TECHNICAL MEMORANDUM

RADIOLOGICAL HUMAN HEALTH ASSESSMENT FOR THE TOWN OF TONAWANDA LANDFILL

TONAWANDA, NEW YORK

FEBRUARY 1999

U.S. Army Corps of Engineers
Buffalo District Office
Formerly Utilized Sites Remedial Action Program

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prepared by

U.S. Army Corps of Engineers, Buffalo District Office, Formerly Utilized Sites Remedial Action Program

with technical assistance from

Science Applications International Corporation ESC-FUSRAP

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ACRONYMS AND ABBREVIATIONS

Ac	Actinium
Am	Americium
BNI	Bechtel National, Inc.
CFR	Code of Federal Regulations
DOE	Department of Energy
EPA	Environmental Protection Agency
EPC	Exposure Point Concentration
ft	foot (feet)
FUSRAP	Formerly Utilized Sites Remedial Action Program
g	gram(s)
ha	hectare
ICRP	International Commission on Radiological Protection
m	meter(s)
MED	Manhattan Engineer District
MPI	Malcolm Pirnie, Inc.
mrem	millirem
NCRP	National Council on Radiation Protection and Measurements
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
Pa-231	Protactinium-231
PPE	Personal Protective Equipment
pCi	picocurie(s)
Ra	Radium
RCRA	Resource Conservation and Recovery Act
RESRAD	Residual Radioactivity
SAIC	Science Applications International Corporation
Th	Thorium
U	Uranium
UCL_{95}	upper 95 percent confidence level
UMTRCA	Uranium Mill Tailings Radiation Control Act
U.S.	United States
WL	Working level
yd	yard(s)

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1. INTRODUCTION

In 1974, the Atomic Energy Commission, a predecessor to the U.S. Department of Energy (DOE), instituted the Formerly Utilized Sites Remedial Action Program (FUSRAP). FUSRAP was transferred from DOE to the U.S. Army Corps of Engineers in 1997. This program was created to identify and remediate or control sites where residual radioactivity exceeding current guidelines remains from the early years of the nation's atomic energy program, or from commercial operations causing conditions that Congress has authorized FUSRAP to remedy. The Town of Tonawanda landfill is one of the sites being managed by the Buffalo District Corps of Engineers under FUSRAP. This document provides an assessment of estimated cancer risk and radiological dose due to residual radioactivity within the Town of Tonawanda landfill and the nearby mudflats, and evaluates the effectiveness of mitigation through standard landfill closure.

1.1 SITE BACKGROUND

The Town of Tonawanda Landfill covers approximately 55 acres and is bounded on the north and northwest by residential development, on the east by Conrail and on the south by the Niagara Mohawk Power Company right-of-way. In the early 1900s, the property contained a quarry reportedly in the northwest corner which was abandoned when groundwater was encountered some 60 ft below the surface. Landfill operations began in the mid-1930s and continued through October of 1989. During its operation, the landfill accepted a range of materials including household wastes, incinerator ash (from the incineration of sewage treatment plant sludge and municipal waste), and unburned municipal wastes. Although the landfill operated primarily as a sanitary landfill, it was operated prior to passage of the Resource Conversation and Recovery Act (RCRA), thus the types of materials that may have been disposed in the landfill is not well documented.

In 1979 a radiological flyover survey identified elevated radium-226 (Ra-226) concentrations in the Tonawanda area including the Ashland 1, Ashland 2 and Seaway Landfills and the Linde Air Products Site (See Figures 1 and 2) (EG&G 1979). Although the reference did not indicate at what level the exposure rate readings were for, the assumption is made that they are applicable to the 3-ft level since similar results are presented for the 3-ft level in a later survey by the same company. This survey did not identify elevated radioactivity in the Town of Tonawanda Landfill. In 1984, another radiological flyover survey identified americium-241 (Am-241) in the northeastern portion of the Town of Tonawanda Landfill (See Figure 3) (EG&G 1984). The areas where Am-241 were found is indicated in Figure 3 by the two blue shaded areas. Two flyovers at different elevation were conducted during this survey (100-ft and 300-ft). Based on these results, the Town of Tonawanda hired TMA Eberline to characterize the extent of Am-241 contamination in 1987. The Am-241 waste probably originated from an Am-241 metal foil production facility and reached the landfill via the incineration and disposal of waste water treatment sludge (TMA Eberline 1988). To date there has been no effort to remove Am-241-bearing material from the landfill. In September of 1991, Oak Ridge National Laboratory (ORNL) conducted a survey of the Town of Tonawanda Landfill and the adjacent mudflats to determine if Manhattan Engineer District (MED) related material from Linde Air Products had been deposited in the landfill. The survey included a surface gamma scan and the

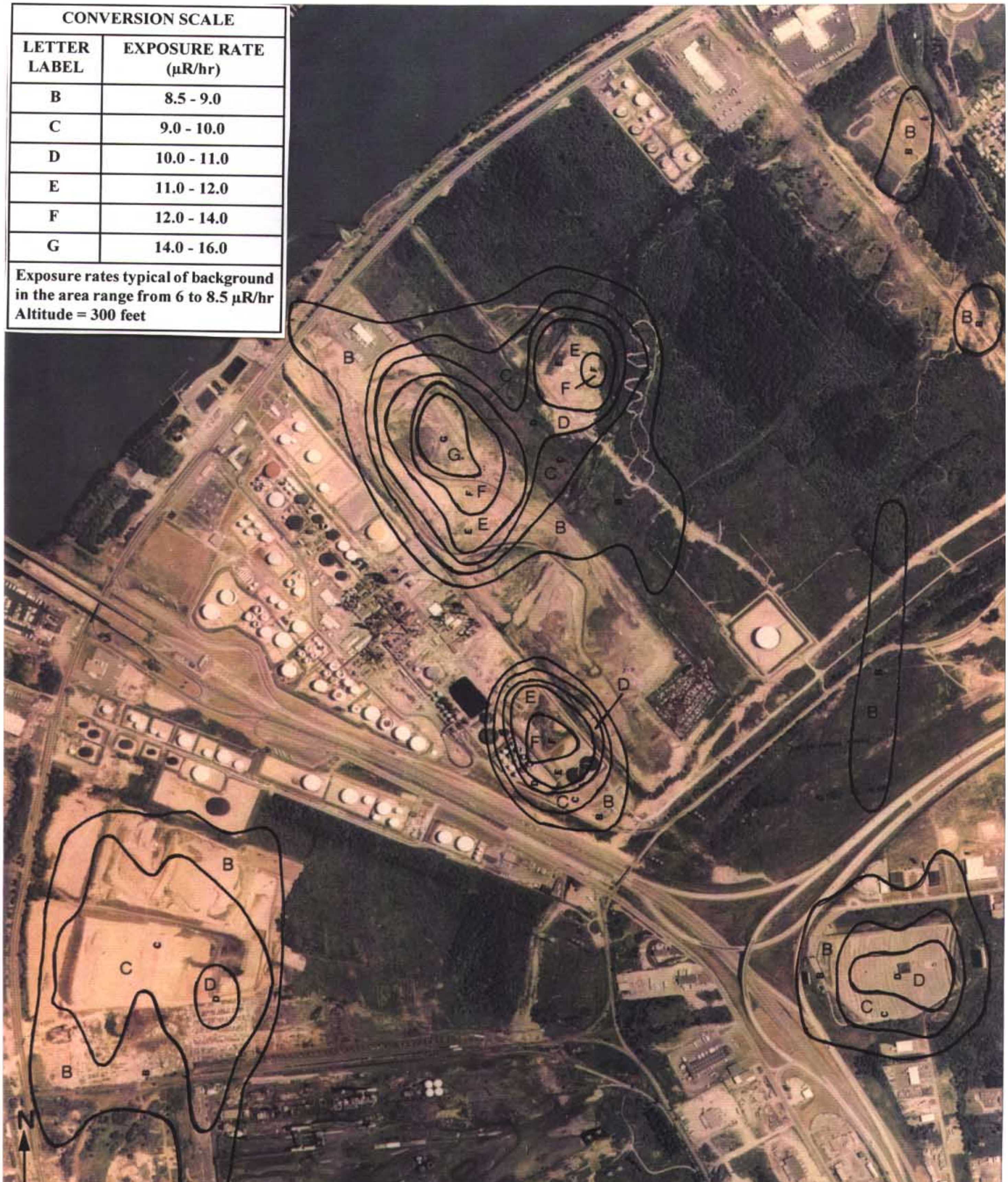
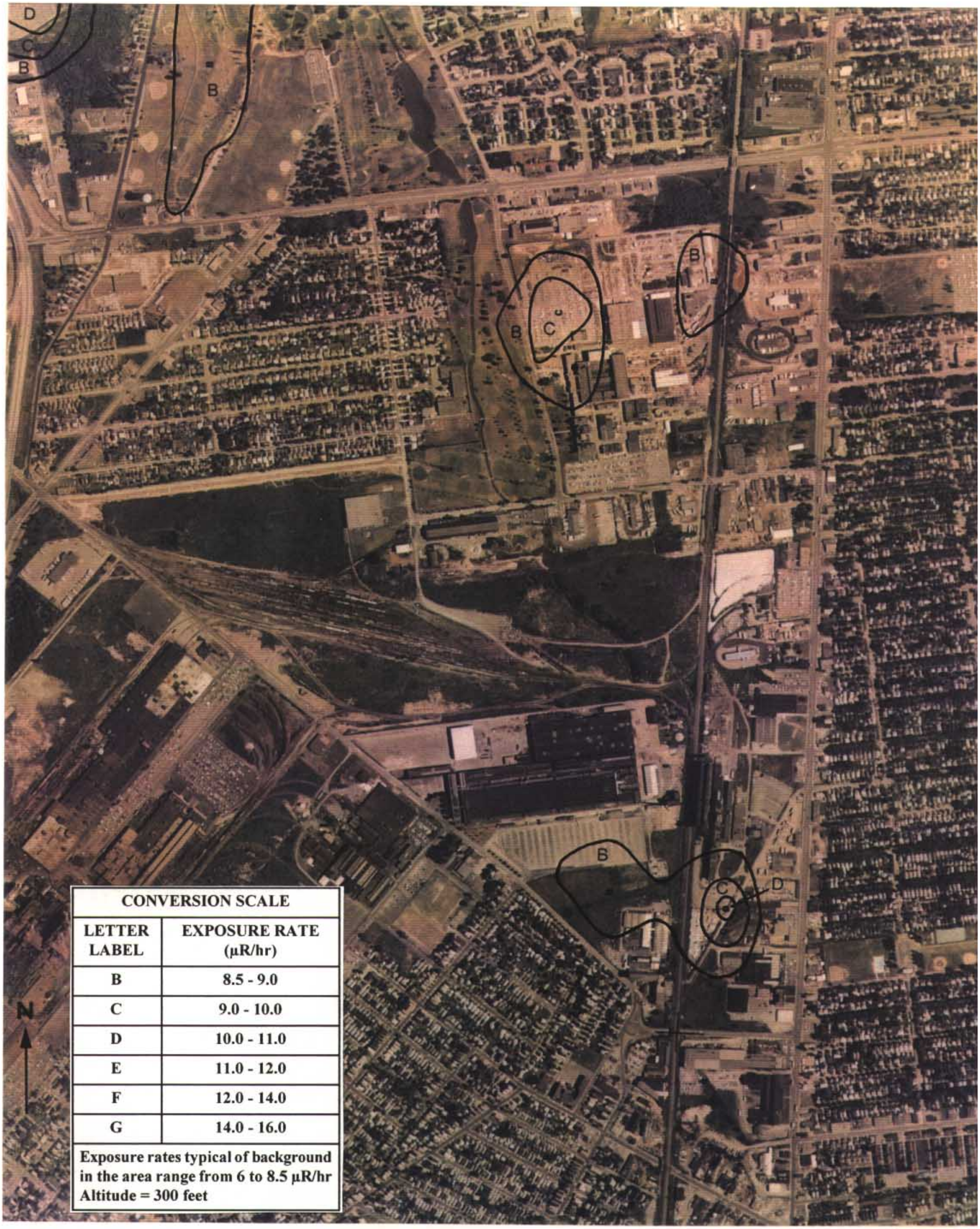


Figure 1. Radiation Contours in the Vicinity of Ashland 1, Ashland 2, and Seaway



CONVERSION SCALE

LETTER LABEL	EXPOSURE RATE (µR/hr)
B	8.5 - 9.0
C	9.0 - 10.0
D	10.0 - 11.0
E	11.0 - 12.0
F	12.0 - 14.0
G	14.0 - 16.0

Exposure rates typical of background in the area range from 6 to 8.5 µR/hr
Altitude = 300 feet

Figure 2. Radiation Contours in the Vicinity of Praxair (formerly Linde Air Products)

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Figure 3. Radiation Contours in Vicinity of Town of Tonawanda Landfill

collection of soil samples for radiological analyses. A total of 172 samples were collected by ORNL. The ORNL survey did identify material with "...technologically enhanced levels of uranium-238 (U-238) not unlike the product material at the Linde plant" and other material "similar to the residues of byproduct of the refinery operation conducted at the Linde plant"(ORNL 1992). The most recent investigation was conducted in 1995 primarily to define the maximum depth of elevated radioactivity (BNI 1995). BNI collected samples at spots identified by gamma scans to have high potential for contamination. The original ORNL data was used to focus the investigation on the northwestern portion of the landfill and the mud flats area immediately east of the incinerators. The 1991 and 1995 sampling locations, including locations with elevated radioactivity are illustrated in Figure 4.

1.2 SCOPE

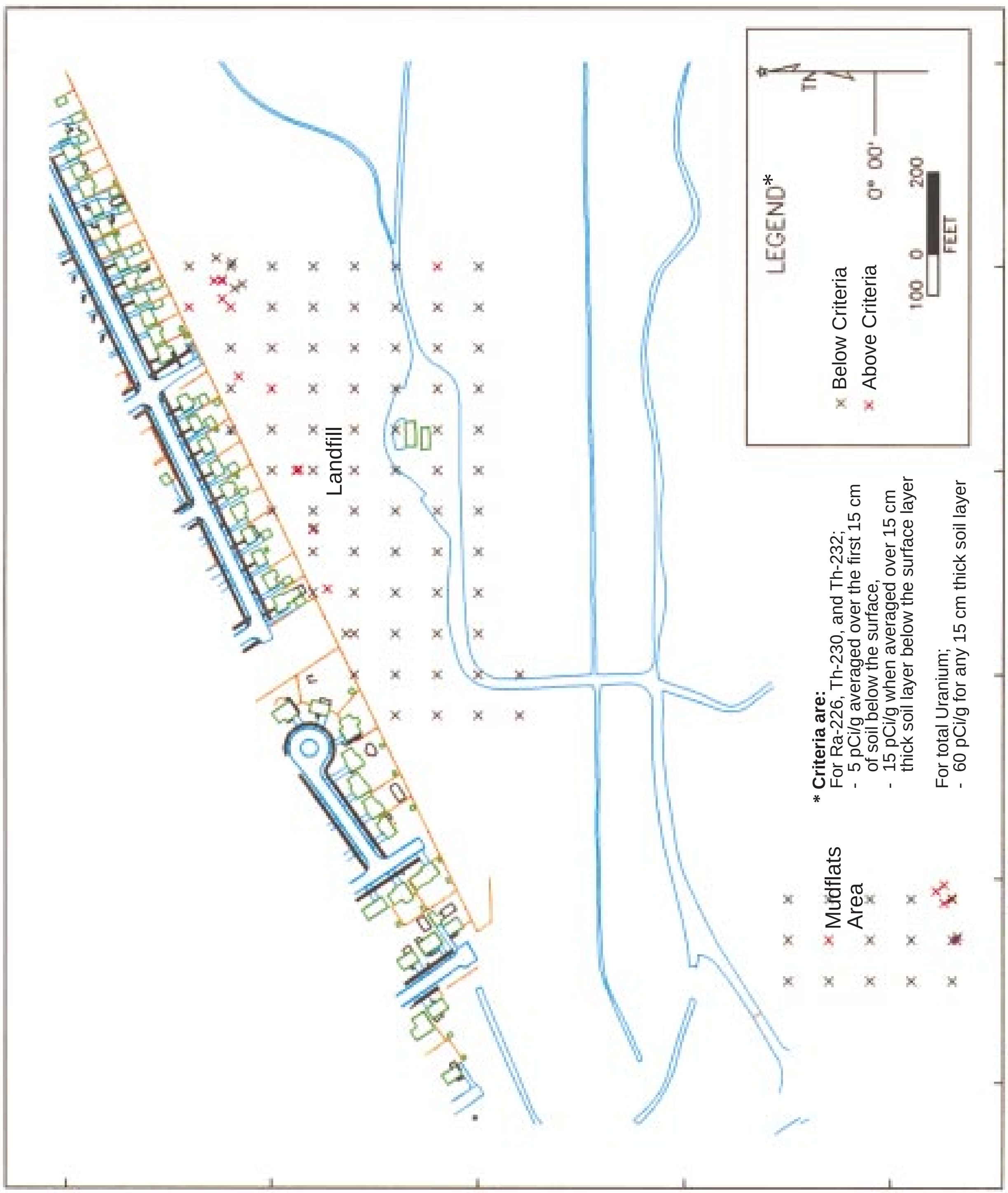
The scope of this human health assessment includes evaluation of potential radiological carcinogenic risk for the Town of Tonawanda Landfill and adjacent Mudflats Area identified in the 1992 and 1995 study areas. The assessment is limited to MED-related materials suspected to have originated from the Linde Air Products site. Scenarios were developed based on existing conditions and potential future uses. Exposure scenarios examined for the landfill include: baseline conditions (recreational use), a remediation worker who excavates MED-related wastes, a worker who constructs the landfill cap for closure, and a recreational user who utilizes the landfill following closure. The post-closure exposure scenarios assume that the landfill is closed in accordance with the closure plans submitted by Malcolm-Pirnie, the town's contractor, without removal of radioactive material. Exposure scenarios for the mudflats include recreational user and industrial worker under conditions of no cover (baseline) and 15 centimeters (6 inches) of cover.

2. HUMAN HEALTH ASSESSMENT

This section describes the method used to determine the concentrations of radioactivity in the soil, describes the assumptions made for the exposure conditions, and reports the results of the assessment. The calculations for the assessment were performed using the Residual Radioactivity (RESRAD) computer model, version 5.82 (Yu, et al. 1993a).

2.1 DATA EVALUATION

Data sets used for the development of a reasonable maximum exposure concentration were taken from two sources, the *Results of the Radiological Survey of the Town of Tonawanda Landfill, Tonawanda, New York* (ORNL 1992), and the FUSRAP technical memorandum *Tonawanda Landfill Field Sampling Results* (BNI 1995). The ORNL report gives results for U-238, Ra-226, Th-232, and Th-230. Likewise, the Bechtel National, Incorporated (BNI) report gives values for U-238, Ra-226, Th-232, and Th-230; but also gives limited results for other relevant gamma



BNI 1995, ORNL 1992

FUS NY Tona 01/99

Figure 4. Sampling Locations - Town of Tonawanda Landfill and Adjacent Mudflats

emitting radionuclides such as Ra-228, Th-228 and U-235. Actinium-227 (Ac-227) and protactinium-231 (Pa-231) are assumed to be in equilibrium with U-235.

Statistical analyses on the data set were used to determine the maximum, minimum, mean, and upper 95 percent confidence level (UCL_{95}) on the mean concentrations for each exposure scenario. The UCL_{95} represents a concentration that will exceed the mean concentration of a randomly drawn set of samples 95 percent of the time. The UCL_{95} values, after subtracting background, were used as the exposure point concentrations (EPC) for the assessment. Site background values are 1.1 pCi/g for Ra-226, 1.2 pCi/g for Th-232, 1.4 pCi/g for Th-230, and 3.1 pCi/g for U-238 (DOE 1993b).

The Town of Tonawanda Landfill database contains soil and sediment sample results from the 1992 ORNL investigation (172 systematic and biased sample results) and the 1995 BNI investigation (19 biased sample results). All samples from both efforts were analyzed by gamma spectroscopy but with one significant difference between the ORNL and BNI approaches. BNI chose to quantify Th-230 separately using alpha spectroscopy (a more costly but much more accurate and reliable method for measuring Th-230 concentrations). ORNL attempted to use gamma spectroscopy to quantify Th-230.

ORNL reported minimum detectable activities (MDAs) for 162 of the 172 samples. A review of the ORNL report reveals that many Th-230 MDAs are 5 to 15 times the associated Ra-226 and U-238 activities and likely are not a true representation of onsite conditions. Detection limits for the samples in which Th-230 was not detected ranged from 2.9 pCi/g to 820 pCi/g with an average of 21.2 pCi/g. Standard EPA baseline risk assessment guidance for nondetected analytes calls for using one-half the detection limit as a surrogate value (for radionuclides, standard practice is to use the detection limit if a result is not available). This approach was followed, including the MDAs in the calculations of the statistics for the data set. Thus, the Th-230 concentrations used in this assessment are likely higher than the actual concentrations in the landfill.

Concentrations of elements for which no or incomplete analytical data are available were set equal to the concentration of the nearest long-lived parent radionuclide (e.g., U-234 was set equal to U-238). Uranium-235 and decay products were set equal to 4.6 percent of the U-238 concentration (i.e., in natural abundances). The results of the data evaluation (including site background values) are listed in Tables 1 through 3.

Table 1 gives separate EPCs for the remediation worker in the landfill and mudflats. As a worst case scenario, the worker in this evaluation is exposed to the entire volume of soil containing radioactivity above criteria presented in the UMTRCA (5 pCi/g Ra-226 or Th-230 in the upper 15 cm (6 in) interval, 15 pCi/g in soil deeper than 15 cm). These criteria were assumed in order to establish volumes of contaminated soil and exposure concentrations. To model this scenario, the data from areas with concentrations greater than UMTRCA criteria in both the landfill and the mudflats area were aggregated into a data subset and the UCL_{95} for the remedial worker was calculated from this data subset. This is a conservative approach considering that if data were included that did not contain elevated radioactivity, the source term would contain lower radionuclide concentrations. By

Table 1. Statistical Summary of Impacted Area Data (Remediation Worker)

Analyte	Results Greater Than Detection Limit	Minimum (pCi/g)	Maximum (pCi/g)	Mean (pCi/g)	UCL_{95} (pCi/g)	Background (pCi/g)	EPC[a] (pCi/g)
Landfill							
Ac-227[b]	Not analyzed						9.24
Pa-231[b]	Not analyzed						9.24
Pb-210[c]	Not analyzed						220.9
Ra-226	41/41	0.32	2,000	128	222	1.1	220.9
Ra-228[d]	Not analyzed						2.2
Th-228[d]	Not analyzed						2.2
Th-230	20/41	0.65	4,300	232	418	1.4	416.6
Th-232	36/41	0.60	3.4	2.33	4.02	1.2	2.2[e]
U-234[f]	Not analyzed						200.9
U-235[b]	Not analyzed						9.24
U-238	38/41	0.88	1,800	127	204	3.1	200.9
Mudflats							
Ac-227[b]	Not analyzed						2.23
Pa-231[b]	Not analyzed						2.23
Pb-210[c]	Not analyzed						40.8
Ra-226	43/43	0.81	120	8.21	41.9	1.1	40.8
Ra-228[d]	Not analyzed						NA
Th-228[d]	Not analyzed						NA
Th-230	7/41	1.4	600	26.8	108	1.4	106.6
Th-232	43/43	0.8	1.5	0.953	1.07	1.2	NA
U-234[f]	Not analyzed						48.5
U-235[b]	Not analyzed						2.23
U-238	39/43	0.79	78	9.38	51.6	3.1	48.5

[a] EPC = UCL_{95} - background
[b] Assumed at 4.6 percent of U-238 specific activity
[c] Assumed to be in secular equilibrium with Ra-226
[d] Assumed to be in secular equilibrium with Th-232
[e] If UCL_{95} > Maximum Detection, then EPC = Maximum Detection - background
[f] Assumed to be in secular equilibrium with U-238

Table 2. Statistical Summary of Landfill Shallow Soil (<2.0 ft) (Construction Worker and Recreationist)

Analyte	Results Greater Than Detection Limit	Minimum (pCi/g)	Maximum (pCi/g)	Mean (pCi/g)	UCL_{95} (pCi/g)	Background (pCi/g)	EPC[a] (pCi/g)
Ac-227[b]	Not analyzed						0.897
Pa-231[b]	Not analyzed						0.897
Pb-210[c]	Not analyzed						65.5
Ra-226	136/136	0.36	2,000	37.9	66.6	1.1	65.5
Ra-228[d]	Not analyzed						0.55
Th-228[d]	Not analyzed						0.55
Th-230	8/136	0.65	4,300	73.9	131	1.4	129.6
Th-232	131/136	0.32	2.6	1.25	1.75	1.2	0.55
U-234[e]	Not analyzed						19.5
U-235[b]	Not analyzed						0.897
U-238	121/136	0.33	310	15.5	22.6	3.1	19.5

[a] EPC = UCL_{95} - background
[b] Assumed at 4.6 percent of U-238 specific activity
[c] Assumed to be in secular equilibrium with Ra-226
[d] Assumed to be in secular equilibrium with Th-232
[e] Assumed to be in secular equilibrium with U-238

Table 3. Statistical Summary of Mudflats Data (Industrial Worker and Recreationist)

Analyte	Results Greater Than Detection Limit	Minimum (pCi/g)	Maximum (pCi/g)	Mean (pCi/g)	UCL_{95} (pCi/g)	Background (pCi/g)	EPC[a] (pCi/g)
Ac-227[b]	Not analyzed						0.46
Pa-231[b]	Not analyzed						0.46
Pb-210[c]	Not analyzed						12.0
Ra-226	43/43	0.81	120	8.21	13.1	1.1	12.0
Ra-228[d]	Not analyzed						NA
Th-228[d]	Not analyzed						NA
Th-230	7/41	1.4	600	26.8	51.1	1.4	49.7
Th-232[d]	43/43	0.80	1.5	0.953	0.988	1.2	NA
U-234[e]	Not analyzed						10.1
U-235[b]	Not analyzed						0.46
U-238	39/43	0.79	78	9.38	13.2	3.1	10.1

[a] EPC = UCL_{95} - background
[b] Assumed at 4.6 percent of U-238 specific activity
[c] Assumed to be in secular equilibrium with Ra-226
[d] Th-232 UCL_{95} below background
[e] Assumed to be in secular equilibrium with U-238

including only data from areas having elevated activity levels, the source term produces the highest possible radionuclide concentrations.

Table 2 gives the EPC for the construction worker (who closes the landfill) and the recreational user (before and after landfill closure). Only surface (top 0.61 m or 2 ft) data are included in the EPC in Table 2. This approach is appropriate because the construction worker and the recreational user are exposed only to surface material and spend equal amounts of time across all of the site, and the majority of the known elevated radioactivity is in the top two feet of soil. Table 3 gives the EPCs for the mudflats area. All data for this area were used in calculation of the UCL_{95} because the area, which is approximately 3 acres, could reasonably serve as an exposure unit for a recreational or industrial scenario, and most of the data were taken in the upper 15 cm (6 in). The inclusion of the biased data with the systematic data increases the EPC and acts as an additional conservative bias to the evaluation.

2.2 EXPOSURE ASSESSMENT

In this section, the exposure scenarios are summarized and the pathways for exposure are identified. A detailed list of exposure parameter values are listed in Appendix A. References for exposure parameter values and/or justification for using non-RESRAD default values are also given in the Appendix A tables. Parameter values were chosen to be consistent with the cleanup guideline derivations for Ashland and Seaway (DOE 1997) unless dictated otherwise by site-specific conditions. Groundwater is not included as a pathway for this assessment because groundwater quality in the area of the landfill may have been impacted by landfill leachate resulting from refuse deposition since the mid-1930s (MPI 1994). In some areas, the refuse is thought to be in direct contact with groundwater. Additionally, the shallow groundwater aquifer (impacted by the landfill) is composed primarily of silts and clays, resulting in unacceptably poor water supply yields. The potential for rainwater leaching MED materials to the groundwater in the Tonawanda area is presented in a letter to the New York State Department of Environmental Conservation, dated April 4, 1997, from the Department of Energy (DOE 1997). Attached to the letter was a “Fact-Sheet” entitled “Radionuclide Mobility in the Groundwater at Tonawanda, New York” (Adler 1997). This fact-sheet presents the case that the MED residue materials at the various sites in Tonawanda are insoluble residues left after the radioactive constituents in the ores being processed were aggressively leached from the ores in a hot acid digestion process. Additionally, the native soils in the Tonawanda area, being naturally rich in clay materials, would attract and capture any small quantities of dissolved radioisotopes remaining in the residues should they leach over time. Because of the low solubility of the radionuclides and the high sorptive characteristics of the soils, no impacts to the groundwater from the MED waste is anticipated.

The risk posed to the nearest resident was not evaluated because the only direct exposure pathway available for a person who does not enter the site is the airborne dust pathway. The landfill is heavily vegetated thus minimizing potential dust emissions. When a remedial action is undertaken, appropriate air monitoring and controls will be initiated at the site prior to the remedial action to ensure compliance with applicable air regulations and to measure potential airborne radioactive dust that might be generated by the remedial activities. Mitigative measures will be instituted if monitoring detects unacceptable offsite migration.

2.2.1 Construction Worker Scenario

The construction worker scenario was chosen to estimate dose if the landfill is closed without removal of the radioactive materials. This scenario may be a remedial option if risks and the associated doses to the worker are not excessive. To model the construction worker scenario, the Town of Tonawanda Landfill closure proposal was used to establish the exposure conditions during landfill closure. Landfill closure plans call for placement of a geotextile membrane over the waste, covering the membrane with an 18 inch clay barrier layer, placing a 12 inch gravel barrier protection layer over that, then covering with 6 inches of topsoil to support vegetation.

Each layer acts as a shield to reduce the workers' exposure during the construction of subsequent layers. No cover depth is assumed during the construction of the lowest layer (the first layer above impacted soils). The added thickness of each subsequent layer was modeled until the cover became sufficiently thick to preclude significant additional risk or until all the layers had been modeled. The doses and incremental cancer risks were then summed for a total risk and dose during the project, if applicable.

The initial activity is assumed to be site preparation. Clearing and grubbing followed by placement of soil over the area and grading of the area would be necessary to prepare the site for proper drainage (i.e. contouring) and subsequent installation of the geotextile membrane. Therefore, it is assumed that the site will be covered by placement of 1 foot , at a minimum, of common earth over the entire site. The area of the site used to calculate the construction worker's exposure is the area that was included in ORNL's systematic sampling grid, 70,100 m^2 (755,000 ft^2). The production rate for clearing and grubbing is given by R.S. Means *Environmental Cost Handling Options and Solutions* unit cost book at 4,310 m^2/hr (1.065 acres/hr) for medium brush, average grub and trees (Rast 1996). The duration for clearing and grubbing is thus given by the equation

$$\frac{70{,}100\ m^2}{4{,}310\ m^2/hr \times 0.63} = 25.8\ hours \qquad (1)$$

where 0.63 is a safety factor accounting for the production inefficiency introduced by safety measures taken to protect the workers.

The duration for the placement of the one foot of soil for contouring the site was based upon backfill productivity rates given in *Mean's Heavy Construction Cost Data* (Smit 1996). The rate for backfill with common earth for a 149 kilowatt (200 horsepower) doxer is 0.02093 hr/m^3 (0.016 hr/yd^3) assuming a 90 m (300 ft) haul from the soil storage area. An additional 0.00262 hr/m^3 (0.002 hr/yd^3)

$$\frac{00\ m^2 \times 0.3048\ m \times (0.02093 + 0.00262)\ hr/m^3}{0.63} = 799\ h \qquad \textbf{(2)}$$

The total time fraction (%) spent at the site without any cover is given by the equation

$$\frac{25.8\ hours + 799\ hours}{8{,}760\ hours/year} = 0.094\ year\ (9.4\%) \qquad \textbf{(3)}$$

where 8,760 is the total number of hours in a year. Exposure pathways include gamma radiation, inhalation, and incidental soil ingestion. The placement of the 1 foot of cover effectively intercepts the inhalation and soil ingestion pathways for subsequent layers, although the pathways were left open in the model. Dust loading in the air was assumed to be 0.0006 g/m^3 as recommended by the *Data Collection Handbook to Support Modeling the Impacts of Radioactive Materials in Soil* (Yu et al. 1993b) for construction activities. Only 30% of the dust in the air is actually respirable, however, (Paustenbach 1989) thus the dust loading was set to 0.00018. The respiration rate was set to 12,300 m^3/year, the average between light and heavy construction activity rates (Yu, et al. 1993b). All relevant exposure parameters are listed in the Appendix A table, "Town of Tonawanda Landfill Construction Scenario."

The same pathway assumptions were made for construction of the next layer except that with the filter layer in place, 0.30 m (12 in) of cover separates the worker from contact with the soil. The duration for placement of the geotextile layer was estimated by using the productivity rate for installation of 130 or 170 mil geotextile of 94 m^2/hr (112.5 yd^2/hr) (Rast 1996). The time required to cover the 70,100 m^2 area included in the ORNL study is

$$\frac{70{,}100\ \text{m}^2}{94\ \text{m}^2/\text{hr} \times 0.63} = 1{,}184\ \text{hours} \qquad \textbf{(4)}$$

If the construction worker is on site 1,184 hours, his occupancy fraction in a 8,760 hour year is approximately 0.14.

For the 18 inch clay layer, the duration of exposure was estimated by using the backfill unit productivity rate in *Mean's Heavy Construction Cost Data* of 0.024 hour/m^3 (0.018 hour/yd^3) for a 149 kilowatt (200 horsepower) dozer and a 90 m (300 ft) haul from the soil storage area. The time required to cover the 70,100 m^2 (755,000 ft^2) impacted area with 0.46 m (18 in) of soil for the filter layer is

$$(70{,}100\ \mathrm{m}^2) \times (0.4572\ \mathrm{m}) \times (0.023542)\ \frac{\mathrm{hour}}{\mathrm{m}^3} = 755\ \mathrm{hours} \qquad \mathbf{(5)}$$

This layer would be compacted with a sheepsfoot or wobbly wheel roller adding 0.0026 hour/m^3 (0.002 hour/yd^3) to the task for an additional 84 hours. A safety factor of 0.63 was then applied to this as shown below:

$$\frac{755\ \mathrm{hours} + 84\ \mathrm{hours}}{0.63} = 1{,}332\ \mathrm{hours} \qquad \mathbf{(6)}$$

for an occupancy fraction of 0.15.

A new onsite time fraction was calculated based on construction of a 0.3 m (1 ft) thick gravel layer at a productivity rate of 0.0196 hr/m^3 (0.015 hr/yd^3) (Smit 1996) as

$$\frac{70{,}100\ \mathrm{m}^2 \times 0.0196\ \mathrm{hr/m}^3 \times 0.305\ \mathrm{m}}{0.63} = 666\ \mathrm{hrs} \qquad \mathbf{(7)}$$

representing an onsite time fraction of 0.076 (based on 8,760 hours in a year). Actual risk and dose for the gravel layer were negligible. Consequently, the remaining layers were not modeled, as additional risk would also have been negligible.

2.2.2 Recreational Scenario

The recreational scenario is used to represent likely current and near-term future uses. There is some evidence that the area has been used for recreational purposes and many closed landfills have been subsequently developed as parks in the region. To model the recreational exposure, the fraction of time (percent of time) spent outdoors onsite was set to 0.011 (1.1%) representing 0.27 hours per day (EPA 1990). The actual occupancy factor would likely be lower considering that the areas with elevated radioactivity are localized and isolated, so continuous exposures during recreational activity are unlikely. The recreational cases were modeled with and without cover. The no cover calculation represents current (baseline) conditions. For the future case, a cover depth of 0.9 m (3 ft) was assumed to represent the minimum depth if the landfill is closed in accordance with the current proposal. In the mudflats area, a 15 cm cover (6 in) is modeled as well as the no cover case. Dust loading was set to 0.00003 g/m^3 assuming 0.0001 g/m^3 (NRC 1992) and a 30-percent respirable fraction (Paustenbach 1989). An inhalation rate of 12,300 m^3/year (Yu et al. 1993b for moderate to heavy exercise) and a soil ingestion rate of 100 mg/day are assumed (EPA 1990). Exposure pathways include direct gamma radiation, soil ingestion and dust inhalation. All relevant exposure parameters are listed in the Appendix A table, "Town of Tonawanda Landfill Recreational Scenario."

2.2.3 Industrial Worker Scenario

The industrial worker is a likely future use for the mudflats. If the land is developed for commercial or industrial use, it will likely be paved, thus greatly reducing the potential for exposure to radioactive materials. The industrial worker is assumed to be onsite 8 hours per day, spending 1 hour outdoors and 7 hours indoors, for 250 days each year giving an onsite time fraction of 0.20 indoors and 0.029 outdoors. The inhalation rate was left at 8400 m^3/yr, the RESRAD default. The exposure duration was set to 25 years based on EPA's 1990 Exposure Factors Handbook recommendation for the reasonable upper bound for a residence time (EPA 1990). Soil ingestion was set to a rate of 18.25 g/yr based on an ingestion rate of 50 mg/day. The industrial worker was modeled only for the mudflats area. Cover depth was set at 0 for one estimate and 15 cm (6 in) for another. All relevant exposure parameters can be found in the tables in Appendix A, "Mudflats Industrial Scenario". Exposure pathways include direct gamma radiation, soil ingestion and dust inhalation.

2.2.4 Remediation Worker Scenario

The remedial worker exposure is evaluated to assess whether the material may impose greater risk when remediated than if it remains in place. The risk to the remedial worker is directly proportional to the volume of impacted soil (more soil equates to longer excavation times and more contact with radioactive material). The volume of impacted soil was estimated to be 7700 m^3 (10,100 yd^3) in the landfill and 1300 m^3 (1700 yd^3) in the mudflats according to the most recent volume estimates. This information was used to estimate the duration of the exposure. From Mean's *Heavy Construction Cost Data* (Smit 1996), a backhoe with a 0.76 m^3 (1.0 yd^3) bucket can excavate 30.6 m^3/hour (40 yd^3/hour). Using a safety and productivity factor of 0.63 (SAIC 1996) to account for increased time to accomplish tasks due to the health and safety requirements when excavating radioactive materials, the duration of exposure during remediation is:

$$\frac{7{,}690\ m^3}{30.6\ m^3/\text{hour} \times 0.63} = 399\ \text{hours (landfill)} \qquad \textbf{(8)}$$

or

$$\frac{1330\ m^3}{30.6\ m^3/\text{hr} \times 0.63} = 69\ \text{hours (mudflats)} \qquad \textbf{(9)}$$

Based on 8,760 hours in a year, the fraction of time spent onsite is 0.046 for the landfill and 0.0079 for the mudflats.

An inhalation rate of 12,300 m^3/year was chosen consistent with the construction worker scenario. Radiation workers would be required to wear a respirator in areas where airborne contamination is likely. An assumed Assigned Protection Factor of 10 would filter out 90% of the dust in the air, thus a mass loading of 0.00006 g/m^3 was used representing 10% of the construction dust loading with only respirable particles passing through the filter. The soil ingestion pathway was suppressed because the respirator would prevent incidental soil ingestion. The pathways evaluated include external gamma and dust inhalation. All relevant exposure parameters are listed in the Appendix A table, "Town of Tonawanda Landfill Remediation Worker Scenario."

2.3 RESULTS

RESRAD computes doses and risks for a 1,000 year period. The cancer risks reported below are for the maximum within the 1,000 year period (which was at 1,000 years) for the baseline and expected future use cases, and at 0 years for the short-term construction scenarios (landfill closure and remediation). This is because if remediation or closure occur, they are most likely to occur in the near future whereas the recreational and industrial scenarios are either planned long-term future uses or the baseline case with no change in use or conditions projected. The calculated radiological doses and excess lifetime cancer risks for the scenarios evaluated are shown in Table 4.

Table 4. Summary of Results

Scenario	Major Radionuclide	Major Pathway: Dose	Total Dose and Risk	
			Dose (mrem/yr)	Risk
Landfill				
Recreational (Baseline)	Th-230	Gamma: 9.9 mrem/yr	10	5.4×10^{-5}
Recreational (Post Closure)	NA[a]	NA	<<0.1	$<<10^{-6}$
Construction	Ra-226	Gamma: 73 mrem	86	4.5×10^{-5}
Remediation	Ra-226	Gamma: 109 mrem	110	6.5×10^{-5}
Mudflats				
Industrial, no cover	Th-230	Gamma: 42 mrem/year	43	6.4×10^{-4}
Industrial, 6 in. cover	Th-230	Gamma: 6.4 mrem/year	6.4	9.6×10^{-5}
Recreation, no cover	Th-230	Gamma: 2.8 mrem/year	2.9	1.5×10^{-5}
Recreation, 6 in. cover	Th-230	Gamma 0.9 mrem/year	0.9	4.8×10^{-6}
Remediation	Ra-226	Gamma: 3.4 mrem	3.5	2.0×10^{-6}

[a] Not Applicable - modeled doses and risks are negligible

Results indicate that risk from exposure to radionuclides at the site is due primarily to external gamma radiation from Ra-226 (as shown in Table 4) including Ra-226 ingrowth from Th-230. 40 CFR 300.430 requires that remediation goals at CERCLA sites shall be developed at concentration levels that represent an upper bound lifetime incremental cancer risk between 10^{-4} and 10^{-6}. The baseline risk to the landfill recreational user is an incremental lifetime cancer risk of 5.4×10^{-5}. For the mudflats, recreational use is predicted to result in a cancer risk of 1.5×10^{-5}. The recreational cancer risk following landfill closure is negligible due to the 0.9-m (3-ft) clean soil cover, however the 15 cm (6 in) cover in the mudflats only reduces recreational excess cancer risk to 4.8×10^{-6}. The relatively higher doses and risks estimated for the construction worker and the remediation worker in the landfill are conservatively high because there are a few data points that skew the data distribution. As shown in Appendix B, the number of boreholes with elevated radioactivity (well above 2 × background) over the 70,000-m^2 (750,000-ft^2) study area is small. For example, one borehole (B7) contains three significantly elevated sample results (2,000-pCi/g Ra-226, 1,000-pCi/g Ra-226, and 4,300-pCi/g Th-230) that are atypical of the data set as a whole.

2.3.1 Construction Worker Scenario

The landfill construction worker's excess lifetime cancer risk is estimated at 4.5×10^{-5} as a result of landfill closure activities. The largest contributor to this risk is external gamma radiation from Ra-226 representing over 90 percent of the total dose from gamma radiation. Lead-210 is the source of the next highest dose due to soil ingestion. This estimate is very conservative considering the distribution of the data and the influence of a few sample results.

The construction worker exposure could easily be reduced with minimal planning. Referring again to Appendix B, there are a limited number of borehole locations containing elevated radioactivity. The assessment assumes that none of the radioactive material is covered prior to site preparation activities. In reality, the elevated radioactivity is localized in relatively small areas and could easily be covered prior to closure activities (see Figure 1). In fact, covering the areas known to contain elevated radioactivity with clean soil would reduce the construction worker dose and risk to negligible levels.

2.3.2 Recreational Scenario

For the baseline (current) case, the model predicts a dose of 10 mrem/yr resulting from regular recreational activities at the landfill. The exposure is almost all due to gamma radiation from Ra-226 initially, and from ingrowth of Ra-226 from Th-230 in future centuries. This dose would result in a predicted increased lifetime risk of cancer of 5.4×10^{-5}. The reason the increase in cancer risk for the recreational user is slightly higher than for the construction worker even though the dose is significantly less is that the recreational user's exposure duration is greater than that of the construction worker. It was assumed that the recreational user would continue using the landfill for recreational purposes for a period of 9 years, a period recognized by EPA as the average duration for a resident at a single location (EPA 1992).

No measurable dose or risk is calculated for the future recreational user following landfill closure. This outcome is expected because closing the landfill requires 0.9 m (3 ft) of clean cover material to be placed over the landfill. The evaluation is dependent upon maintenance of the cover. If the cover were to be breached, doses (and risks) could be higher.

The baseline case for recreation in the mudflats area indicates an increased cancer risk of 1.5×10^{-5}. A 6 inch cover over the contaminated area would reduce the dose for a recreational exposure to 0.9 mrem/year bringing excess risk down to 4.8×10^{-6}.

2.3.3 Industrial Scenario

The industrial worker would receive a dose of 43 mrem due primarily to gamma radiation from Ra-226 built up by Th-230 decay. This results in an increased lifetime cancer risk of 6.4×10^{-4}. If 6 inches of cover were placed over the mudflats (e.g. an asphalt parking lot) then the dose would be reduced to 6.4 mrem/yr and the cancer risk would be reduced to 9.6×10^{-5}. If the area is developed for industrial or commercial use, much of the area would be covered with asphalt or building slabs. Thus the 6 inch cover assumption would be the most likely actual condition following commercial or industrial development.

2.3.4 Remediation Worker Scenario

The remediation worker's dose is estimated to be 110 mrem in the landfill and 3.5 mrem in the mudflats during the removal activities. The largest contributor to dose is gamma radiation producing 97 percent of the total dose and cancer risk. Again, this estimate is very conservative considering the distribution of the data and the influence of a few sample results. Even with these conservative estimates, however, the estimated dose is well below the 5,000 mrem/year limit allowed for radiation workers. This exposure is predicted to result in an increased lifetime cancer risk of 6.5×10^{-5} at the landfill and 2.0×10^{-6} at the mudflats.

2.3.5 Radon

Radon emissions from the landfill following closure were predicted by the model to barely exceed the UMTRCA criteria of 20 pCi/m^2/s for Rn-222 flux averaged over the entire surface of the disposal site. Although the RESRAD model predicted 22 pCi/m^2/s at present increasing to 29 pCi/m^2/s at 1,000 years, the actual flux is likely to be much lower due to the highly conservative parameter estimates used in the calculations and the bias of the data set. Radon flux in the mudflats was estimated at 5.8 pCi/m^2/s increasing to about 10 in 1,000 years. UMTRCA additionally requires that reasonable effort shall be made to achieve an average radon decay concentration not to exceed 0.02 Working Levels (WL) in a habitable building. The WL is defined as any combination of Rn progeny in 1 L of air that results in the emission of 1.3×10^5 million electron volts of alpha particle energy. This criterion would not apply to the landfill since no habitable structures could be erected due to post-closure care. The estimated concentration of indoor radon at the mudflats is 0.012 WL initially rising to 0.022 after 1,000 years.

2.4 UNCERTAINTIES

2.4.1 Parameter Assumptions

Exposure parameters were selected to provide conservative, yet reasonable estimates of potential radiological doses and risks to each receptor. Site-specific measurements and data were used, where available, to describe site conditions as accurately as possible. Where site-specific data were not available, parameter values were chosen to provide reasonably conservative estimates of exposure, with preferential use of parameter values from previous site analyses (e.g., Tonawanda site

Feasibility Study, Baseline Risk Assessment) or standard default values recommended by EPA or other authorities. In other cases, parameter values (e.g., distribution coefficients for most radionuclides) were determined from a survey of the scientific literature. Pertinent references for parameter values are in Appendix A. Exposure scenarios and parameter values have been consistently chosen to provide conservative, yet reasonable, estimates of potential radiation risk.

2.4.2 Weighted Average Assumptions

An additional uncertainty in the sample data relates to the volumetric distribution of the residual radioactive materials. Each data point is given equal weight in calculating the concentration statistics, although each data point does not necessarily represent a fixed volume of soil nor are sampling locations uniformly distributed throughout the site. Since many sample locations are biased toward locations of increased direct gamma activity, the sample statistics are likely to over-estimate the actual radionuclide concentrations in site soils.

2.4.3 Impacted Zone Distribution Assumptions

The residual radioactivity is assumed (modeled) to be uniformly distributed throughout a 0.61-m (2 ft) thick layer of soil across the impacted areas. Actual site conditions are expected to be much more irregular, such that the thickness of this residual soil layer may range from several feet to a few inches. Similarly, the radionuclide concentrations are not homogeneous throughout the site. The 0.61-meter homogeneous layer assumed for this analysis represents an idealized model of actual conditions, but still provides a conservative dose estimate.

2.4.4 Groundwater Assumptions

Groundwater is not considered a legitimate exposure pathway in this assessment. This is because groundwater sampling in the region has demonstrated poor water quality and low yield (MPI 1994) and because residential use will likely be prohibited by land use restrictions. The use of groundwater is, therefore, highly unlikely and not considered a potential pathway in this assessment.

2.4.5 Thorium-230 Source Term

As discussed in Section 2.1, the majority of the Th-230 data are MDAs taken directly from the 1992 ORNL report. No data qualifiers are listed, and the reported MDA values are in most cases many times the associated Ra-226 and U-238 concentrations (when equilibrium conditions are expected). Following standard EPA protocol for radionuclides, much of the landfill site incorrectly appears to contain elevated radioactivity.

2.4.6 Future Land Use

The selection of scenarios for evaluation were based on the most reasonable future land use given the present uses and local trends. The Town of Tonawanda Landfill and the Mudflats area are currently zoned industrial by the Town of Tonawanda. Residential development in the landfill appears highly unlikely due to aesthetics and the physical health problems that may arise from residing on a closed landfill. Deed restrictions could further reduce the possibility that the land may be used for different, possibly unacceptable, land uses, such as residential or industrial. Similarly, the mudflats would be poorly suited for residential development because it is located between a major interstate highway and the landfill. Although the stated intended land uses used for this assessment are the most likely for the future, there is always an uncertainty about the potential for other land uses to occur well into the future. Should the use of the land change to where an individual is in contact with the residual radiological materials for extended periods, the risk to the individual could be unacceptable. Therefore, land use restrictions should be maintained for the longest possible period.

2.5 SUMMARY AND CONCLUSIONS

2.5.1 Summary

The remediation worker in the landfill receives the highest dose, 110 mrem, however this dose is only incurred once, explaining why the industrial worker in the mudflats are has a much lower annual dose, 43 mrem if no cover is placed over the contamination, but has a higher cancer risk than the remedial worker. The industrial worker has the highest cancer risk because the remedial worker's dose is only incurred once whereas the industrial worker's dose in the mudflats is incurred every year as long as the receptor is employed at this location. The landfill construction worker will receive a single dose of about 86 mrem. Under current conditions, a recreational user of the landfill receives a lower dose than other scenarios at the landfill. After closure, exposures have negligible effect assuming post closure care maintains the cover over the radioactive materials. By leaving impacted material in place and covering it with one foot of clean soil, all receptors considered will be adequately protected from the radioactive material in the landfill. Future likely receptors are also adequately protected should the cover material become nonexistent after the site surveillance and maintenance required under current regulations for landfills is no longer required.

For the mudflats area, the cancer risk for an industrial worker (6.4×10^{-4}) is at the high end of the CERCLA risk range. The risk drops significantly however, when 15cm (6 inches) of soil is placed over the contaminated areas and the risk to the recreational user is within acceptable limits even under the baseline (no cover) conditions.

2.5.2 Conclusions

If the isolated areas containing elevated radioactivity assumed to be related to MED activities are covered with approximately one foot of clean soil, no measurable risk will be incurred during landfill closure activities. The clean soil will provide an additional buffer zone for future land users. Leaving the material in place is also consistent with current landfill practices. That is, materials known to contain Am-241 have not been removed and incinerator ash including waste water sludge (both known to contain elevated concentrations of Ra-226) are known to have been deposited in the landfill without consideration for removal.

In addition, recovering the radioactive material from the landfill would impose additional hazards on the remediation workers beyond what is normally encountered during remediation of radioactive materials. Pockets of poisonous gas such as hydrogen sulfide or explosive gas such as methane may be encountered during excavation. The risks to the workers from these other hazards must be weighed against the benefit of recovering the radiological contamination.

In the mudflats area, institutional controls or remediation may be necessary. Potentially unacceptable risks could result if development is not curtailed. The potential exists for risks outside of the CERCLA accepted risk range should the site be used for industrial purposes in its present condition.

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APPENDIX A

RESRAD SITE AND SCENARIO SPECIFIC INPUT PARAMETERS

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Town of Tonawanda Landfill Construction Scenario

RESRAD Parameter	Value	Units	Reference/Comments
Area of Impacted Zone	70,000	m^2	Area covered during the 1991 ORNL investigation (includes all systematic and biased sample locations from 1991 and 1995 efforts).
Thickness of Impacted Zone	0.61	m	Most site data (including the highest Ra-226 and Th-230 values) were collected from ≤2 ft in depth.
Cover Depth	0	m	The site is assumed to be uncovered during site preparation. One foot of soil would be placed followed by 0.0033 m (geotextile) and a 0.3048 m (clay layer).
Density of Impacted Zone	1.5	g/m^3	RESRAD Default
Impacted Zone Erosion Rate	0	m/yr	Not applicable during landfill construction activities.
Impacted Zone Total Porosity	0.45	—	1993 Tonawanda FS
Impacted Zone Effective Porosity	0.2	—	RESRAD Default
Impacted Zone Hydraulic Conductivity	123	m/yr	1993 Tonawanda FS
Evapotranspiration Coefficient	0.46	—	1993 Tonawanda FS
Precipitation	1.23	m/yr	1993 Tonawanda FS
Runoff Coefficient	0.25	—	1993 Tonawanda FS
Inhalation Rate	12,300	m^3/yr	(Yu et al. 1993) assuming a mixture of heavy and moderate activity
Mass Loading for Inhalation	0.00018	g/m^3	(Yu et al. 1993) assumes 600 $\mu g/m^3$ of air for construction activities. It is assumed that only 30% of the dust is respirable. Dust loading will likely have little impact on dose when considering that covering the site will reduce and eventually eliminate the source term. The modeled scenario assumes no cover over the impacted area during the entire exposure time.
Exposure Duration	1	yr	Reasonable time of exposure during construction activities.
Fraction of Time Spent Indoors	0	—	No indoor activities
Fraction of Time Spent Outdoors	0.34	—	Based on calculated number of hours for construction activities.
Soil Ingestion	175.2	g/yr	(EPA 1992) 480 mg/day for construction or landscaping activities.
External Gamma	Active	—	Assumed
Inhalation	Active	—	Assumed
Plant Ingestion	Suppressed	—	Assumed
Meat Ingestion	Suppressed	—	Assumed
Aquatic Foods	Suppressed	—	Assumed
Drinking Water	Suppressed	—	Assumed
Soil Ingestion	Active	—	Assumed
Radon	Suppressed	—	Assumed

Town of Tonawanda Landfill Recreational Scenario

RESRAD Parameter	Value	Units	Reference/Comments
Area of Impacted Zone	70,000	m^2	Area covered during the 1991 ORNL investigation (includes all systematic and biased sample locations from 1991 and 1995 efforts).
Thickness of Impacted Zone	0.61	m	Most site data (including the highest Ra-226 and Th-230 values) were collected from ≤2 ft in depth.
Cover Depth	0.9, 0	m	Landfill cap constructed over the impacted zone is planned to be 0.9 m thick for the future recreational user. 0 m used for the current condition baseline.
Cover Depth Erosion Rate	0	m/yr	No erosion for a well maintained landfill cover.
Density of Impacted Zone	1.5	g/m^3	RESRAD Default
Impacted Zone Total Porosity	0.45	—	1993 Tonawanda FS
Impacted Zone Effective Porosity	0.2	—	RESRAD Default
Impacted Zone Hydraulic Conductivity	123	m/yr	1993 Tonawanda FS
Evapotranspiration Coefficient	0.46	—	1993 Tonawanda FS
Precipitation	1.23	m/yr	1993 Tonawanda FS
Runoff Coefficient	0.25	—	1993 Tonawanda FS
Inhalation Rate	12,300	m^3/yr	(Yu et al. 1993) assuming a mixture of heavy and moderate activity
Mass Loading for Inhalation	0.00003	g/m^3	(NRC 1992) 100 $\mu g/m^3$ of air for ambient conditions. Total mass loading is modified using a respirable fraction of 30% (Paustenbach 1989). Approximately 30% of the ambient dust falls in the range of <10 m. in diameter and corresponds roughly to the range applicable for the ICRP lung model (0.2 to 10 m.)
Exposure Duration	9	yr	(EPA 1992) Average time for a resident at a single location.
Fraction of Time Spent Indoors	0	—	No indoor activities
Fraction of Time Spent Outdoors	0.011	—	Based on 0.27 hours/day (EPA 1990)
Soil Ingestion	36.5	g/yr	(EPA 1990) 100 mg/day for normal incidental ingestion.
External Gamma	Active	—	Assumed
Inhalation	Active	—	Assumed
Plant Ingestion	Suppressed	—	Assumed
Meat Ingestion	Suppressed	—	Assumed
Aquatic Foods	Suppressed	—	Assumed
Drinking Water	Suppressed	—	Assumed
Soil Ingestion	Active	—	Assumed
Radon	Suppressed	—	Assumed

Town of Tonawanda Landfill Remediation Worker Scenario

RESRAD Parameter	Value	Units	Reference/Comments
Area of Impacted Zone	5,138	m^2	Sum of contaminated areas modeled by EarthVision software November 20, 1998
Thickness of Impacted Zone	1.5	m	EarthVision volume estimate (7,690 m^3) divided by area estimate.
Cover Depth	0	m	The remedial worker must remove cover to reach contaminated soil
Density of Impacted Zone	1.5	g/m^3	RESRAD Default
Impacted Zone Erosion Rate	0	m/yr	Not applicable during landfill construction activities
Impacted Zone Total Porosity	0.45	—	1993 Tonawanda FS
Impacted Zone Effective Porosity	0.2	—	RESRAD Default
Impacted Zone Hydraulic Conductivity	123	m/yr	1993 Tonawanda FS
Evapotranspiration Coefficient	0.46	—	1993 Tonawanda FS
Precipitation	1.23	m/yr	1993 Tonawanda FS
Runoff Coefficient	0.25	—	1993 Tonawanda FS
Inhalation Rate	12,300	m^3/yr	(Yu et al. 1993) assuming a mixture of heavy and moderate activity.
Mass Loading for Inhalation	0.00006	g/m^3	(Yu et al. 1993) assumes 600 $\mu g/m^3$ of air for construction activities and a 90% reduction due to use of a respirator. It is assumed that 100% of the dust that passes through the respirator is respirable.
Exposure Duration	1	yr	Reasonable time of exposure during construction activities.
Fraction of Time Spent Indoors	0	—	No indoor activities
Fraction of Time Spent Outdoors	0.046	—	Based on 503 hours of construction activities.
Soil Ingestion	0.0	g/yr	Incidental soil ingestion precluded by respirator.
External Gamma	Active	—	Assumed
Inhalation	Active	—	Assumed
Plant Ingestion	Suppressed	—	Assumed
Meat Ingestion	Suppressed	—	Assumed
Aquatic Foods	Suppressed	—	Assumed
Drinking Water	Suppressed	—	Assumed
Soil Ingestion	Suppressed	—	Assumed
Radon	Suppressed	—	Assumed

Mudflats Remediation Worker Scenario

RESRAD Parameter	Value	Units	Reference/Comments
Area of Impacted Zone	2,696	m^2	Sum of contaminated areas modeled by EarthVision software November 20, 1998
Thickness of Impacted Zone	0.5	m	EarthVision volume estimate (1,334 m^3) divided by area estimate.
Cover Depth	0	m	The remedial worker must remove cover to reach contaminated soil
Density of Impacted Zone	1.5	g/m^3	RESRAD Default
Impacted Zone Erosion Rate	0	m/yr	Not applicable during landfill construction activities
Impacted Zone Total Porosity	0.45	—	1993 Tonawanda FS
Impacted Zone Effective Porosity	0.2	—	RESRAD Default
Impacted Zone Hydraulic Conductivity	123	m/yr	1993 Tonawanda FS
Evapotranspiration Coefficient	0.46	—	1993 Tonawanda FS
Precipitation	1.23	m/yr	1993 Tonawanda FS
Runoff Coefficient	0.25	—	1993 Tonawanda FS
Inhalation Rate	12,300	m^3/yr	(Yu et al. 1993) assuming a mixture of heavy and moderate activity.
Mass Loading for Inhalation	0.00006	g/m^3	(Yu et al. 1993) assumes 600 µg/m^3 of air for construction activities and a 90% reduction due to use of a respirator. It is assumed that 100% of the dust that passes through the respirator is respirable.
Exposure Duration	1	yr	Reasonable time of exposure during construction activities.
Fraction of Time Spent Indoors	0	—	No indoor activities
Fraction of Time Spent Outdoors	0.0079	—	Based on 503 hours of construction activities.
Soil Ingestion	0.0	g/yr	Incidental soil ingestion precluded by respirator.
External Gamma	Active	—	Assumed
Inhalation	Active	—	Assumed
Plant Ingestion	Suppressed	—	Assumed
Meat Ingestion	Suppressed	—	Assumed
Aquatic Foods	Suppressed	—	Assumed
Drinking Water	Suppressed	—	Assumed
Soil Ingestion	Suppressed	—	Assumed
Radon	Suppressed	—	Assumed

Mudflats Industrial Scenario

RESRAD Parameter	Value	Units	Reference/Comments
Area of Impacted Zone	10,000	m^2	RESRAD Default.
Thickness of Impacted Zone	0.61	m	Most site data (including the highest Ra-226 and Th-230 values) were collected from ≤2 ft in depth.
Cover Depth	0, .15	m	Doses and risks calculated for both no cover and 15 cm conditions.
Erosion Rate	0.00006	m/yr	(Yu et al. 1993) Suggested value for a non-agricultural setting
Density of Impacted Zone	1.5	g/m^3	RESRAD Default
Impacted Zone Total Porosity	0.45	—	1993 Tonawanda FS
Impacted Zone Effective Porosity	0.2	—	RESRAD Default
Impacted Zone Hydraulic Conductivity	123	m/yr	1993 Tonawanda FS
Evapotranspiration Coefficient	0.46	—	1993 Tonawanda FS
Precipitation	1.23	m/yr	1993 Tonawanda FS
Runoff Coefficient	0.25	—	1993 Tonawanda FS
Inhalation Rate	8,400	m^3/yr	(EPA 1990) 20 m^3/day inhalation rate.
Mass Loading for Inhalation	0.00003	g/m^3	(NRC 1992) 100 µg/m^3 of air for ambient conditions. Total mass loading is modified using a respirable fraction of 30% (Paustenbach 1989). Approximately 30% of the ambient dust falls in the range of <10 m. in diameter and corresponds roughly to the range applicable for the ICRP lung model (0.2 to 10 m.)
Exposure Duration	25	yr	(EPA 1990) Reasonable upper bound
Fraction of Time Spent Indoors	0.1998	—	(EPA 1990) 7 hours per day, 250 days per year indoors
Fraction of Time Spent Outdoors	0.02854	—	(EPA 1990) 1 hour per day, 250 days per year outdoors
Soil Ingestion	18.25	g/yr	(EPA 1990) 50 mg/day for workplace soil ingestion.
External Gamma	Active	—	Assumed
Inhalation	Active	—	Assumed
Plant Ingestion	Suppressed	—	Assumed
Meat Ingestion	Suppressed	—	Assumed
Aquatic Foods	Suppressed	—	Assumed
Drinking Water	Suppressed	—	Assumed
Soil Ingestion	Active	—	Assumed
Radon	Suppressed	—	Assumed

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APPENDIX B

SAMPLES WITH ELEVATED ACTIVITY

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Samples With Elevated Activity

Station	Starting Depth (ft)	Ending Depth (ft)	U-238	Th-230	Ra-226	Th-232
B12	0	0.5	220	ND	1.6	1.3
B12	0.5	1	170	ND	1.5	1.4
B12	1	1.5	89	ND	2.8	2.1
B13	0	0.5	30	27	16	0.94
B13	0.5	1	35	ND	14	0.86
B13	1	1.5	35	31	19	0.87
B13	1.5	2	34	ND	33	0.97
B14	0	0.5	12	ND	13	0.82
B14	0.5	1	18	ND	22	1.1
B14	1	1.5	16	ND	12	0.92
B14	1.5	2	13	ND	20	1.0
B15	0	0.5	78	600	120	0.90
B29RBH1	0	1.5	6.4	7.9	4.2	1.1
B29RBH4	0	1.5	15	1.3	58.3	1.1
B29RBH5	0	1.5	33.3	13.4	1.3	1.4
B29RBH5	1.5	3	230	376.5	557	2.2
B3	0	0.5	18	ND	11	0.84
B4	0	0.5	ND	820	240	ND
B5	0	0.5	ND	1300	440	ND
B5	0.5	1	78	660	120	0.9
B6	0	0.5	57	ND	300	ND
B6	0.5	1	18	ND	75	1.1
B7	0	0.5	120	ND	170	0.84
B7	0.5	1	150	4300	2000	ND
B7	1	1.5	310	ND	1000	ND
B7	1.5	2	290	ND	46	0.92
S54	0	0.5	56	ND	1.5	1.3
B13	2	2.5	20	ND	22	0.87
B29RBH5	3	5	585	157.8	124	1.9
B29RBH5	5	7	244	25.5	19.1	3.4
B29RBH5	7	9	244	35.7	24.3	2
B29RBH5	9	11	220	2.9	8.4	1.5
B29RBH5	11	11.5	96.8	3.6	8.1	0.77
B7	2	2.5	1800	ND	21	0.79

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