TECHNICAL MEMORANDUM

APPLICATION OF 10 CFR PART 40, APPENDIX A, CRITERION 6(6) AND DERIVATION OF BENCHMARK DOSES FOR THE SEAWAY LANDFILL AREAS A, B, AND C

TONAWANDA, NEW YORK

JULY 21, 2000

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

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prepared by
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with technical assistance from
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ACRONYMS AND ABBREVIATIONS

Ac	actinium
ALARA	as low as reasonably achievable
ARAR	applicable or relevant and appropriate requirement
BFI	Browning-Ferris Industries
cm	centimeter(s)
DCH	Data Collection Handbook
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DSR	dose-to-source ratio
EFH	Exposure Factors Handbook
EPA	U.S. Environmental Protection Agency
FUSRAP	Formerly Utilized Sites Remedial Action Program
ft	foot (feet)
g	gram(s)
m	meter(s)
µg	microgram(s)
mg	milligram(s)
mrem	millirem(s)
NYSDEC	New York State Department of Environmental Conservation
Pa	protactinium
Pb	lead
pCi	picoCurie(s)
Ra	radium
RESRAD	RESidual RADioactivity
SOR	sum-of-the-ratios
Th	thorium
U	uranium
UCL_{95}	upper 95% confidence level
USACE	U.S. Army Corps of Engineers

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1. INTRODUCTION

This memorandum develops potential cleanup goals for the Formerly Utilized Sites Remedial Action Program (FUSRAP) Seaway site. These cleanup criteria would be used if 10 Code of Federal Regulations (CFR) Part 40, Appendix A, Criterion 6(6) [henceforth Criterion 6(6)] is selected as an applicable or relevant and appropriate requirement (ARAR). Criterion 6(6) is not applicable to FUSRAP sites but may be relevant and appropriate at Seaway. The Seaway site is shown in (see Figure 1).

10 CFR Part 40 Appendix A was developed to provide the Nuclear Regulatory Commission (NRC) licensees with a clear and consistent regulatory basis for remediating soils and buildings from thorium mills and uranium recovery facilities. Appendix A states that site operations including decommissioning must meet a level of protection for the public health equivalent to, or more stringent than, the standards promulgated in 40 CFR Part 192, Subparts D and E. The most relevant Part 192 standards are defined as follows:

> *The concentration of radium-226 in land averaged over any area of 100 square meters shall not exceed the background level by more than –*
> *(1) 5 pCi/g, averaged over the first 15 cm of soil below the surface, and*
> *(2) 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface.*

40 CFR Part 192 sets radium cleanup standards but does not provide specific cleanup goals for non-radium radionuclides such as uranium and thorium. Criterion 6(6) provides a means to derive cleanup goals for site-related non-radium radionuclides through the benchmark dose. Criterion 6(6) specifically states:

> *Byproduct material containing concentrations of radionuclides other than radium in soil … must not result in a total effective dose equivalent (TEDE) exceeding the dose from the cleanup of radium contaminated soil to the above standard (benchmark dose), and must be at levels which are as low as reasonably achievable. If more than one residual radionuclide is present in the same 100-square-meter area, the sum of the ratios for each radionuclide of concentration present to the concentration limit will not exceed "1" (unity). A calculation of the potential peak annual TEDE within 1000 years to the average member of the critical group that would result from the standard (not including radon) on the site must be submitted for approval.*

In other words, radium shall be limited in soil to 5 pCi/g above background in the top 15 cm or 15 pCi/g above background below 15 cm. If other radionuclides are present, their concentration limits are calculated to produce the same (benchmark) dose as 5 pCi/g of radium in the top 15 cm or 15 pCi/g of radium below 15 cm. The unity rule applies when multiple contaminants are present. This memorandum calculates the concentrations of FUSRAP-related radionuclides in site soils that correspond to the surface and subsurface benchmark doses. Doses are calculated using the RESRAD computer code and follows the approach used in recent dose calculations for the Seaway site (USACE 2000b).

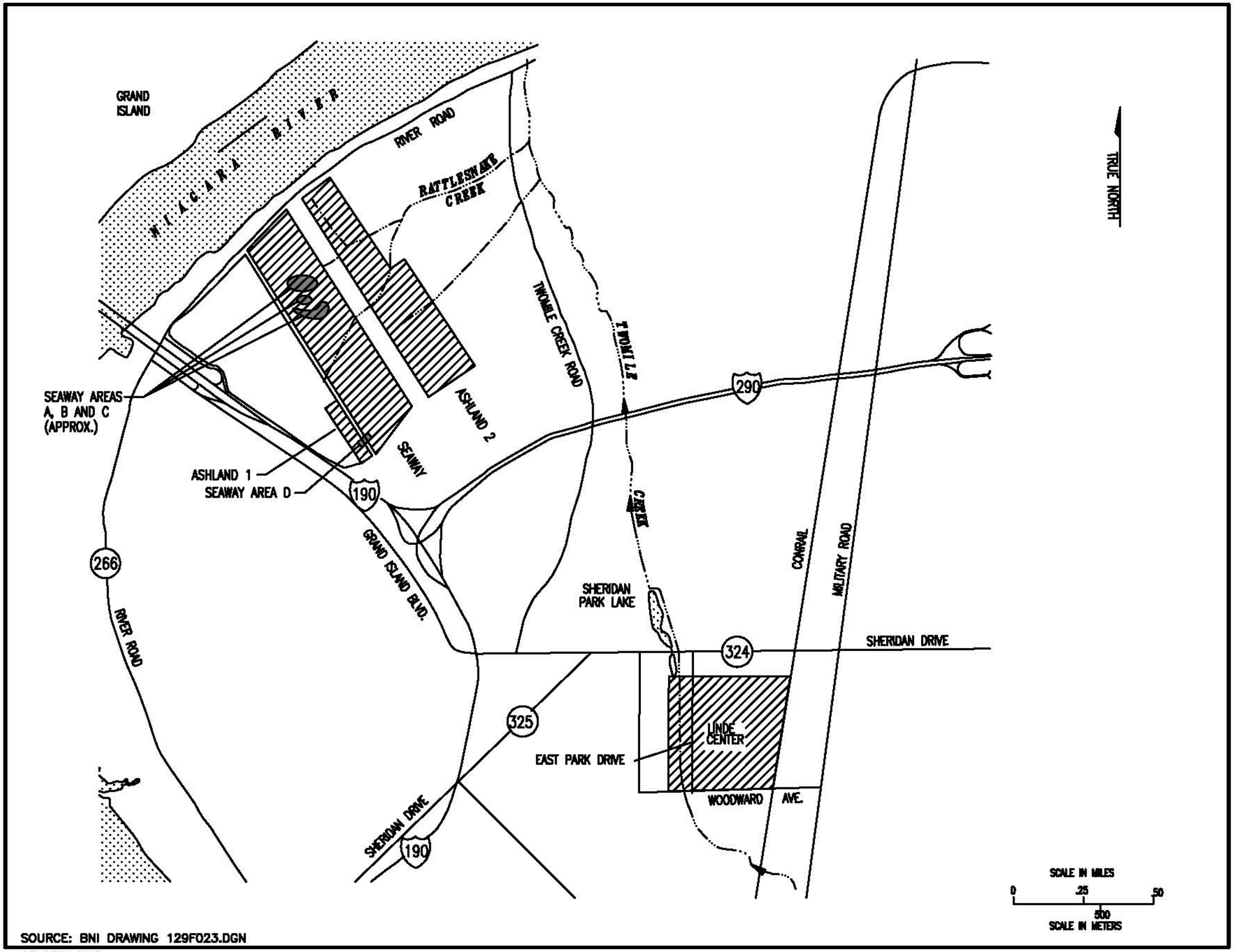

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FIGURE 1
LOCATION (ILAND 1, ASHLAND 2, SEAWAY AND LINDE SITES

1.1 SITE BACKGROUND

The Seaway Industrial Park is one of the sites being assessed by the Buffalo District Corps of Engineers under the FUSRAP program. Seaway Industrial Park Development, Inc owns the nearly 100 property located within the town of Tonawanda, New York (Figure 1). Most of the site was used as an industrial landfill operated by Browning-Ferris Industries (BFI). There are no buildings and little vegetation in the areas that received radioactive materials.

From 1944 to 1946, residues from uranium ore processing conducted at the Linde (now Praxair) property were sent to the Haist property (now known as Ashland 1). The uranium ore processing was performed in support of wartime activities related to the Manhattan Engineer District. In 1974, Ashland Oil, Inc. excavated approximately 4,600 m^3 (6,000 yd^3) of the residue and transported it to the adjacent Seaway property. Some of these residues were deposited in Areas A, B, and C, shown in Figure 2. Area A is approximately 4 hectares (9 acres) and Areas B and C combined are approximately 1 hectares (3 acres). The residue was left in small, isolated piles in Areas B and C, but was spread to a depth of less than 0.6 m (2 ft) in Area A. Although the residue was not originally covered, it has been mixed with clean material due to the continuing landfill operations at Seaway. As a result of this mixing, the volume of potentially impacted waste has become much greater than the original 4,600 m^3 (6,000 yd^3) taken from Ashland 1. Areas B and C are now covered by as much as 12 meters (40 feet) of refuse and fill material. About 40% of Area A has been covered with up to 3 meters (10 feet). The New York State Department of Environmental Conservation (NYSDEC) requested that BFI refrain from placing any additional material in the affected areas in 1978 (Mitrey 1978). A fourth area, Area D located on the Ashland 1 site, is being addressed as part of the Ashland 1 remedy.

1.2 SCOPE

The scope of this memorandum includes the calculation of surface and subsurface benchmark doses, the derivation of non-radium concentrations that would produce the benchmark doses, and an evaluation of hypothetical residual concentrations assuming Criterion 6(6) were selected as an ARAR for the Seaway site. Dose calculations are performed consistent with the methods described in recent dose/risk calculations for the Seaway site (USACE 2000b). Data sets used for the evaluation hypothetical residual concentrations were taken from five sources:

1. *Radiological Survey of the Seaway Industrial Park Tonawanda, New York* (DOE 1978a);
2. *Preliminary Engineering and Environmental Evaluation of the Remedial Action Alternatives for the Seaway Industrial Park, Tonawanda, New York* (FBDU 1981);
3. *Remedial Investigation Report for the Tonawanda Site* (DOE 1993a);
4. *Additional Surface Characterization of Areas B and C at the Seaway Site* (USACE 1999a); and
5. *Synopsis of Volume Calculations for Seaway Site Areas A, B, and C* (USACE 1999b).

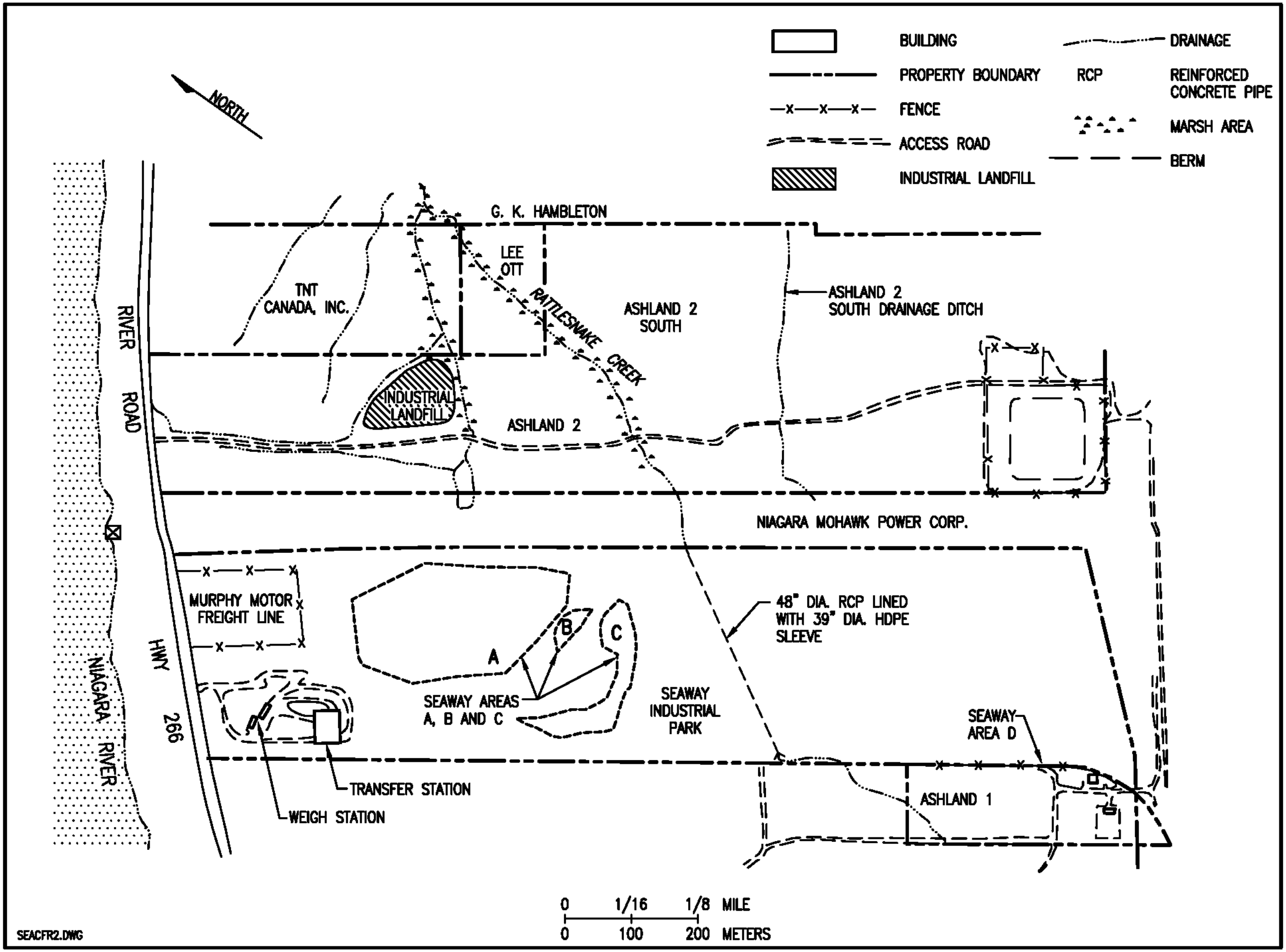

FIGURE 2
LOCATION DETAILS – SEAWAY PROPERTIES

2. EXPOSURE ASSESSMENT

The exposure assessment consists of the identification and description of potentially exposed receptors, the identification of exposure pathways, and an evaluation of the hypothetical source term after implementation of Criterion 6(6). Information produced in the assessment is consistent with recent dose assessment methods used by USACE for the Seaway site (USACE 2000b) including the use of the site-specific parameter values listed in Table 1. One exception is the assessment unit size. The fixed contaminated zone surface area of 2,000 m^2 is employed here to be consistent with anticipated future application of the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (DoD 1997) and to be consistent with benchmark evaluations for the Linde site (USACE 2000a). All dose calculations are performed using the RESRAD computer code Version 5.82. Calculations are performed for exposure to surface soil (no cover) and subsurface soil assuming there is 0.15 m (6 inches) of clean cover. A surface and subsurface benchmark dose estimate is, therefore, provided for each potential receptor.

2.1 POTENTIALLY EXPOSED RECEPTORS

The potential receptors evaluated in this memorandum represent a plausible future receptor (recreational) and a conservative plausible but unlikely receptor (industrial) due to the fact that the sight is a landfill with use restrictions and site configuration, which consist of steep slopes. The physical characteristics of each receptor are described below and are listed in Table 2.

2.1.1 Recreational Scenario

Recreational exposure is evaluated as the a plausible future use consistent with the Town of Tonawanda Waterfront Region Master Plan. The recreational receptor is assumed to be present at the site for 3 hours per week for 50 weeks per year (onsite occupancy fraction of 0.017), all outdoors. Incidental soil ingestion is set to 36.5 g/year (100 mg/day) (EPA 1991) and the mass (dust) loading is set to 0.00003 g/m^3 representing 100 $\mu g/m^3$ (Yu et al. 1993b) with a 30% respirable fraction (Paustenbach 1989). The inhalation rate is set to 12,300 m^3/y based on guidance from the Data Collection Handbook (Yu et al. 1993b).

2.1.2 Industrial Scenario

An industrial worker is evaluated as a conservative plausible but unlikely future receptor. The industrial receptor is assumed to be present on site 7 hours per day indoors and 1 hour per day outdoors for 250 work days per year (occupancy fractions of 0.20 and 0.029, respectively). The incidental soil ingestion is set to 18.25 g/year (50 mg/day) (EPA 1991) and the mass loading is set to 0.00003 g/m^3 representing 100 $\mu g/m^3$ (Yu et al. 1993b) with a 30% respirable fraction (Paustenbach 1989). The inhalation rate is set to 7,300 m^3/y based on guidance from the U.S. Environmental Protection Agency (EPA) (EPA 1991).

Table 1. Site Specific Parameters for the Seaway Site

Parameter	Default	All Areas	Basis
Area of Contaminated Zone, m^2	10,000	2,000	Surface area selected to be consistent with anticipated use of MARSSIM and the Criterion 6(6) evaluation performed for the Linde site. Approach deviated from range of surface areas evaluated in (USACE 2000b) in favor of consistent evaluation unit.
Thickness of Contaminated Zone, m	2.0	2.0	Default thickness assumed.
Cover Depth, m	0.15	0.0	Assumed as a minimum depth only for exposure to subsurface soils.
Erosion Rate, m/yr	0.001	0.0	Erosion assumed to be negligible when cover is considered.
Contaminated Zone Total Porosity	0.4	0.45	Baseline Risk Assessment (DOE 1993b).
Contaminated Zone Hydraulic Conductivity, m/yr	10	123	Baseline Risk Assessment (DOE 1993b).
Evapotranspiration Coefficient	0.5	0.46	Baseline Risk Assessment (DOE 1993b).
Precipitation, m/yr	1.00	0.96	Remedial Investigation (DOE 1993a).
Runoff Coefficient	0.2	0.25	Baseline Risk Assessment (DOE 1993b).
Saturated Zone Total Porosity	0.4	0.45	Baseline Risk Assessment (DOE 1993b).
Saturated Zone Hydraulic Conductivity, m/yr	100	123	Baseline Risk Assessment (DOE 1993b).
Saturated Zone Hydraulic Gradient	0.02	0.00045	Remedial Investigation (DOE 1993a).
Distribution Coefficient U, cm^3/g	50	10	Remedial Investigation (DOE 1993a).
Distribution Coefficients all other isotopes	—	—	Assumes values for clay found in (Yu et al. 1993b). Specific values in units of cm^3/g are as follows: 2400 for actinium, 550 for lead, 2700 for protactinium, 9100 for radium, and 5800 for thorium.
Contamination Fraction of Household Water	1.0	0.0	Groundwater pathway suppressed.
Depth of Soil Mixing Layer, m	0.15	0.05	5 cm reasonable for non-agricultural setting according to Argonne National Laboratory (creator of the RESRAD code) representative.

Table 2. Scenario Specific Parameters for the Seaway Site

Parameter	Default	Recreational	Industrial	Basis
Inhalation Rate, m^3/yr	8,400	12,300	7,300	(EPA 1990): Average outdoor inhalation rate for recreational receptor assuming activity mix of 37% moderate, 28% at rest or light activity, 7% high activity level. (EPA 1991) Reasonable upper bound for industrial worker.
Mass Loading for Inhalation, g/m^3	0.0001	0.00003	0.00003	(Yu et al. 1993b): Assumes 0.0001 g/m^3 adjusted for 30% respirable fraction (Paustenbach 1989).
Exposure Duration, yr	30	9	25	(EPA 1991): Reasonable maximum duration for industrial worker and average duration for an individual at a single location for recreation.
Time Fraction Indoors	0.5	0	0.20	No indoor activities for recreational receptor. (EPA 1990): Industrial worker assumes 8 hr/day for 250 days/yr of which 7 hr/day is spent indoors.
Time Fraction Outdoors	0.25	0.017	0.029	Recreation assumes 3 hrs/wk, 50 wk/yr. (EPA 1990): Industrial worker assumes 8 hr/day for 250 days/yr of which 1 hr/day is spent outdoors.
Soil Ingestion Rate g/yr	36.5	36.5	18.25	(EPA 1991): Industrial 50 mg/day in the workplace. 100 mg/day for recreational activities.

2.2 EXPOSURE PATHWAYS

Complete exposure pathways for the Seaway site include soil ingestion, dust inhalation (excluding radon), and external radiation. There is no surface water (ponds or streams) within the site boundaries. Thus the surface water consumption and fish ingestion pathways are considered to be incomplete. An individual would have to drill through thick layers of landfill refuse in order to gain access to groundwater. The groundwater is also known to contain high levels of dissolved solids and is characterized by low yields (DOE 1993a). Groundwater in the vicinity of the Seaway site is non-potable and the groundwater consumption pathway is considered to be incomplete. The area is zoned as industrial and it is unlikely that less stringent zoning will occur given the site history. It is therefore reasonable to assume that produce or livestock-related pathways are incomplete. All incomplete pathways are deactivated prior to performing RESRAD "runs".

Radon is specifically excluded from benchmark dose calculations consistent with draft implementation guidance. The Criterion 6(6) implementation guidance found in 64 Fed. Reg. 17690 (1999) states that the benchmark dose evaluation does not include radon. However, the radon emissions are evaluated as part of another memorandum (USACE 2000b).

2.3 SOURCE TERM

A statistical analysis of the Seaway data is used to determine the maximum, minimum, mean, and upper 95% confidence level (UCL_{95}) on the mean residual concentrations, etc. assuming cleanup under Criterion 6(6). This evaluation is conducted to help predict an estimate of residual concentrations of individual radionuclides that would remain in site soils. Summary data may then be compared to data from other analyses like those found in (USACE 2000b). In order to complete this evaluation, the concentrations of some radionuclides are estimated. That is, the site database does not contain results for all relevant radionuclides, and historical characterization efforts do not report results for all relevant radionuclides. In order to evaluate a "complete" data set, known relationships between radionuclides are used to estimate values for missing data in the database. Table 3 lists the assumed relationships between site radionuclides.

The benchmark dose is a net (above background) value. Therefore, background is subtracted from site data to estimate the site residual. The site-specific 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). Ac-227, Pa-231, and U-235 are assumed to be present in background at naturally occurring abundance, meaning 4.6% of the U-238 concentration or 0.14 pCi/g. In addition, Pb-210 is assumed to be in equilibrium with Ra-226 [per Criterion 6(6) guidance], U-234 is assumed to be in equilibrium with U-238, and Ra-228 and Th-228 are assumed to be in equilibrium with Th-232. Background concentrations are listed in Table 3.

Having defined relationships for estimating missing data and background concentrations, a sum-of-the-ratios (SOR) data set was created. The SOR data set contains for each sample a result for each of the radionuclides listed in Table 3. The following steps were used to create this data set:

- The gross concentration of each missing radionuclide was estimated using the relationships from Table 3, if required; and
- Background was subtracted to produce the estimated net results of each radionuclide.

Results for each sample were then subjected in a SOR calculation (i.e., the unity rule was applied). The calculation was generally performed as shown below in Equation 1:

$$SOR = \sum_k \frac{C_k - B_k}{L_k} \qquad \text{(Eq. 1)}$$

where "C" is the concentration of radionuclide "k", "B" is the background concentration for radionuclide "k", and "L" is the limit or cleanup goal for radionuclide "k" corresponding to the benchmark dose. Limits (L) for each radionuclide are presented in Section 3. Note that there are four separate SOR calculations using Equation 1: one for recreational and surface soil, one for recreational and subsurface soil, one for industrial and surface soil, and one for industrial and subsurface soil. The input parameters for Equation 1 are discussed in more detail in Section 3 and Appendix A.

Table 3. Assumed Radionuclide Relationships for Seaway Residuals and Background Values

Radionuclide	Radionuclide Relationship [a]	Basis	Background (pCi/g)
Actinium-227 (Ac-227)	1.02 × Ra-226	From regression analysis (USACE 2000b)	0.14
Protactinium-231 (Pa-231)	1.02 × Ra-226	Assumes equilibrium with Ac-227	0.14
Radium-226 (Ra-226)	–	No known relationships. Lead-210 (Pb-210) included with Ra-226.	1.1
Thorium-230 (Th-230)	(Ra-226–1.1)×20.188+1.4	From regression analysis (USACE 2000b)	1.4
Thorium-232 (Th-232) [b]	–	No known relationships	1.2
Uranium-234 (U-234) [c]	1.0 × U-238	Assumes natural abundance relationship with U-238	3.1
Uranium-235 (U-235) [c]	0.046 × U-238	Assumes natural abundance relationship with U-238	0.14
Uranium-238 (U-238) [c]	–	No known relationships	3.1

[a] Radionuclide relationships only used when analytical data are not available. If no individual Ra-226, Th230, Th-232, or U-238 results are reported, value assumed to be 0.0 because no known relationships are available for these radionuclides.
[b] The Th-232 values account for Th-228 and Ra-228 and assume they are in equilibrium with Th-232.
[c] Add the three uranium results to get U-Total.

After the SOR calculation was performed for each sample, any samples with an SOR estimate greater than 1.0 were consider as excavated waste that would be shipped offsite. If a subsurface sample was treated as excavated waste, any shallower samples within the same borehole were also considered as waste in order to model excavation activities. Remaining sample results were assumed to represent residual concentrations and were summarized by area including Area A, Area B, Area C, and Area B and C combined (deep soils).

3. RESULTS

3.1 BENCHMARK DOSE ESTIMATES

Table 4 and Table 5 present the dose-to-source ratios (DSRs) generated by the RESRAD code, benchmark dose estimates for surface and subsurface soils, and the concentrations of each radionuclide that would produce the benchmark dose. The DSR values are in units of mrem/yr per pCi/g and represent the factors that convert soil concentrations into dose. These factors are used in the following two ways:

1. The DSR for Ra-226 (assumed to be in equilibrium with Pb-210) is used to calculate the benchmark dose by multiplying against 5 pCi/g. That is, Ra-226 DSR (mrem/yr per pCi/g) × 5 (pCi/g) = benchmark (mrem/yr); and
2. The DSR for non-radium radionuclides are used to estimate the limiting concentration (L) that would produce the benchmark dose. That is, benchmark (mrem/yr) ÷ DSR_k (mrem/yr per pCi/g) = L_k (pCi/g), where the subscript "k" represents the radionuclide of interest.

Table 4. Seaway Surface Soil Benchmark Dose Estimates and Associated SOR Concentration Limits

Analyte	Industrial		Recreational	
	DSR [a]	SOR Conc. Limit (pCi/g) [b]	DSR [a]	SOR Conc. Limit (pCi/g) [b]
Ac-227	3.952E-01	22	4.645E-02	19
Pa-231	7.839E-02	110	1.072E-02	83
Ra-226 [c]	1.755E+00	5.0	1.783E-01	5.0
Th-230	3.596E-03	2,400	6.523E-04	1,400
Th-230 (1k) [d]	6.028E-01	15	6.149E-02	14
Th-232 [e]	2.512E+00	3.5	2.548E-01	3.5
U-Total [f]	1.455E-02	605	1.588E-03	560
Benchmark Dose (mrem/yr) [c]		8.8		0.89

[a] Dose-to-source-ratio (DSR) in mrem/yr per pCi/g.
[b] Concentration producing the benchmark dose. All values except U-Total rounded to two significant digits.
[c] Surface soil benchmark dose defined for exposure to Ra-226 and Pb-210 in equilibrium at 5.0 pCi/g.
[d] Th-230 dose highest at end of 1,000 years evaluation period.
[e] The Th-232 values account for Th-228 and Ra-228 and assume they are in equilibrium with Th-232.
[f] Assumes natural abundance relationship between uranium isotopes as shown in Table 3.

Table 5. Seaway Subsurface Soil Benchmark Dose Estimates and Associated SOR Concentration Limits

Analyte	Industrial		Recreational	
	DSR [a]	SOR Conc. Limit (pCi/g) [b]	DSR [a]	SOR Conc. Limit (pCi/g) [b]
Ac-227	2.254E-02	180	2.268E-03	180
Pa-231	2.207E-03	1,900	2.221E-04	1,800
Ra-226 [c]	2.711E-01	15	2.727E-02	15
Th-230	2.627E-06	1,600,000	2.642E-07	1,600,000
Th-230 (1k) [d]	9.264E-02	44	9.319E-03	44
Th-232 [e]	4.252E-01	9.6	4.278E-02	9.6
U-Total [f]	1.349-03	3,039	1.357E-04	3,021
Benchmark Dose (mrem/yr) [c]		4.1		0.41

[a] Dose-to-source-ratio (DSR) in mrem/yr per pCi/g.
[b] Concentration producing the benchmark dose. All values except U-Total rounded to two significant digits.
[c] Subsurface soil benchmark dose defined for exposure to Ra-226 and Pb-210 in equilibrium at 15 pCi/g.
[d] Th-230 dose highest at end of 1,000 years evaluation period.
[e] The Th-232 values account for Th-228 and Ra-228 and assume they are in equilibrium with Th-232.
[f] Assumes natural abundance relationship between uranium isotopes as shown in Table 3.

Results indicate that the surface soil benchmark dose for the industrial receptor is 8.8 mrem/yr and while the subsurface benchmark dose is 4.1 mrem/yr. The surface soil benchmark dose for the recreational receptor is 0.89 mrem/yr and while the subsurface benchmark dose is 0.41 mrem/yr. These benchmarks are calculated for the current year (year 0.0) because the dose from Ra-226 decreases over time. Only a Th-230 value is presented for a non-zero year. This is because Th-230 produces a maximum dose at the end of the 1,000-year evaluation period due to Ra-226 ingrowth. To be conservative, calculations used to generate the SOR data set were performed using the year 1,000 value for Th-230 and the current year values for all other radionuclides.

Results also indicate that industrial benchmark doses for the Seaway site are the same as those calculated for the Linde site (USACE 2000a). Slight differences in potential SOR concentration limits for some radionuclides are noted, however. The reason for the slight differences are related to the exposure parameters used in the RESRAD model. The specific exposure parameters that cause the differences are the following:

- An outdoor occupancy fraction of 0.029 was used at Seaway while a rounded value of 0.03 was used at Linde;
- An inhalation rate recommended by EPA was used at Seaway while the RESRAD default was used at Linde; and
- The mass loading factor was adjusted by a 30 percent respirable fraction at Seaway but not at Linde.

These factors mostly impact doses from radionuclides that are internal hazards like uranium as opposed to external (gamma) hazards like Ra-226. Thus, the benchmark dose defined for Ra-226 stays the same within two significant digits while potential SOR concentration limits for uranium vary by about 10 percent.

3.2 RESIDUAL DATA

Using the values in Tables 3, 4, and 5 SOR calculations were performed as described in Section 2.3 using the basic equation shown in Equation 1. Having specific values for "L" and "B" as described in Section 2.3, SOR equations for the recreational and industrial scenarios and for surface and subsurface soil are presented in Appendix A. Specifically, all data points that exceeded an SOR of 1.0 (and any shallower sample within the same borehole) was removed from consideration. The remaining data set was then summaries in order to evaluate the hypothetical residual. Using this approach, statistical summaries for Areas A, B, and C are presented in Tables 6, 7, 8, and 9. Table 6 presents summary statistics for Area A; Table 7 presents summary statistics for Area B; Table 8 presents summary statistics for Area C; Table 9 presents summary statistics for Areas B and C combined (deep samples).

Table 6. Area A Summary Statistics for Criterion 6(6) Residuals

Radionuclide	Results > Detection Limit	Minimum Detect (pCi/g)	Maximum Detect (pCi/g)	Mean (pCi/g)	UCL_{95} (pCi/g)	Gross Residual Concentration (pCi/g) [a]
Residuals for Industrial Scenario SOR Equations						
Ac-227	122/ 122	0.12	4.18	1.27	1.40	1.40
Pa-231	119/ 122	0.12	4.18	1.27	1.40	1.40
Ra-226	119/ 122	0.12	4.10	1.24	1.38	1.38
Th-230	121/ 122	0.00	37.74	4.84	5.94	5.94
Th-232	54/69	0.50	3.00	1.27	1.44	1.44
U-234 [b]	35/102	0.30	9.70	4.92	5.60	5.60
U-235 [b]	35/102	0.00	0.45	0.23	0.26	0.26
U-238 [b]	35/102	0.30	9.70	4.92	5.60	5.60
Residuals for Recreational Scenario SOR Equations						
Ac-227	122/ 122	0.12	4.18	1.27	1.40	1.40
Pa-231	119/ 122	0.12	4.18	1.27	1.40	1.40
Ra-226	119/ 122	0.12	4.10	1.24	1.38	1.38
Th-230	121/ 122	0.00	37.74	4.84	5.94	5.94
Th-232	54/69	0.50	3.00	1.27	1.44	1.44
U-234 [b]	35/102	0.03	9.70	4.92	5.60	5.60
U-235 [b]	35/102	0.00	0.45	0.23	0.26	0.26
U-238 [b]	35/102	0.03	9.70	4.92	5.60	5.60

[a] Smaller of maximum detect and UCL_{95} and includes background.
[b] Add the three uranium results to get the U-Total residual concentrations.

Table 7. Area B Summary Statistics for Criterion 6(6) Residuals

Radionuclide	Results > Detection Limit	Minimum Detect (pCi/g)	Maximum Detect (pCi/g)	Mean (pCi/g)	UCL_{95} (pCi/g)	Gross Residual Concentration (pCi/g) [a]
Residuals for Industrial Scenario SOR Equations						
Ac-227	12/15	1.31	7.80	2.85	3.83	3.83
Pa-231	0/15	-	-	0.25	1.17	1.17
Ra-226	12/15	0.12	0.30	0.19	0.22	0.22
Th-230	15/15	0.78	3.09	1.78	2.18	2.18
Th-232	15/15	0.51	1.65	1.02	1.22	1.22
U-234 [b]	15/15	1.02	2.60	1.67	1.92	1.92
U-235 [b]	3/15	0.13	0.24	0.12	0.16	0.16
U-238 [b]	15/15	0.89	2.32	1.56	1.79	1.79
Residuals for Recreational Scenario SOR Equations						
Ac-227	12/15	1.31	7.80	2.85	3.83	3.83
Pa-231	0/15	-	-	0.25	1.17	1.17
Ra-226	12/15	0.12	0.30	0.19	0.22	0.22
Th-230	15/ 5	0.78	3.09	1.78	2.18	2.18
Th-232	15/15	0.51	1.65	1.02	1.22	1.22
U-234 [b]	15/15	1.02	2.60	1.67	1.92	1.92
U-235 [b]	3/15	0.13	0.24	0.12	0.16	0.16
U-238 [b]	15/15	0.89	2.32	1.56	1.79	1.79

[a] Smaller of maximum detect and UCL_{95} and including background.
[b] Add the three uranium results to get the U-Total residual concentrations.

Table 8. Area C Summary Statistics for Criterion 6(6) Residuals

Radionuclide	Results > Detection Limit	Minimum Detect (pCi/g)	Maximum Detect (pCi/g)	Mean (pCi/g)	UCL_{95} (pCi/g)	Gross Residual Concentration (pCi/g) [a]
Residuals for Industrial Scenario SOR Equations						
Ac-227	10/18	0.16	4.74	1.41	1.98	1.98
Pa-231	0/18	-	-	0.64	1.43	1.43
Ra-226	15/18	0.16	2.07	0.33	0.52	0.52
Th-230	18/18	1.06	32.57	5.66	8.78	8.78
Th-232	18/18	0.51	1.30	0.79	0.89	0.89
U-234 [b]	18/18	1.05	31.47	5.72	8.89	8.89
U-235 [b]	8/18	0.21	1.37	0.25	0.38	0.38
U-238 [b]	18/18	0.78	33.36	5.62	8.92	8.92
Residuals for Recreational Scenario SOR Equations						
Ac-227	10/18	0.16	4.74	1.41	1.98	1.98
Pa-231	0/18	-	-	0.64	1.43	1.43
Ra-226	15/18	0.16	2.07	0.33	0.52	0.52
Th-230	18/18	1.06	32.57	5.66	8.78	8.78
Th-232	18/18	0.51	1.30	0.79	0.89	0.89
U-234 [b]	18/18	1.05	31.47	5.72	8.89	8.89
U-235 [b]	8/18	0.21	1.37	0.25	0.38	0.38
U-238 [b]	18/18	0.78	33.36	5.62	8.92	8.92

[a] Smaller of maximum detect and UCL_{95} and includes background
[b] Add the three uranium results to get the U-Total residual concentrations.

Table 9. Area B/C Deep Soil Summary Statistics for Criterion 6(6) Residuals

Radionuclide	Results > Detection Limit	Minimum Detect (pCi/g)	Maximum Detect (pCi/g)	Mean (pCi/g)	UCL_{95} (pCi/g)	Gross Residual Concentration (pCi/g) [a]
Residuals for Industrial Scenario SOR Equations						
Ac-227	20/20	0.26	2.96	1.29	1.55	1.55
Pa-231	20/20	0.26	2.96	1.29	1.55	1.55
Ra-226	20/20	0.25	2.90	1.27	1.52	1.52
Th-230	20/20	0.00	37.74	7.87	11.80	11.80
Th-232	20/20	0	0	0	0	0
U-234 [b]	18/18	0.13	3.70	1.69	2.07	2.07
U-235 [b]	18/18	0.01	0.17	0.08	0.10	0.10
U-238 [b]	18/18	0.13	3.70	1.69	2.07	2.07
Residuals for Recreational Scenario SOR Equations						
Ac-227	20/20	0.26	2.96	1.29	1.55	1.55
Pa-231	20/20	0.26	2.96	1.29	1.55	1.55
Ra-226	20/20	0.25	2.90	1.27	1.52	1.52
Th-230	20/20	0	37.74	7.87	11.80	11.80
Th-232	0/0	0	0	0	0	0
U-234 [b]	18/18	0.13	3.70	1.69	2.07	2.07
U-235 [b]	18/18	0.01	0.17	0.08	0.10	0.10
U-238 [b]	18/18	0.13	3.70	1.69	2.07	2.07

[a] Smaller of maximum detect and UCL_{95} and includes background.
[b] Add the three uranium results to get the U-Total residual concentrations.

The results in Table 6, 7, 8, and 9 show that the differences between the industrial and recreational SOR equations have an insignificant impact on the Seaway data set. As a result, the estimated residual concentrations for the industrial and recreational scenarios are identical.

A comparison of the summary statistics from the Criterion 6(6) evaluation and summary statistics developed for the 40 CFR Part 192 evaluation (remove Th-230 > 40 pCi/g) in (USACE 2000b) does show some small differences. For example, Area A residual UCL_{95} concentrations for Ra-226, Th-230, and U-238 are approximately 1.4 pCi/g, 5.9 pCi/g, and 5.6 pCi/g, respectively, after remediation using Criterion 6(6). The corresponding concentrations are estimated at 1.5 pCi/g, 7.6 pCi/g, and 5.6 pCi/g, respectively, after remediation using the 40 pCi/g, Th-230 guidelines based on 40 CFR Part 192 (USACE 2000b). In general, the residual concentrations after remediation using Criterion 6(6) are slightly lower than the estimated residuals based on 40 CFR Part 192. The comparison of residual data sets suggest that if doses (or radiological risks) are acceptable using 40 CFR Part 192 criteria, the doses (and radiological risks) would also be acceptable using the Criterion 6(6) developed in this memorandum.

USACE also evaluated, with respect to compliance with the Criterion 6(6) benchmark dose standards, the estimated residuals based on cleanup using the 40 pCi/g Th-230 cleanup guideline established to comply with the standards of 40 CFR Part 192. Using the estimated residual concentrations, based on cleanup to 40 pCi/g of Th-230 (USACE 2000b), in the four SOR calculations shown in Appendix A and discussed in Section 3, the resulting SORs were all below unity, even when using the surface SOR concentration limits for both the industrial worker and recreational scenarios. Therefore, cleanup using the 40 pCi/g Th-230 cleanup guideline should result in a site that meets the 10 CFR Part 40 benchmark dose standards as detailed in this technical memorandum.

4. UNCERTAINTIES

4.1 PARAMETER ASSUMPTIONS

Exposure parameters are selected to provide a conservative, yet reasonable, estimate of potential radiological dose for each receptor. Site-specific data are used, when available, to describe site conditions as accurately as possible. Where site-specific data are not available, parameter values are chosen to provide reasonably conservative estimates of dose with preferential use of parameter values from the Baseline Risk Assessment (DOE 1993b) or standard default values recommended by EPA or other authorities. Exposure scenarios and parameter values are consistently chosen to provide conservative, yet reasonable, estimates of potential radiation dose in accordance with the principle of keeping radiation exposures “As Low As Reasonably Achievable” (ALARA). Sources of parameter values are given in Tables 1 and 2.

4.2 LIMITATIONS ON AVAILABLE DATA

As described in (USACE 2000b), results for all FUSRAP-related radionuclides are not included in the site database. A review of site data also reveals that characterization efforts over the years have targeted various radionuclides, but focussed primarily on Ra-226, Th-230, and U-238. Given these limitations, the source term estimate described in Section 2.3 and presented in Section 3.2 are subject to significant uncertainty that could result in an overestimation or underestimation of actual residual concentrations. Given that many of the relationships described in Table 3 are based on expected natural conditions or are biased toward baseline contaminated conditions, it is likely that residual concentrations are overestimated.

Given the uncertainty in site data and in keeping with the principle of ALARA, the more conservative of the receptor-specific equations in Appendix A could be used. In this case, the recreational scenario SOR equations for surface and subsurface soils would be used. This approach would assure that neither potential receptor would receive a dose above the respective benchmark. There are other ALARA actions USACE may use at Seaway that have been shown to be effective at the Ashland 2 site. A field screening guideline is used to find and excavate areas thus resulting in some over-excavation. Using this approach, the experience at the Ashland 2 site demonstrated that the residual radionuclide concentrations were far less than the residuals based on the conservative modeling of contaminated areas and volumes. Specifically, cleanup using the 40 pCi/g Th-230 guideline at the Ashland 2 site has produced residuals below field screening levels. In fact, cleanup to the 40 pCi/g Th-230 guideline has resulted in average residual Th-230 and Ra-226 concentrations of 5.17 pCi/g and 0.85 pCi/g, respectively (IT 1999).

4.3 DISTRIBUTION COEFFICIENTS

Values for the distribution coefficient (K_d) were taken from the Data Collection Handbook (Yu et al. 1993b) except for uranium, which was measured during the remedial investigation. The Data Collection Handbook provides distribution coefficients for the elements in sand, loam, clay, and organic soil types. Of these soil types, the glacial till that characterizes the Tonawanda area is most similar to clay. Thus the clay values were used for all the isotopes except uranium. This is a conservative assumption compared with the RESRAD default values because use of the default values would increase the rate of leaching to groundwater leading to reduction in the contaminant concentration over time. (Groundwater is not a complete pathway, so reduction in groundwater concentration as a result of using clay values does not understate risk.)

5. CONCLUSIONS

Results indicate that the surface soil benchmark dose for the industrial receptor is 8.8 mrem/yr and while the subsurface benchmark dose is 4.1 mrem/yr. The surface soil benchmark dose for the recreational receptor is 0.89 mrem/yr and while the subsurface benchmark dose is 0.41 mrem/yr. These industrial scenario values are the same as the benchmark doses generated for the Linde site to within two significant digits. (A recreational scenario was not evaluated for the Linde site.)

The USACE evaluation of residual radionuclides, based on cleanup to the 40 CFR Part 192 standards using a cleanup guideline of 40 pCi/g Th-230, found that the residual dose and risks were acceptable (USACE 2000b). Cleanup using the Criterion 6(6) benchmark dose standards results in average residual concentration levels slightly less than those resulting from cleanup using the 40 pCi/g Th-230 guideline. Thus, cleanup to the Criterion 6(6) standards would result in doses and risks lower than those computed based on cleanup to the 40 CFR Part 192 standards. USACE also found that cleanup using the 40 pCi/g Th-230 cleanup guideline should result in a remediated site with residual radionuclide concentrations at levels that would also meet all of the Criterion 6(6) benchmark doses and associated SOR standards discussed in this technical memorandum. Therefore, use of the 40 pCi/g Th-230 cleanup guideline should result in a remediated site that meets the Criterion 6(6) standards as well as the 40 CFR Part 192 standards. In addition to remediation using the 40 pCi/g Th-230 guideline, USACE will also ensure that the Criterion 6(6) benchmark SOR standards are also met on a 100 m^2 unit basis.

To ensure that benchmark standard is satisfied, residual data (from the excavation) would be placed in the combined SOR equations as shown in Appendix A. The approach is considered to be ALARA based on USACE experience at Ashland 2, and given the multiple conservative assumptions used in the dose models.

6. REFERENCES

DoD 1997, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM),* NUREG- 1575, EPA 402-R-97-016, Department of Defense, et al., December

DOE 1978a. *Radiological Survey of the Seaway Industrial Park Tonawanda, New York*, DOE/EV-0005/6, Oak Ridge, Tennessee, May.

DOE 1978b. *Radiological Survey of the Ashland Oil Company (Former Haist Property), Tonawanda, New York*, DOE/EV-0005/4, Oak Ridge, Tennessee, May.

DOE 1993a. *Remedial Investigation Report for the Tonawanda Site*, DOE/OR/21949-300, Oak Ridge, Tennessee, February.

DOE 1993b. *Baseline Risk Assessment for the Tonawanda Site*, DOE/OR/21950-003, Oak Ridge, Tennessee, August.

DOE 1997. *Radionuclide Cleanup Guideline Derivation for Ashland 1, Ashland 2, and Seaway,* DOE/OR/21950-1023, Oak Ridge, Tennessee, September.

EPA 1990. *Exposure Factors Handbook*, EPA/600/8-89/043, Washington, D.C., July.

EPA 1991. *Human Health Evaluation Manual, Supplemental Guidance: "Standard Default Exposure Factors*", OSWER Directive 9285.6-03, Washington, D.C., March.

FBDU (Ford, Bacon, and Davis of Utah, Inc.) 1981. *Preliminary Engineering and Environmental Evaluation of the Remedial Action Alternatives for the Seaway Industrial Park, Tonawanda, New York*, FBDU 409-312, Salt Lake City, Utah, December.

IT 1999. *Project Construction Report, FUSRAP Ashland 2 Phase Remedial Action*, Tonawanda, New York, IT Corporation, September.

Mitrey, Robert J. 1978. NYSDEC Buffalo, New York. Letter from R. Mitrey to James Sandonato, Seaway Industrial Park Development, Inc. CCN 058879, September 14.

Paustenbach, Dennis H. 1989. *The Risk Assessment of Environmental and Human Health Hazards: a Textbook of Case Studies*. New York: John Wiley and Sons.
SAIC 1996. Revised cost estimate, 11/4/96.

USACE 1999a. *Additional Surface Characterization of Areas B and C at the Seaway Site*, Technical Memorandum, Oak Ridge, Tennessee, March.
USACE 2000a. *Linde Site Radiological Assessment, Tonawanda, New York*, Revision 1 of a Technical Memorandum prepared by SAIC for the Buffalo District Office, February.

USACE 2000b. *Modeling Of Radiological Risks From Residual Radioactive Materials Following Implementation Of Remedial Alternatives For Seaway Landfill Areas A, B, And C, Tonawanda, New York*, Revision 2 of a Technical Memorandum prepared by SAIC for the Buffalo District Office, June.

Yu, C., A.J. Zielen, J.J. Cheng, Y.C. Yuan, L.G. Jones, D.J. LePoire, Y.Y. Wang, C.O. Loureiro, E. Gnanapragasam, E. Faillace, A. Wallo III, W.A. Williams, and H. Peterson 1993a. *Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.61*. Argonne: Argonne National Laboratory.

Yu, C., C. Loureiro, J.J. Cheng, L.G. Jones, Y.Y. Wang, Y.P. Chia, and E. Faillace 1993b. *Data Collection Handbook to Support Modeling the Impacts of Radioactive Materials in Soil*. Argonne: Argonne National Laboratory.

APPENDIX A

SUM-OF-THE-RATIOS CALCULATIONS BY RECEPTOR AND DEPTH INTERVAL

INDUSTRIAL SCENARIO SOR EQUATIONS*

Surface Soil:

$$SOR = \frac{^{227}Ac - B_k}{22} + \frac{^{231}Pa - B_k}{110} + \frac{^{226}Ra - B_k}{5.0} + \frac{^{230}Th - B_k}{15} + \frac{^{232}Th - B_k}{3.5} + \frac{U_{Total} - B_k}{605}$$

Subsurface Soil:

$$SOR = \frac{^{227}Ac - B_k}{180} + \frac{^{231}Pa - B_k}{1{,}900} + \frac{^{226}Ra - B_k}{15} + \frac{^{230}Th - B_k}{44} + \frac{^{232}Th - B_k}{9.6} + \frac{U_{Total} - B_k}{3{,}039}$$

RECREATIONAL SCENARIO SOR EQUATIONS*

Surface Soil:

$$SOR = \frac{^{227}Ac - B_k}{19} + \frac{^{231}Pa - B_k}{83} + \frac{^{226}Ra - B_k}{5.0} + \frac{^{230}Th - B_k}{14} + \frac{^{232}Th - B_k}{3.5} + \frac{U_{Total} - B_k}{560}$$

Subsurface Soil**:**

$$SOR = \frac{^{227}Ac - B_k}{180} + \frac{^{231}Pa - B_k}{1{,}800} + \frac{^{226}Ra - B_k}{15} + \frac{^{230}Th - B_k}{44} + \frac{^{232}Th - B_k}{9.6} + \frac{U_{Total} - B_k}{3{,}021}$$

* B_k represents the background concentration for that specific radionuclide. The historical background values for each of the radionuclides are listed in Table 3. The Th-232 limit takes into account Th-228 and Ra-228, both in equilibrium with Th-232.