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Derivation of Guidelines for Uranium Residual Radioactive Material in Soil at the Colonie Site, Colonie, New York

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NOTATION

The following is a list of the acronyms, initialisms, and abbreviations (including units of measure) used in this document.

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
ALARA	as low as reasonably achievable
BNI	Bechtel National, Inc.
CFR	Code of Federal Regulations
CISS	Colonie Interim Storage Site
Conrail	Consolidated Rail Corporation
DOE	U.S. Department of Energy
FUSRAP	Formerly Utilized Sites Remedial Action Program
MED	Manhattan Engineer District
NL	National Lead
ORNL	Oak Ridge National Laboratory
RCRA	Resource Conservation and Recovery Act
RESRAD	residual radioactive material guideline computer code
SAIC	Science Applications International Corporation

UNITS OF MEASURE

°C	degree(s) Celsius	m	meter(s)
cm	centimeter(s)	m ³	cubic meter(s)
cm ³	cubic centimeter(s)	mi	mile(s)
°F	degree(s) Fahrenheit	mph	mile(s) per hour
ft	foot (feet)	mrem	millirem(s)
g	gram(s)	pCi	picocurie(s)
h	hour(s)	s	second(s)
ha	hectare(s)	yd ³	cubic yard(s)
in.	inch(es)	yr	year(s)
km	kilometer(s)

DERIVATION OF GUIDELINES FOR URANIUM RESIDUAL RADIOACTIVE MATERIAL IN SOIL AT THE COLONIE SITE, COLONIE, NEW YORK

by

D. Dunning

SUMMARY

Residual radioactive material guidelines for uranium in soil were derived for the Colonie site located in Colonie, New York. 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 with radioactive material as a result of operations conducted by National Lead (NL) Industries from 1958 to 1984; these activities included brass foundry operations, electroplating of metal products, machining of various components using depleted uranium, and limited work with small amounts of enriched uranium and thorium. The Colonie site comprises the former NL Industries property, now designated the Colonie Interim Storage Site (CISS), and 56 vicinity properties contaminated by fallout from airborne emissions; 53 of the vicinity properties were previously remediated between 1984 and 1988. In 1984, DOE accepted ownership of the CISS property from NL Industries. Residual radioactive material guidelines for individual radionuclides and total uranium were derived on the basis of the requirement that the 50-year committed effective dose equivalent to a hypothetical individual who lives or works in the immediate vicinity of the 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 DOE residual radioactive material guideline computer code, RESRAD, was used in this evaluation; RESRAD implements the methodology described in the DOE manual for establishing residual radioactive material guidelines.

Three potential scenarios were considered for the site. These scenarios vary with regard to future land use at the site, sources of water used, and sources of food consumed. The results of the evaluation indicate that the dose constraints would not be exceeded within 1,000 years, provided that the soil concentration of total uranium (including uranium-234, uranium-235, and uranium-238) at the site does not exceed 950 pCi/g for Scenario A (industrial worker, the current and expected future site use), 250 pCi/g for Scenario B (urban resident, using a municipal water supply — a plausible but unlikely future use), and 660 pCi/g for Scenario C (subsistence farmer, using water from an on-site well for all purposes — a plausible but very unlikely land use). The CISS property is currently owned by DOE, located in an urban industrial area, and zoned for commercial/industrial use.

The total 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 the activity concentration ratio of 1:0.32:0.015 (based on the measured activity concentration ratios of uranium-238 and uranium-235). Consequently, if uranium-238 is measured as the indicator radionuclide, the soil concentration limits would be 710 pCi/g for Scenario A, 190 pCi/g for Scenario B, and 490 pCi/g for Scenario C. These guidelines were calculated 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. In setting the actual residual radioactive material guidelines for this 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 and whether the contamination is isolated and localized.

1 INTRODUCTION

The Colonie site includes the Colonie Interim Storage Site (CISS) property and several vicinity properties that were contaminated by operations at the former National Lead (NL) Industries facility. The CISS property was acquired by the U.S. Department of Energy (DOE) in 1984 and subsequently designated for remedial action under the 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, to identify, evaluate, and, if necessary, decontaminate sites previously used by the AEC or its predecessor, the Manhattan Engineer District (MED), or otherwise designated for FUSRAP responsibility.

Remedial actions at the Colonie site will follow the guidelines established in DOE Order 5400.5 (DOE 1990). The DOE residual radioactive material computer code, RESRAD (Yu et al. 1993a), is used to derive residual radionuclide guidelines on a site-specific basis. This report presents guidelines for residual concentrations of uranium in soils at the Colonie site, 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 land use scenarios. The dose constraint of 30 mrem/yr is not currently required under DOE Order 5400.5 but is specified in proposed DOE regulations (DOE 1993) to account for additional dose contributions from other potential sources of radiation exposure.

1.1 SITE DESCRIPTION AND SETTING

The CISS property is located at 1130 Central Avenue (State Route 5) in the Town of Colonie, Albany County, New York, approximately 6.4 km (4 mi) northwest of downtown Albany (Figure 1). The boundary line between the Town of Colonie and the City of Albany is located just south of CISS. Elevation of the property ranges from about 65 to 70 m (215 to 230 ft) above mean sea level. CISS is bounded by a wooded lot owned by the Town of Colonie on the northwest, Consolidated Rail Corporation (Conrail) railroad tracks on the southwest and south, commercial property on the east, Central Avenue on the northeast, and a Niagara Mohawk electrical substation on the north (Figure 2).

The CISS property occupies about 4.5 ha (11.2 acres), including the former NL Industries property and buildings. The property comprises approximately 1.6 ha (4 acres) of paved surfaces, 1.6 ha (4 acres) of lawn areas, and the 1.2-ha (3-acre) foundation of the main building, which occupies the central portion of the site; the main building was demolished and removed from the site during 1995. Two small storage buildings are located along the southwestern border of the property.

FIGURE 1 Location of the Colonie Site (Source: Modified from SAIC 1995)

FIGURE 2 Details of the Colonie Interim Storage Site (Source: Modified from SAIC 1995)

Fifty-six vicinity properties (i.e., residential and commercial properties near CISS) have been identified as containing elevated levels of radioactive contamination due to fallout of airborne emissions from the NL Industries facility and designated for remedial action (ANL/Bechtel National, Inc. 1990). Of the 56 vicinity properties, 53 were remediated in 1984, 1985, and 1988. The contamination found at the remediated properties was depleted uranium and was typically located in the upper 5 cm (2 in.) of soil. Approximately 920 m^3 ($1,200 \text{ yd}^3$) of waste soil generated from these remedial activities was stored within the CISS building until 1995, when it was shipped to an off-site disposal facility. The three vicinity properties that have not yet been remediated border the CISS property; they include the Conrail property on the south and southwest, the Niagara Mohawk substation on the north, and the Town of Colonie property on the northwest. A total estimated soil volume of $1,070 \text{ m}^3$ ($1,400 \text{ yd}^3$) will potentially require remediation at these three vicinity properties (Science Applications International Corporation [SAIC] 1995).

Land use in the vicinity of CISS is mixed commercial and residential, and the site is zoned for industrial use ("Industrial F"). In 1990, there were 76,494 persons living in Colonie; in 1991,

293,400 persons were living in Albany County (Bureau of the Census 1992). Public water for the area around the Colonie site is from the Latham Water District in the Town of Colonie. The water sources include the Mohawk River, several wells, and several reservoirs. No public water supply wells have been identified within a 4.8-km (3-mi) radius of the site (SAIC 1995).

The regional climate is humid, with a mean annual precipitation of 90.7 cm (35.7 in.), of which approximately 16.5 cm (6.5 in.) is snow. With a precipitation to snow conversion of 1 to 10, total snowfall averages 165.4 cm (65.1 in.). The annual daily maximum temperature for the area is 14.2°C (57.6°F), and the average daily minimum is 2.7°C (36.8°F). Predominant wind directions are from the south, south-southeast, west, and west-northwest, with a mean wind speed of 16 km/h (10 mph); light winds (0 to 5 km/h [0 to 3 mph]) are most common in the area (Gale Research Company 1985; National Oceanic and Atmospheric Administration 1983).

1.2 SITE HISTORY

Industrial operations at the Colonie site began in 1923, when the Embossing Company purchased a portion of the present-day CISS to construct a facility for manufacturing wood products and toys. In 1927, Magnus Metal Company, Inc., purchased the property and converted the facility to a brass foundry for manufacturing railroad components.

In 1937, NL Industries purchased the Magnus facility and an adjacent lot, which contained a portion of Patroon Lake, and continued the brass foundry operations. At some point before 1941, NL Industries began filling Patroon Lake with used casting sands and debris from site operations. After World War II, the plant began casting aluminum mainframes for jet airplanes. In 1958, the nuclear division of NL Industries began producing items manufactured from uranium and thorium under a license issued by the AEC. Brass foundry operations were discontinued in 1960.

Between 1958 and 1984, NL Industries carried out a number of processes that used radioactive materials consisting primarily of depleted uranium, as well as smaller amounts of enriched uranium and thorium. Operations were conducted at the plant to reduce depleted uranium tetrafluoride to depleted uranium metal, which was then fabricated into shielding components, ballast weights, and projectiles. Other processes included an electroplating operation for plating uranium with nickel and cadmium. From 1966 to 1972, NL Industries manufactured fuel from enriched uranium for experimental nuclear reactors. As a result of plant operations, the site buildings, grounds, and vicinity properties became radioactively contaminated.

On February 15, 1980, the New York State Supreme Court issued a temporary restraining order barring NL Industries from operating its facility because of unacceptable airborne emissions of uranium compounds. The temporary restraining order was amended on May 12, 1980, to allow NL Industries to continue limited operation. The amended order required the company to initiate an

independent investigation to assess all adverse environmental conditions in on-site soil and vicinity properties that may have been caused by airborne discharges of radioactive particulates from the plant.

Congress directed DOE to conduct remedial action at the site under the Energy and Water Appropriations Act of 1984. In 1984, the Secretary of Energy accepted an offer from NL Industries to donate the land, buildings, and equipment to DOE to help expedite the cleanup. In 1985, DOE also acquired a portion of the Niagara Mohawk property bordering CISS to the north and northwest and subsequently designated it as part of CISS.

Since 1978, numerous radiological surveys and sampling activities have been conducted at the Colonie site. In 1980 and 1981, Teledyne Isotopes conducted radiological surveys of the NL Industries facility and its vicinity (Teledyne Isotopes 1980, 1981). In 1984, Bechtel National, Inc., (BNI) conducted a preliminary geological investigation of the site and began an ongoing routine environmental monitoring program. In 1988, Oak Ridge National Laboratory (ORNL) conducted a radiological designation survey of the Conrail property (ORNL 1988), which resulted in this property being added to the Colonie site. More recently, BNI has conducted additional characterization studies at CISS involving soil-gas, soil, sediment, surface water, and groundwater sampling (BNI 1992a, 1992b, 1993a, 1993b, 1993c).

In 1984, 1985, and 1988, DOE removed approximately 920 m^3 ($1,200 \text{ yd}^3$) of radioactively contaminated soil from 53 of the 56 contaminated vicinity properties (BNI 1986, 1989); a cleanup guideline of 35 pCi/g for uranium-238 in soil was used (DeLaney 1984). The removed soil was stored under a synthetic cover in the main building at CISS.

From 1984 to 1995, CISS was used for interim storage of radioactively contaminated materials removed from the 53 vicinity properties; these contaminated materials have now been removed and shipped off-site for disposal. In 1992, actions were initiated to prepare the CISS building for final remediation, including (1) removal and disposal of mixed radioactive and chemical waste previously stored in the building in accordance with a Resource Conservation and Recovery Act (RCRA) Part A permit and closure of the building as a RCRA waste storage area, (2) removal and disposal of asbestos-containing materials, (3) removal of equipment and nonstructural building appurtenances, and (4) building housekeeping. During 1995, the building was demolished and removed from the site.

1.3 DERIVATION OF CLEANUP GUIDELINES

According to the site history (Section 1.2), potential radioactive contaminants at the Colonie site include uranium and thorium, with their respective decay products. DOE has established generic

cleanup guidelines for thorium in soil (DOE 1990). Cleanup guidelines for uranium, however, must be derived on a site-specific basis.

This report presents the derivation of the residual radioactive material guidelines for uranium (uranium-234, -235, -238, and total uranium) that apply to remedial action at the Colonie site. The derived guidelines represent the residual concentration of each radionuclide in a homogeneously contaminated area that must not be exceeded if the site is to be released for use without radiological restrictions. Guidelines for total uranium are derived by assuming that uranium-238, -234, and -235 are present in the activity concentration ratio of 1:0.32:0.015 for depleted uranium on the basis of the measured activity concentration ratios of uranium-238 and uranium-235 (Berger 1982). Although historical operations at the site also included management of enriched uranium, site characterization data have not identified enriched uranium as a contaminant of concern in site soils.

The derivation of site-specific residual radioactive material guidelines for the Colonie 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. 1993a). For each radionuclide of concern, it was assumed that only that radionuclide is present at an above-background concentration. The RESRAD computer code, version 5.61, 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). DOE will establish the final guidelines for residual radioactive materials at this site by applying the as low as reasonably achievable (ALARA) policy to the derived guidelines presented in this report, along with other factors, such as whether a particular scenario is reasonable and appropriate and whether the contamination is isolated and localized.

2 SCENARIO DEFINITIONS

Three potential exposure scenarios were considered for the Colonie site. Each scenario assumes that, at some time within 1,000 years, the site will be released for use without radiological restrictions following remediation.

Scenario A (the expected 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 or meat or milk from livestock raised in the decontaminated area.

Scenario B (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. The hypothetical resident is assumed to obtain all water from a distant source not affected by site conditions (e.g., the current 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 or fish grown in a pond in the decontaminated area.

Scenario C (a plausible but very unlikely scenario) assumes the presence of a subsistence farmer at the site who drinks water obtained from a well located 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 that is 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 B. All water used for drinking, household purposes, irrigation, and livestock watering is assumed to be drawn from the on-site well. (There is no current agricultural activity at the site, and production of livestock or construction of a fishing pond in the decontaminated area is considered extremely unlikely.)

Potential radiation doses resulting from nine exposure pathways were analyzed; the first pathway would result in external radiation, and the rest would result in internal radiation: (1) direct exposure to decontaminated soil, (2) inhalation of contaminated dust, (3) inhalation of emanating radon-222, (4) incidental ingestion of soil, (5) 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) ingestion of meat and (7) milk from livestock that is fed with fodder grown in the decontaminated area and irrigated with water drawn from the on-site well, (8) ingestion of fish from a pond downgradient from the decontaminated area, and (9) ingestion of drinking water drawn from the on-site well.

The RESRAD computer code, version 5.61 (Yu et al. 1993a), was used to calculate the potential radiation doses to each hypothetical future receptor under the following assumptions:

- 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 resident and subsistence farmer 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. 1993b).
- The airborne dust loading is 0.1 mg/m^3 .
- The house or building foundation depth is set to maximize the radon inhalation dose but not to exceed 1 m below ground surface (RESRAD default is -1), with an effective radon diffusion coefficient of $3 \times 10^{-7} \text{ m}^2/\text{s}$ (Yu et al. 1993b).
- The size of the decontaminated area is large enough that 10% and 50% of the produce consumed by the resident (Scenario B) and subsistence farmer (Scenario C), respectively, are grown in a garden in the decontaminated area. The industrial worker does not consume produce from an on-site garden.
- Ingestion of meat or milk from livestock raised in the decontaminated area is considered for the subsistence farmer (Scenario C) only. The size of the decontaminated area is large enough to produce all forage for feeding livestock used for meat and milk consumed by the subsistence farmer in Scenario C. The industrial worker and resident do not consume meat or milk from livestock raised on-site.
- The site is currently served by an uncontaminated municipal water supply. However, under Scenario C, a well located at the downgradient edge of the decontaminated area provides all water for drinking, household purposes, livestock watering, and irrigation of the on-site garden. The industrial worker and resident do not use water from an on-site well.
- An on-site pond, constructed in the decontaminated area, provides 50% of the aquatic food (fish) consumed by the subsistence farmer (Scenario C). The industrial worker and resident do not consume any aquatic food from the decontaminated area.

- After remedial action, no cover material is placed over the decontaminated area. No erosion of the contaminated material occurs.
- The entire area of the site is assumed to be uniformly contaminated with residual radioactive materials to a depth of 0.35 m (1 ft). (However, site characterization data indicate that soil contamination at the site actually is localized and generally limited to more shallow depths, except for the former burial area in the vicinity of Patroon Lake [SAIC 1995], where radiological contamination has been detected as deep as 6.4 m [21 ft]. The effect of the assumed depth and areal extent of contamination is addressed in a sensitivity analysis.)
- The distribution coefficient for uranium in soil was measured at $184 \text{ cm}^3/\text{g}$ (SAIC 1995); this value is used for all uranium isotopes in all soil zones. For all radioactive decay products, RESRAD default distribution coefficient values are assumed (Yu et al. 1993b).
- Site-specific estimates of hydrogeologic properties are used for the total porosity, effective porosity, hydraulic conductivity, hydraulic gradient, and unsaturated zone thickness (SAIC 1995). Site-specific meteorologic parameters include precipitation and wind speed (SAIC 1995). In the absence of site-specific data for other parameters, other site characteristics are assumed to be adequately characterized by RESRAD default parameter values.

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

TABLE 1 Summary of Pathways Considered for Scenarios A, B, and C at the Colonie Site^a

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

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

3 DOSE/SOURCE CONCENTRATION RATIOS

The RESRAD computer code, version 5.61 (Yu et al. 1993a), was used to calculate the dose/source concentration ratio $DSR_{ip}(t)$ for radionuclide i and pathway p at time t after remediation. 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 all scenarios, the maximum dose/source concentration ratios are predicted to occur at time zero (immediately after remediation) for all radionuclides.

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 in soil at the site for uranium-234, -235, and -238.

For this analysis, guideline values have been derived for total uranium, where W_i is assumed to represent the activity concentration ratios of 1:1.335, 0.32:1.335, and 0.015:1.335 for uranium-238, -234, and -235, respectively; the average uranium-235 concentration in site soil has been measured at 1.5% of the uranium-238 activity concentration, well below the natural activity concentration ratio of 4.7% (Berger 1982). 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 Colonie 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 influence the results in each case. For all scenarios, the external exposure and particulate inhalation pathways are important contributors to dose. Therefore, uncertainty 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 relatively 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, that is, the predicted

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

Pathway	Maximum Dose/Source Concentration Ratio (mrem/yr)/(pCi/g) ^a		
	Uranium-234	Uranium-235	Uranium-238
External exposure	6.7×10^{-5}	1.3×10^{-1}	2.2×10^{-2}
Particulate inhalation	1.2×10^{-2}	1.1×10^{-2}	1.1×10^{-2}
Ingestion of soil	2.4×10^{-3}	2.2×10^{-3}	2.3×10^{-3}

^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 (Resident) at the Colonie Site

Pathway	Maximum Dose/Source Concentration Ratio (mrem/yr)/(pCi/g) ^a		
	Uranium-234	Uranium-235	Uranium-238
External exposure	2.4×10^{-4}	4.4×10^{-1}	7.9×10^{-2}
Particulate inhalation	4.9×10^{-2}	4.6×10^{-2}	4.4×10^{-2}
Ingestion of soil	7.7×10^{-3}	7.3×10^{-3}	7.4×10^{-3}
Ingestion of produce from on-site garden	4.8×10^{-3}	4.5×10^{-3}	4.6×10^{-3}

^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 (Subsistence Farmer) at the Colonie Site

Pathway	Maximum Dose/Source Concentration Ratio (mrem/yr)/(pCi/g) ^a		
	Uranium-234	Uranium-235	Uranium-238
External exposure	2.4×10^{-4}	4.4×10^{-1}	7.9×10^{-2}
Particulate inhalation	4.9×10^{-2}	4.6×10^{-2}	4.4×10^{-2}
Ingestion of soil	7.7×10^{-3}	7.3×10^{-3}	7.4×10^{-3}
Ingestion of produce from on-site garden	2.4×10^{-2}	2.3×10^{-2}	2.3×10^{-2}
Ingestion of meat from on-site livestock	3.4×10^{-3}	3.2×10^{-3}	3.3×10^{-3}
Ingestion of milk from on-site livestock	8.7×10^{-3}	8.2×10^{-3}	8.2×10^{-3}

^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 Total Dose/Source Concentration Ratios for the Colonie Site

Radionuclide	Total Dose/Source Concentration Ratio (mrem/yr)/(pCi/g) ^a		
	Scenario A ^b	Scenario B ^c	Scenario C ^d
Uranium-234	1.4×10^{-2}	6.2×10^{-2}	9.3×10^{-2}
Uranium-235	1.4×10^{-1}	5.0×10^{-1}	5.3×10^{-1}
Uranium-238	3.5×10^{-2}	1.4×10^{-1}	1.7×10^{-1}
Total Uranium	3.2×10^{-2}	1.2×10^{-1}	1.5×10^{-1}

^a All values are reported to two significant figures.

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

^c Resident using water from uncontaminated municipal sources (plausible but unlikely future use scenario: 30 mrem/yr dose limit).

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

dose is insensitive to uncertainties in soil properties, meteorological parameters, distribution coefficients, water consumption rates, and other parameters related to the leaching and transport of radionuclides.

For this analysis, RESRAD default parameter values were used if no site-specific data were available. These default values are based on national average or reasonable maximum values. In addition, the contaminated zone thickness (0.35 m) used to derive the dose/source concentration ratios was calculated by dividing the estimated volume of contaminated soil ($15,900 \text{ m}^3$) by the area of the site ($45,000 \text{ m}^2$) (SAIC 1995). This calculation assumes that the soil is uniformly contaminated to that depth throughout the entire site. Sensitivity analyses were conducted to investigate the impact of alternative assumptions regarding the depth and areal distribution of contamination. In the extreme case where the entire volume of contaminated soil is assumed to be located within the area of the former Patroon Lake (approximately $7,000 \text{ m}^2 \times 2.3 \text{ m}$ average depth), the dose/source concentration ratios for total uranium would be unchanged for Scenario A, decreased by approximately 2% for Scenario B, and increased by approximately 30% for Scenario C.

Some exposure pathways evaluated in this analysis have been included for purposes of completeness but are considered very unlikely. For example, the production of meat and milk from livestock raised on-site and the development of a fishing pond are considered under Scenario C but are extremely unlikely given the urban location and physical characteristics of the site. Therefore, the calculated dose/source concentration ratios are considered to be conservative (i.e., likely to overestimate doses).

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 a dose limit of DL for an individual, the residual radioactive material guideline, G , for each radionuclide of concern at the Colonie 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 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; Yu et al. 1993a). The calculated residual radioactive material guidelines for individual radionuclides of interest (uranium-234, -235, and -238) and total uranium are presented in Table 6.

To calculate the total uranium guidelines, it was assumed that the activity concentration ratio of uranium-238, -234, and -235 is 1:0.32:0.015 (Berger 1982). The derived guidelines for total

TABLE 6 Residual Radioactive Material Guidelines for the Colonie Site^a

Radionuclide	Guideline (pCi/g) ^b		
	Scenario A	Scenario B	Scenario C
Uranium-234	2.1×10^3	4.8×10^2	1.1×10^3
Uranium-235	2.2×10^2	6.0×10^1	1.9×10^2
Uranium-238	8.5×10^2	2.1×10^2	6.1×10^2
Total Uranium	9.5×10^2	2.5×10^2	6.6×10^2

^a Scenario A: Industrial worker (current use scenario, 30 mrem/yr dose constraint). Scenario B: Resident using water from uncontaminated municipal sources (plausible but unlikely future use scenario, 30 mrem/yr dose limit). Scenario C: Subsistence farmer using water from on-site well for drinking, household purposes, livestock watering, and irrigation (plausible but very unlikely future use scenario, 100 mrem/yr dose limit).

^b All values are reported to two significant figures.

uranium for Scenarios A, B, and C are 950, 250, and 660 pCi/g, 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 1.335; the resulting uranium-238 limits would be 710, 190, and 490 pCi/g for Scenarios A, B, and C, respectively.

The sum-of-the-fractions rule applies when the derived radionuclide guidelines for remediation of a site are implemented. The summation of the radionuclide concentrations, S_i , remaining on-site following decontamination (averaged over an area of 100 m² and a depth of 15 cm) and divided by their 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 by using the sum-of-the-fractions rule (DOE 1990).

The derived guidelines presented in Table 6 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 accordance with the ranges given in Table 7.

TABLE 7 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 m² are to be averaged over an area of 1 m², 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 ANALYSIS OF THE COLONIE SITE**

The following exposure scenarios were analyzed for the Colonie site, in Colonie, Albany County, New York:

- Scenario A: Industrial Use of the Site. A hypothetical person is assumed to work in the decontaminated area of the site.
- Scenario B: 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., 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 is raised for the production of meat or milk, and no pond is constructed on-site to provide fish and other aquatic foods.
- Scenario C: 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 Colonie 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 Analysis of the Colonie Site

Parameter ^a	Unit	Value		
		Scenario A	Scenario B	Scenario C
Dose limit	mrem/yr	30	30	100
Area of contaminated zone ^b	m ²	45,000	45,000	45,000
Thickness of contaminated zone ^b	m	0.35	0.35	0.35
Length parallel to aquifer flow ^b	m	200	200	200
Cover depth	m	0	0	0
Density of contaminated zone	g/cm ³	1.5	1.5	1.5
Contaminated zone erosion rate	m/yr	0	0	0
Contaminated zone total porosity ^c	-	0.40	0.40	0.40
Contaminated zone effective porosity ^c	-	0.33	0.33	0.33
Contaminated zone hydraulic conductivity ^c	m/yr	31	31	31
Contaminated zone b parameter	-	4.9	4.9	4.9
Evapotranspiration coefficient	-	0.5	0.5	0.5
Precipitation ^c	m/yr	0.91	0.91	0.91
Irrigation	m/yr	0.2	0.2	0.2
Irrigation mode	-	Not used	Overhead	Overhead
Runoff coefficient	-	0.2	0.2	0.2
Watershed area for pond	m ²	Not used	Not used	1,200,000
Density of saturated zone	g/cm ³	Not used	Not used	1.5
Saturated zone total porosity ^c	-	Not used	Not used	0.40
Saturated zone effective porosity ^c	-	Not used	Not used	0.33
Saturated zone hydraulic conductivity ^c	m/yr	Not used	Not used	410
Saturated zone hydraulic gradient ^c	-	Not used	Not used	0.01
Saturated zone b parameter	-	Not used	Not used	4.9
Water table drop rate	m/yr	Not used	Not used	0
Well pump intake depth ^c (below water table)	m	Not used	Not used	10
Well pumping rate	m ³ /yr	Not used	Not used	250
Model: nondispersion (ND) or mass-balance (MB)	-	Not used	Not used	ND
Number of unsaturated zone strata	-	Not used	Not used	0
Distribution coefficient (all zones)				
Uranium-238 ^d	cm ³ /g	180	180	180
Uranium-235 ^d	cm ³ /g	180	180	180
Uranium-234 ^d	cm ³ /g	180	180	180
Protactinium-231 ^{d,e}	cm ³ /g	50	50	50
Thorium-230 ^{d,e}	cm ³ /g	60,000	60,000	60,000
Actinium-227 ^{d,e}	cm ³ /g	20	20	20
Radium-226 ^{d,e}	cm ³ /g	70	70	70
Lead-210 ^{d,e}	cm ³ /g	100	100	100

TABLE A.1 (Cont.)

Parameter ^a	Unit	Value		
		Scenario A	Scenario B	Scenario C
Inhalation rate	m ³ /yr	8,400	8,400	8,400
Mass loading for inhalation	g/m ³	0.0001	0.0001	0.0001
Indoor occupancy time fraction	-	0.2	0.50	0.50
Outdoor occupancy time fraction	-	0.03	0.25	0.25
Shielding factor from external radiation afforded by indoor occupancy	-	0.7	0.7	0.7
Fraction of outdoor dust present indoors	-	0.4	0.4	0.4
Shape factor, external gamma	-	1	1	1
Dilution length for airborne dust inhalation	m	3	3	3
Soil ingestion rate	g/yr	36	36	36
Fruit, vegetable, and grain consumption	kg/yr	Not used	160	160
Leafy vegetable consumption	kg/yr	Not used	14	14
Milk consumption from on-site livestock	L/yr	Not used	Not used	92
Meat consumption from on-site livestock	kg/yr	Not used	Not used	63
Fish consumption	kg/yr	Not used	Not used	5.4
Other seafood consumption	kg/yr	Not used	Not used	0.9
Drinking water intake	L/yr	Not used	Not used	510
Storage time for				
Fruits, nonleafy vegetables, grain	days	Not used	Not used	14
Leafy vegetables	days	Not used	Not used	1
Milk	days	Not used	Not used	1
Meat	days	Not used	Not used	20
Fish and seafood	days	Not used	Not used	7
Drinking water (well or surface water)	days	Not used	Not used	1
Livestock fodder	days	Not used	Not used	45
Fraction of drinking water from on-site well	-	Not used	Not used	1
Fraction of aquatic food from on-site pond	-	Not used	Not used	0.5
Livestock fodder intake for meat	kg/d	Not used	Not used	68
Livestock fodder intake for milk	kg/d	Not used	Not used	55
Livestock water intake for meat	L/d	Not used	Not used	50
Livestock water intake for milk	L/d	Not used	Not used	160
Livestock intake of soil	kg/d	Not used	Not used	0.5
Mass loading for foliar deposition	g/m ³	Not used	0.0001	0.0001
Depth of soil mixing layer	m	Not used	0.15	0.15
Depth of roots	m	Not used	0.9	0.9
Contamination fraction				
Drinking water	-	Not used	Not used	1
Household water	-	Not used	0	1
Livestock	-	Not used	Not used	1
Irrigation	-	Not used	0	1

TABLE A.1 (Cont.)

Parameter ^a	Unit	Value		
		Scenario A	Scenario B	Scenario C
Produce	-	Not used	0.1	0.5 ^f
Meat	-	Not used	Not used	1.0 ^f
Milk	-	Not used	Not used	1.0 ^f
Groundwater fractional usage (balance from surface water)				
Drinking water	-	Not used	Not used	1
Household water	-	Not used	Not used	1
Livestock water	-	Not used	Not used	1
Irrigation	-	Not used	Not used	1
Total porosity of the house or building	-	0.1	0.1	0.1
Volumetric water content of cover material	-	Not used	Not used	Not used
Volumetric water content of the foundation	-	0.03	0.03	0.03
Diffusion coefficient for radon gas	m ² /s			
in cover material		Not used	Not used	Not used
in foundation material		3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}
in contaminated zone material		2.0×10^{-6}	2.0×10^{-6}	2.0×10^{-6}
Emanating power of radon gas	-	0.25	0.25	0.25
Radon vertical dimension of mixing	m	2.0	2.0	2.0
Average annual wind speed ^c	m/s	4.4	4.4	4.4
Average building air exchange rate	hr ⁻¹	0.5	0.5	0.5
Height of the building (room)	m	2.5	2.5	2.5
Bulk density of building foundation	g/cm ³	2.4	2.4	2.4
Thickness of building foundation	m	0.15	0.15	0.15
Building indoor area factor	-	0	0	0
Building depth below ground surface ^{a,g}	m	-1	-1	-1

^a Parameter values listed are generic (RESRAD default) values except where indicated (Yu et al. 1993a, 1993b).

^b For this analysis, the entire site area is assumed to be uniformly contaminated to a depth of 0.35 m.

^c Site-specific estimate (Science Applications International Corporation 1995).

^d Distribution coefficient values for uranium are based on laboratory analyses of site-specific soil samples (Science Applications International Corporation 1995); for other radionuclides, RESRAD default values are assumed.

^e Radionuclide is a decay product.

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

^g Depth calculated by RESRAD to maximize radon inhalation dose but not to exceed 1 m below ground surface.

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