4×10^{-1}	2.1×10^{-1}
Total Uranium	2.8×10^{-2}	1.7×10^{-2}	1.2×10^{-1}	2.3×10^{-1}

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

particulate inhalation pathways contribute most of the dose. Therefore, uncertainties in parameters affecting these pathways (e.g., occupancy factors, thickness of the contaminated zone, shielding provided by buildings and site features, mass loading of contaminated airborne particulates, inhalation rate) have the greatest impact on the model predictions, and parameters related to other pathways have little impact. Because the maximum dose occurs at time zero for these scenarios, uncertainties in parameters related to the leaching of radionuclides from the contaminated zone do not affect the results. In Scenario D, however, for which a large fraction of the total dose is contributed by the drinking water pathway, the predicted dose would be very sensitive to uncertainties in parameters related to the leaching and transport of radionuclides. Such parameters include soil properties, meteorological parameters, distribution coefficients, water consumption rates, thickness of the contaminated zone, and others.

One area of particular uncertainty in this analysis is the distribution coefficient, K_d. For five site-specific soil samples analyzed, K_d ranged from 0.89 to 197 cm^3/g (Redmon 1994b). The mean of these results (50 cm^3/g) has been used for this analysis. Use of the minimum result (about 1 cm^3/g) would lead to predictions of more rapid uranium migration in groundwater and higher DSR ratio estimates for Scenario D (9.5 mrem/yr per pCi/g for total uranium). Under these conditions, the dominant contributor to dose would be the groundwater ingestion pathway, and the peak dose would occur approximately 45 years after remedial action. However, the source term would be rapidly depleted through groundwater migration, and the total DSR for the site would decrease rapidly after a few years.

For the purposes of this analysis, RESRAD default parameter values were used if no site-specific data were available. The default values are based on national average or reasonable maximum values. The contaminated zone thickness of 1 m used to derive the dose/source concentration ratios is based on the measured depth of contaminated soils, with the assumption that the soil is uniformly contaminated to that depth. In reality, following remediation of the site, the residual contamination would occur in localized areas, primarily in the near-surface soil, and would not be dispersed uniformly throughout the site to this depth. Therefore, the calculated dose/source concentration ratios are conservative. Furthermore, some exposure pathways evaluated in this analysis have been included for purposes of completeness, but are considered very unlikely to be applicable in this case. For example, production of meat and milk from livestock raised on-site is considered very unlikely given the urban location and physical characteristics of the site. Similarly, development of a fishing pond at the site is not likely given the physical and hydrogeologic characteristics of the site, surrounding land use, and the availability of other fishing resources in the area.

4 RESIDUAL RADIOACTIVE MATERIAL GUIDELINES

A residual radioactive material guideline represents the concentration of residual radioactive material that can remain in a decontaminated area and still allow use of that area without radiological restrictions. Given a dose limit of H_{EL} for an individual, the residual radioactive material guideline, G, for uranium at the MSP site can be calculated as

$$G = H_{EL} / DSR ,$$

where DSR is the total dose/source concentration ratio listed in Table 6. The dose limit, H_{EL}, used to derive the residual radioactive material guidelines is 30 mrem/yr for the current-use and likely future-use scenarios and 100 mrem/yr for all other plausible future-use scenarios (DOE 1990, 1992; Yu et al. 1993). The calculated residual radioactive material guidelines for individual uranium isotopes (uranium-234, uranium-235, and uranium-238) and total uranium are presented in Table 7.

For calculation of the total uranium guidelines for the MSP site, 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 1,100 pCi/g for Scenario A, 1,800 pCi/g for Scenario B, 860 pCi/g for Scenario C, and 430 pCi/g for Scenario D. 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 540 pCi/g, 880 pCi/g, 420 pCi/g, and 210 pCi/g for Scenarios A, B, C, and D, respectively.

The law of sum-of-the-fractions applies in implementation of the derived radionuclide guidelines for remediation of a site. That is, the summation of the fractions of radionuclide concentrations S_i remaining on-site, averaged over an area of 100 m^2 and a depth of 15 cm and divided by the respective guidelines, G_i, should not be greater than unity:

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

The residual guidelines for uranium, as approved by DOE, will be implemented in conjunction with the authorized guidelines for radium and thorium using the law of the sum-of-the-fractions (DOE 1990).

The derived guidelines presented in Table 7 apply to a large, homogeneously contaminated area. For a small, isolated area of contamination (i.e., a hot-spot), the allowable concentration that can remain on-site may be higher than the homogeneous guideline, depending on the size of the area of contamination and in accord with the ranges given in Table 8.

TABLE 7 Residual Radioactive Material Guidelines for Uranium for Scenarios A-D

	Guideline[a] (pCi/g), by Scenario			
Radionuclide	Scenario A[b]	Scenario B[c]	Scenario C[d]	Scenario D[e]
Uranium-234	2.1×10^3	2.9×10^3	1.5×10^3	4.5×10^2
Uranium-235	1.8×10^2	3.4×10^2	1.6×10^2	9.6×10^1
Uranium-238	8.5×10^2	1.5×10^3	7.1×10^2	4.8×10^2
Total Uranium	1.1×10^3	1.8×10^3	8.6×10^2	4.3×10^2

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

[b] Industrial worker (current-use scenario: 30 mrem/yr dose constraint).

[c] Recreational user (plausible future-use scenario: 30 mrem/yr dose constraint).

[d] Resident using water from uncontaminated municipal sources (unlikely but plausible future-use scenario: 100 mrem/yr dose limit).

[e] Subsistence farmer using water from on-site well for drinking, household purposes, livestock watering, and irrigation (unlikely but plausible future-use scenario: 100 mrem/yr dose limit).

TABLE 8 Ranges for Hot-Spot Multiplication Factors

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

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

Source: Yu et al. (1993).

5 REFERENCES

Bechtel National, Inc., 1985, *Radiological Survey Report for the Former Middlesex Sampling Plant*, DOE/OR/20722-20, prepared for U.S. Department of Energy, Oak Ridge, Tenn., March.

Bechtel National, Inc., 1989a, *Preliminary Assessment for Middlesex Sampling Plant*, Job No. 14501, Oak Ridge, Tenn., July.

Bechtel National, Inc., 1989b, *Site Inspection for Middlesex Sampling Plant*, Job No. 14501, Oak Ridge, Tenn., July.

Bechtel National, Inc., 1991, *Characterization Report for the Interim Storage Piles at the Middlesex Sampling Plant*, DOE/OR/21949-247, prepared for U.S. Department of Energy, Oak Ridge, Tenn., Dec.

BNI — see Bechtel National, Inc.

DOE — see U.S. Department of Energy.

Oak Ridge National Laboratory, 1980, *Radiological Survey of the Middlesex Municipal Landfill Site, Middlesex, New Jersey,* DOE/EV-005/20, Oak Ridge, Tenn.

ORNL — see Oak Ridge National Laboratory.

Redmon, M.E., 1994a, memorandum from Redmon (Bechtel National, Inc., Oak Ridge, Tenn.) to D.E. Dunning (Argonne National Laboratory, Oak Ridge, Tenn.), Sept. 23.

Redmon, M.E., 1994b, memorandum from Redmon (Bechtel National, Inc., Oak Ridge, Tenn.) to D.E. Dunning (Argonne National Laboratory, Oak Ridge, Tenn.), Oct. 31.

SAIC — See Science Applications International Corporation.

Science Applications International Corporation, 1995, *Characterization Report for the Middlesex Site, Middlesex, New Jersey*, prepared for U.S. Department of Energy, Oak Ridge, Tenn.

U.S. Department of Energy, 1990, "Radiation Protection of the Public and the Environment," DOE Order 5400.5, Washington, D.C., Feb. 8.

U.S. Department of Energy, 1992, *Radiological Control Manual*, DOE N 5480.6, Washington, D.C., June.

U.S. Department of Energy, 1993, "Radiation Protection of the Public and the Environment," Notice of Proposed Rulemaking, 10 CFR Part 834, *Federal Register* 58(56):16268, March 25.

Yu, C., et al., 1993, *Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD Version 5.0,* ANL/EAD/LD-2, Argonne National Laboratory, Argonne, Ill., Sept.

APPENDIX:

SCENARIOS AND PARAMETERS USED FOR ANALYSIS OF THE MSP SITE

The following exposure scenarios were analyzed for the Middlesex Sampling Plant (MSP) site, in Middlesex, New Jersey:

- Scenario A: Industrial Use of the Site. A hypothetical person is assumed to work in the decontaminated area of the site.

- Scenario B: Recreational Use of the Site. A hypothetical person is assumed to use the decontaminated area of the site for recreational purposes (e.g., a community park).

- Scenario C: Residential Use of the Site - Municipal Water Supply. A hypothetical person is assumed to live in the decontaminated area and to use an uncontaminated water source (e.g., a municipal water supply) for drinking, household purposes, and irrigation. The resident is assumed to ingest produce grown in an on-site garden; however, no livestock are raised on the site for the production of meat or milk, and no pond is constructed on-site to provide fish and other aquatic foods.

- Scenario D: Subsistence Farming Use of the Site. A hypothetical person 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 subsistence farmer is assumed to ingest plant foods grown on-site, meat and milk from livestock fed with forage grown in the decontaminated area, and fish from an on-site pond.

The parametric values used in the RESRAD code for the analysis of the MSP site are listed in Table A.1. All parametric values are reported to two significant figures. Some parameters are specific to the site, while other values are generic.

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

Parameter	Unit	Value,[a] by Scenario			
		Scenario A	Scenario B	Scenario C	Scenario D
Dose limit	mrem/yr	30	30	100	100
Area of contaminated zone[b]	m^2	39,000	39,000	39,000	39,000
Thickness of contaminated zone[b]	m	1	1	1	1
Length parallel to aquifer flow[b]	m	200	200	200	200
Cover depth	m	0	0	0	0
Density of contaminated zone	g/cm^3	1.5	1.5	1.5	1.5
Contaminated zone erosion rate	m/yr	0.001	0.001	0.001	0.001
Contaminated zone total porosity[c]	–	0.45	0.45	0.45	0.45
Contaminated zone effective porosity[c]	–	0.35	0.35	0.35	0.35
Contaminated zone hydraulic conductivity[c]	m/yr	63	63	63	63
Contaminated zone "b" parameter	–	5.3	5.3	5.3	5.3
Evapotranspiration coefficient	–	0.5	0.5	0.5	0.5
Precipitation[b]	m/yr	1.1	1.1	1.1	1.1
Irrigation	m/yr	0.2	0.2	0.2	0.2
Irrigation mode	–	Not used	Not used	Overhead	Overhead
Runoff coefficient	–	0.2	0.2	0.2	0.2
Watershed area for pond	m^2	Not used	Not used	Not used	1,000,000
Density of saturated zone	g/cm^3	Not used	Not used	Not used	1.5
Saturated zone total porosity[c]	–	Not used	Not used	Not used	0.45
Saturated zone effective porosity[c]	–	Not used	Not used	Not used	0.35
Saturated zone hydraulic conductivity[c]	m/yr	Not used	Not used	Not used	63
Saturated zone hydraulic gradient[c]	–	Not used	Not used	Not used	0.02
Saturated zone "b" parameter	–	Not used	Not used	Not used	5.3
Water table drop rate	m/yr	Not used	Not used	Not used	0.001
Well pump intake depth[c] (below water table)	m	Not used	Not used	Not used	15
Well pumping rate	m^3/yr	Not used	Not used	Not used	250
Model: nondispersion (ND) or mass-balance (MB)	–	Not used	Not used	Not used	ND
Number of unsaturated zone strata	–	Not used	Not used	Not used	1
Unsaturated zone 1 thickness[c]	m	Not used	Not used	Not used	1.4
Unsaturated zone 1 soil density	g/cm^3	Not used	Not used	Not used	1.5
Unsaturated zone 1 total porosity[c]	–	Not used	Not used	Not used	0.45
Unsaturated zone 1 effective porosity[c]	–	Not used	Not used	Not used	0.35
Unsaturated zone 1 soil b parameter	–	Not used	Not used	Not used	5.3
Unsaturated zone 1 hydraulic conductivity[c]	m/yr	Not used	Not used	Not used	63
Distribution coefficient (all zones)					
Uranium-238[d]	cm^3/g	50	50	50	50
Uranium-235[d]	cm^3/g	50	50	50	50
Uranium-234[d]	cm^3/g	50	50	50	50
Protactinium-231[e]	cm^3/g	50	50	50	50
Thorium-230[e]	cm^3/g	60,000	60,000	60,000	60,000
Actinium-227[e]	cm^3/g	20	20	20	20
Radium-226[e]	cm^3/g	70	70	70	70
Lead-210[e]	cm^3/g	100	100	100	100
Inhalation rate	m^3/yr	8400	8400	8400	8400
Mass loading for inhalation	g/m^3	0.0001	0.0001	0.0001	0.0001
Indoor occupancy time fraction	–	0.2	0	0.50	0.50

TABLE A.1 (Cont.)

Parameter	Unit	Value,[a] by Scenario: Scenario A	Scenario B	Scenario C	Scenario D
Outdoor occupancy time fraction	–	0.03	0.086	0.25	0.25
Shielding factor from external radiation afforded by indoor occupancy	–	0.7	Not used	0.7	0.7
Fraction of outdoor dust present indoors	–	0.4	Not used	0.4	0.4
Shape factor, external gamma	–	1	1	1	1
Dilution length for airborne dust inhalation	m	3	3	3	3
Soil ingestion rate	g/yr	36.5	36.5	36.5	36.5
Fruit, vegetable, and grain consumption	g/yr	Not used	Not used	160	160
Leafy vegetable consumption	g/yr	Not used	Not used	14	14
Milk consumption from on-site livestock	L/yr	Not used	Not used	Not used	92
Meat consumption from on-site livestock	g/yr	Not used	Not used	Not used	63
Fish consumption	kg/yr	Not used	Not used	Not used	5.4
Other seafood consumption	kg/yr	Not used	Not used	Not used	0.9
Drinking water intake	L/yr	Not used	Not used	Not used	510
Fraction of drinking water from on-site well	–	Not used	Not used	Not used	1
Fraction of aquatic food from on-site pond	–	Not used	Not used	Not used	0.5
Livestock fodder intake for meat	kg/d	Not used	Not used	Not used	68
Livestock fodder intake for milk	kg/d	Not used	Not used	Not used	55
Livestock water intake for meat	L/d	Not used	Not used	Not used	50
Livestock water intake for milk	L/d	Not used	Not used	Not used	160
Livestock intake of soil	kg/d	Not used	Not used	Not used	0.5
Mass loading for foliar deposition	g/m^3	Not used	Not used	0.0001	0.0001
Depth of soil mixing layer	m	Not used	Not used	0.15	0.15
Depth of roots	m	Not used	Not used	0.9	0.9
Contamination fraction					
Drinking water	–	Not used	Not used	Not used	1
Household water	–	Not used	Not used	0	1
Livestock	–	Not used	Not used	Not used	1
Irrigation	–	Not used	Not used	0	1
Produce	–	Not used	Not used	0.1	0.5[f]
Meat	–	Not used	Not used	Not used	0.5[f]
Milk	–	Not used	Not used	Not used	0.5[f]
Groundwater fractional usage (balance from surface water)					
Drinking water	–	Not used	Not used	Not used	1
Household water	–	Not used	Not used	Not used	1
Livestock water	–	Not used	Not used	Not used	1
Irrigation	–	Not used	Not used	Not used	1
Total porosity of the house or building	–	0.1	Not used	0.1	0.1
Volumetric water content of cover material	–	Not used	Not used	Not used	Not used
Volumetric water content of the foundation	–	0.03	Not used	0.03	0.03

TABLE A.1 (Cont.)

Parameter	Unit	Value,[a] by Scenario			
		Scenario A	Scenario B	Scenario C	Scenario D
Diffusion coefficient for radon gas	m^2/s	Not used	Not used	Not used	Not used
In cover material					
In foundation material		3.0×10^{-7}	Not used	3.0×10^{-7}	3.0×10^{-7}
In contaminated zone material		2.0×10^{-6}	2.0×10^{-6}	2.0×10^{-6}	2.0×10^{-6}
Emanating power of radon gas	–	0.25	0.25	0.25	0.25
Radon vertical dimension of mixing	m	2.0	2.0	2.0	2.0
Average annual wind speed[b]	m/s	4.5	4.5	4.5	4.5
Average building air exchange rate	h^{-1}	0.5	Not used	0.5	0.5
Height of the building (room)	m	2.5	Not used	2.5	2.5
Bulk density of building foundation	g/cm^3	2.4	Not used	2.4	2.4
Thickness of building foundation	m	0.15	Not used	0.15	0.15
Building indoor area factor	–	0	Not used	0	0
Building depth below ground surface	m	0	Not used	0	0

[a] Parameter values listed are generic (RESRAD default) values except where indicated differently; a dash (–) indicates parameter is dimensionless.

[b] Site-specific estimate (SAIC 1995).

[c] Site-specific estimate (Redmon 1994a).

[d] Distribution coefficient values for uranium are based on laboratory analyses of site-specific soil samples (Redmon 1994b).

[e] Radionuclide is a decay product.

[f] Calculated by RESRAD based on the area of the contaminated zone.

APPENDIX REFERENCES

Redmon, M.E., 1994a, memorandum from Redmon (Bechtel National, Inc., Oak Ridge, Tenn.) to D.E. Dunning (Argonne National Laboratory, Oak Ridge, Tenn.), Sept. 23.

Redmon, M.E., 1994b, memorandum from Redmon (Bechtel National, Inc., Oak Ridge, Tenn.) to D.E. Dunning (Argonne National Laboratory, Oak Ridge, Tenn.), Oct. 31.

Science Applications International Corporation, 1995, *Characterization Report for the Middlesex Site, Middlesex, New Jersey*, prepared for U.S. Department of Energy, Oak Ridge, Tenn., Nov.