FINAL, REV. 2

TECHNICAL MEMORANDUM

MODELING OF RADIOLOGICAL RISKS FROM RESIDUAL RADIOACTIVE MATERIALS FOLLOWING IMPLEMENTATION OF REMEDIAL ALTERNATIVES FOR SEAWAY LANDFILL AREAS A, B, AND C

TONAWANDA, NEW YORK

JUNE 2000

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

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TONAWANDA, NEW YORK

JUNE 2000

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
ALARA	as low as reasonably achievable
BFI	Browning-Ferris Industries
cm	centimeter(s)
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DCH	Data Collection Handbook
DOE	U.S. Department of Energy
EFH	Exposure Factors Handbook
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
FUSRAP	Formerly Utilized Sites Remedial Action Program
ft	foot (feet)
g	gram(s)
HHEM	Human Health Evaluation Manual
m	meter(s)
µg	microgram(s)
mg	milligram(s)
mrem	millirem(s)
NYCRR	New York Compilation of Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
Pa	protactinium
Pb	lead
pCi	picoCurie(s)
Ra	radium
RESRAD	RESidual RADioactivity
RI	remedial investigation
RME	reasonable maximum-exposure
Rn	radon
Th	thorium
U	uranium
UCL_{95}	upper 95% confidence level
USACE	U.S. Army Corps of Engineers
WL	working level
yd	yard(s)

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FOREWORD

An initial version of this document was entitled "TECHNICAL MEMORANDUM, Modeling of Radiological Doses and Cancer Risks From Residual Radioactive Materials Following Implementation of Remedial Alternatives for Seaway Landfill Areas A, B and C", dated August 1998. Revisions were made to that document to reflect four additional factors that occurred after it had been published. The four factors were (1) further refinements to the volume estimates; (2) USACE consideration of refining the Partial Excavation alternative, as described in the 1993 Proposed Plan, to involve partial excavation in Areas A, B and C; (3) more detailed evaluation of the radon pathway; and (4) a more detailed evaluation of the impacts of cover depth. This revised document reflects the latest volume estimates as well as an alternative which involves partial excavation in Areas A, B and C. This revision replaces the original document dated August 1998 and Revision 1 dated June 1999.

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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). 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 Seaway Industrial Park is one of the sites being managed by the Buffalo District Corps of Engineers under the FUSRAP program. This document provides an assessment of estimated radiological dose and carcinogenic risk from exposure to residual radioactivity within the Seaway Industrial Park landfill following implementation of alternatives considered for remediation. Estimates of indoor radon concentrations, outdoor radon concentrations, and radon flux are also provided for comparison to relevant standards.

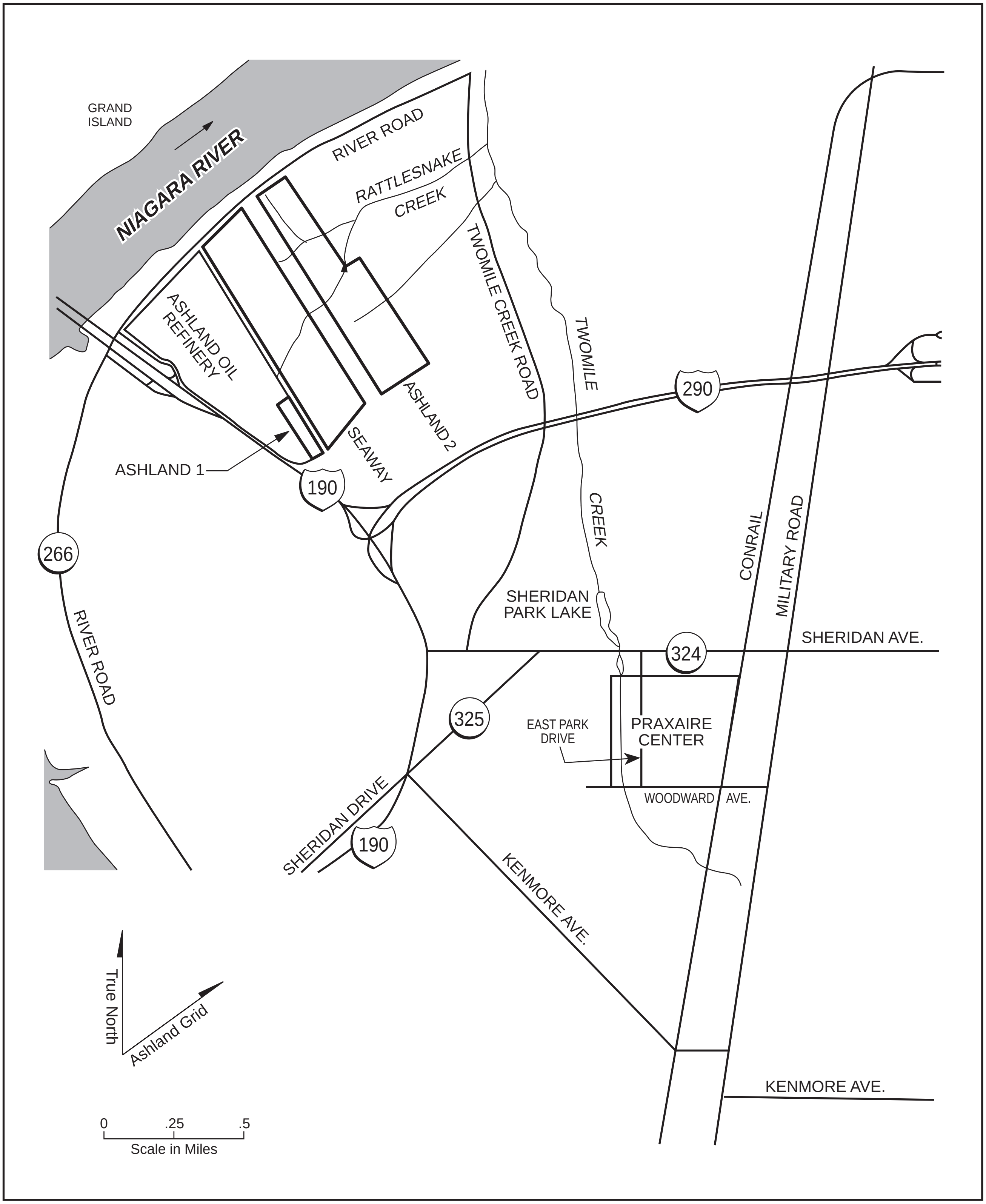
1.1 SITE BACKGROUND

The Seaway Industrial Park covers nearly 100 acres within the town of Tonawanda, New York (Figure 1). The site is owned by Seaway Industrial Park Development, Inc. 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., the current owner of the former Haist property, 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.

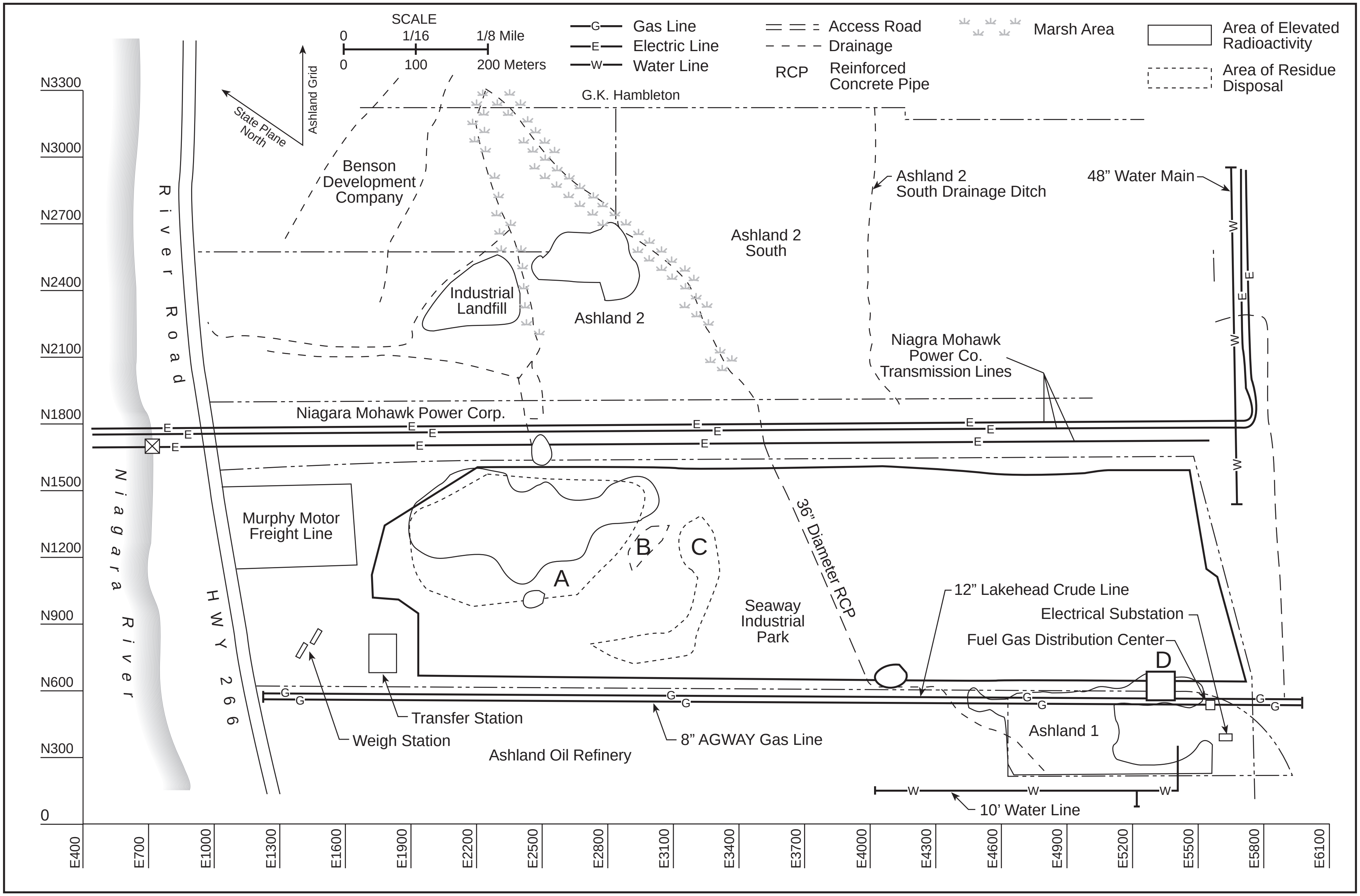
1.2 SCOPE

The scope of this assessment includes evaluation of potential radiological doses and carcinogenic risks from exposure to residual radioactive materials in Areas A, B and C, and estimation of radon levels that could be produced by the residual materials. Areas B and C were



FUS/Tonawanda 01/99

Figure 1. Tonawanda Sites



FUS NY Seaway 01/99

Figure 2. Areas within Seaway Industrial Park Containing MED Radioactive Residues

combined in some evaluation scenarios because their depositional history is similar, their current status (mostly buried beneath fill) is the same, and Areas B and C are small compared to Area A.

Exposure scenarios for these areas were constructed based on the possible remedial alternatives and potential future uses. Remedial worker scenarios were evaluated to establish short-term effects of the remediation. Remedial activities may include either excavation or capping or both, depending upon the action considered. Recreational exposure was evaluated as the most likely future use consistent with the Town of Tonawanda Waterfront Region Master Plan. Commercial or industrial exposure also was evaluated as a conservative plausible future use. The remedial alternatives considered include no action; cap and cover with no excavation; excavation to an average concentration of 40 pCi/g Th-230 in Area A; excavation of material exceeding 40 pCi/g Th-230 in Area A; excavation to an average concentration of 40 pCi/g Th-230 in Areas A, B, and C; excavation of material exceeding 40 pCi/g Th-230 in Areas A, B, and C; and partial excavation of material exceeding 40 pCi/g Th-230 in the upper 4 feet in Areas A and C (Area B does not exceed the Th-230 criterion in the upper four feet). The proposed levels of cleanup were derived in the *Radionuclide Cleanup Guideline Derivation for Ashland 1, Ashland 2, and Seaway* (DOE 1997). Excavation to an average concentration of 40 pCi/g of Th-230 corresponds to Approach 1 in the Guideline Derivation and excavation of material exceeding 40 pCi/g of Th-230 corresponds to Approach 2. The cap and cover alternative assumes the landfill is capped similar to the approach outlined in New York State regulations for a commercial landfill as specified in 6 New York Compilation of Rules and Records (NYCRR) 360. Area D shown in Figure 2 will be addressed under the Ashland 1 remedy. Detailed development and evaluation of these alternatives is discussed in the Feasibility Study Addendum.

2. RADIOLOGICAL RISK ASSESSMENT

This section describes the method used to determine the concentrations of radionuclides in the soil before and after remediation, lists the assumptions made for the exposure conditions, reports the results of the radiological risk assessment (including dose estimates), and provides the results of the radon calculations. The calculations for the radiological dose/risk and radon assessments were performed using the RESidual RADioactivity (RESRAD) computer software, version 5.82 (Yu et al. 1993a).

2.1 DATA EVALUATION

Data sets used for the evaluation of reasonable maximum exposure concentrations were taken from five sources: the *Radiological Survey of the Seaway Industrial Park Tonawanda, New York* (DOE 1978a), the *Preliminary Engineering and Environmental Evaluation of the Remedial Action Alternatives for the Seaway Industrial Park, Tonawanda, New York* (Ford, Bacon, and Davis of Utah 1981), the *Remedial Investigation Report for the Tonawanda Site* (DOE 1993a), the *Additional Surface Characterization of Areas B and C at the Seaway Site* (USACE 1999a) and the *Synopsis of Volume Calculations for Seaway Site Areas A, B, and C* (USACE 1999b). The data sets were inconsistent with respect to analytes. Most of the samples in the 1978 study reported results only for Ra-226, although results were also reported for U-238 in 20 samples.

The 1981 study reported both U-238 and Ra-226 for all samples, but did not provide any thorium data. The remedial investigation (RI) evaluated all samples taken at Seaway Industrial Park for U-238, Ra-226, Th-232, and Th-230. Areas B and C could not be located during the RI because these areas were covered by as much as 12 meters (40 feet) of refuse and fill material before the RI took place. Consequently, no thorium data is available for Areas B and C from the early studies as no data were collected from Areas B and C during the RI.

Although the buried material was not located during the RI, the RI did find Th-230 at concentrations in Area A that were not at equilibrium with other radionuclides in the U-238 decay chain. This was due to the fact that the process of extracting uranium from ore necessarily depleted the uranium from the residues. In addition, radium was sometimes recovered as well as uranium, further distorting the natural relative abundance in the uranium chain. With no data available for Th-230 buried under Areas B and C, it was necessary to assume that the ratio of Th-230 to Ra-226 was the same as the ratio in Area A. This assumption is reasonable because the material buried in Areas B and C is believed to have originated from the same source as the material in Area A. A regression analysis was performed on the data in Area A to obtain a multiplication factor to produce surrogate data for Th-230 in Areas B and C. The best fit for the data in Area A was found to be given by the equation Th-230 (above background) = 20.188 $\times$ Ra-226 (above background). For samples with no Th-230 result for Area A and for the buried material in Areas B and C, the Th-230 concentration was estimated using this 20.188 multiplication factor. Although no data were available for Th-232 prior to the RI, surrogate data for Th-232 was not developed because Th-232 concentrations are not significant compared with the other radionuclides.

USACE performed an additional investigation in Areas B and C in 1998. The data provided in the 1999 report (collected in 1998) includes all the radionuclides of concern, but are limited to the top 8 feet of fill material in Area B and the top 4 feet of Area C. Th-230 regression analysis results were, therefore, used only on pre-RI data.

In the *Radiological Survey of the Ashland Oil Company (Former Haist Property), Tonawanda, New York* (DOE 1978b), results are reported for U-238, Ra-226, Th-232, and Ac-227. Actinium-227, a decay product of U-235, is naturally present in secular equilibrium with U-235, or at an activity of about 4.6% of the U-238 activity. The Ashland 1 data indicated Ac-227 is present at much higher concentrations than would normally be expected. Because the concentrations of Ac-227 at Ashland 1 were high enough to contribute significantly to dose, and the material at Seaway originated from Ashland 1, the potential presence of elevated Ac-227 could not be neglected even though no historical data are available for Ac-227 at Seaway. The hypothesis was tested that the Ac-227 may be present in some nearly constant proportion to Ra-226 at Ashland 1. A regression analysis was performed on the Ashland 1 data to determine whether Ra-226 could be used to predict Ac-227 concentrations. Initially, the regression indicated that the concentration of Ac-227 was approximately 1.8 times higher than the Ra-226. However, there is a single data point that, if ignored, changed the factor from 1.8 to 1.02. It was suspected that the data point was not representative of the data set as a whole (the suspect Ac-227 value was 1500 pCi/g and the next highest Ac-227 value was 390 pCi/g). A data point may be considered an outlier if it is more than 3 standard deviations greater or smaller than the mean (Younger 1985). The suspect data point was determined to be an outlier on the basis of this test and was excluded from regression calculations. It has also been observed at other sites where similar work with uranium ores was conducted that the concentration of Ac-227 is approximately equal to the concentration of Ra-226.Thus, surrogate values for Ac-227 were generated for the Seaway data set based on the relationship of Ac-227 = 1.02 × Ra-226. The results of the regression with the outlier removed are presented in the attachment to this technical memorandum. Ac-227 was assumed to be in secular equilibrium with its long-lived parent isotope Pa-231. Surrogate data were not developed for the data from the 1999 study because both Th-230 and Ac-227 concentrations were measured.

A statistical analysis of the data set was used to determine the maximum, minimum, mean, and upper 95% confidence level (UCL_{95}) on the mean concentrations for Area A and for Areas B and C. The UCL_{95} represents a concentration that exceeds the mean concentration of a randomly drawn set of samples 95% of the time. The smaller of the maximum detects and UCL_{95} values, after subtracting background, were used as the exposure point concentrations (EPC) for the risk assessment. Because radon standards include contributions from background, the radon EPC is simply the smaller of the maximum detect and the UCL_{95}. A surrogate source term value for Th-230 was obtained for Areas B and C by multiplying the UCL_{95} ratio of Ra-226 to Th-230 in Area A (20.188) by the source term value for Ra-226 in Areas B and C. The multiplication 20.188 factor was calculated using linear regression analysis and is consistent with volume estimate methods. The results of the statistical analysis including the linear regression results are presented in Table 1. EPCs for Areas B and C combined are used only for calculating dose and risk to the remediation workers. These workers are the only individuals considered to have a reasonable chance of being exposed to radiologically contaminated materials buried under 40 feet of refuse and fill material. For other modeling purposes, the baseline concentrations in Areas B and C for areas near the surface were also computed from the 1998 data and are reported in Table 2. No surrogate values were needed in the Table 2 data set because samples collected in 1998 were analyzed for Ac-227 and Th-230.

Background concentrations were subtracted from the smaller of the maximum detect and the UCL_{95} because radiation protection guidelines, including the site-specific guideline developed for Seaway (DOE 1997), are based on dose above background. The site-specific background values subtracted were 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 was adjusted for background by assuming its presence in background at its naturally occurring abundance, 4.6% of the U-238 concentration (0.14 pCi/g). The background adjusted EPC values are presented in Tables 1 and 2. As noted above, EPCs used to estimate radon levels are not background-adjusted.

To obtain an estimate of residual concentrations following excavation of all contaminated materials exceeding the cleanup guideline of 40 pCi/g Th-230 (DOE 1997), all samples in the data set exceeding 40 pCi/g Th-230 were removed and the remaining data were aggregated into a new data set. New EPC concentrations for all radionuclides were calculated as described above for the baseline data set. The predicted post-remedial concentrations are given in Table 3. To estimate dose and radiological risk for cleanup to an average of 40 pCi/g of Th-230, a scaling factor was obtained by dividing 40 pCi/g by the Th-230 UCL_{95} from the full excavation in Table 3. Because dose and risk are proportional to concentration, multiplying the dose and risk associated with removing everything exceeding 40 pCi/g of Th-230 by the scaling factor provides an estimate of the doses and radiological risks if the site is cleaned up to an average of 40 pCi/g of Th-230. This factor is calculated to be 5 in Area A and $2\frac{2}{3}$ in Areas B and C.

Table 1. Statistical Summary of Baseline Data to Depth

Analyte [a]	Results > Detection Limit	Minimum Detect (pCi/g)	Maximum Detect (pCi/g)	Mean (pCi/g)	UCL_{95} (pCi/g)	Net EPC (pCi/g) [b]
Area A (No Action)						
Ac-227	—	—	—	—	9.0	8.9
Pa-231	—	—	—	—	9.0	8.9
Pb-210	—	—	—	—	8.8	7.7
Ra-226	248/251	0.12	140	7.5	8.8	7.7
Ra-228	—	—	—	—	1.7	0.50
Th-228	—	—	—	—	1.7	0.50
Th-230 [c]	250/251	0.0	2800	130	160	160
Th-232	93/125	0.50	21	1.5	1.7	0.50
U-234	—	—	—	—	12	8.9
U-235	—	—	—	—	0.55	0.41
U-238	84/180	0.030	74	11	12	8.9
Areas B and C Combined Deep Soils (remediation worker exposures only)						
Ac-227	—	—	—	—	15	15
Pa-231	—	—	—	—	15	15
Pb-210	—	—	—	—	15	14
Ra-226	51/51	0.25	93	8.4	15	14
Ra-228	—	—	—	—	0.0	0.0
Th-228	—	—	—	—	0.0	0.0
Th-230 [d]	—	—	—	—	280	280
Th-232	—	—	—	—	0.0	0.0
U-234	—	—	—	—	15	12
U-235	—	—	—	—	0.69	0.55
U-238	37/37	0.13	100	7.2	15	12

[a] Where analytical results are not available: Ac-227 = 1.02 × Ra-226; Pa-231 = Ac-227; Pb-210 = Ra-226, Ra-228 = Th-228 = Th-232; U-234 = U-238, U-235 = 0.046 × U-238. All values rounded to two significant digits.

[b] Smaller of UCL_{95} and Maximum Detected Value minus background using the following background concentrations: Ac-227, Pa-231 and U-235 = 0.14 pCi/g; Pb-210 and Ra-226 = 1.1 pCi/g; Ra-228, Th-228 and Th-232 = 1.2 pCi/g, Th-230 = 1.4 pCi/g, and U-234 and U-238 = 3.1 pCi/g.

[c] Includes combination of analytical data and estimated values using multiplication factor. Gross Th-230 = 20.188 × (Ra-226 – 1.1) + 1.4 based on regression analysis.

[d] Gross Th-230 = 20.188 × (Ra-226 – 1.1) + 1.4 based on regression analysis.

Table 2. Statistical Summary of Baseline Data Near the Surface

Analyte [a]	Results > Detection Limit	Minimum Detect (pCi/g)	Maximum Detect (pCi/g)	Mean (pCi/g)	UCL_{95} (pCi/g)	Net EPC (pCi/g) [b]
Area B Upper 4 ft (No Action and Remove upper 4 ft)						
Ac-227	9/12	1.3	7.8	2.6	3.8	3.7
Pa-231	—	—	—	—	3.8	3.7
Pb-210	—	—	—	—	0.23	0.0
Ra-226	9/12	0.12	0.30	0.19	0.23	0.0
Ra-228	—	—	—	—	1.2	0.0
Th-228	—	—	—	—	1.2	0.0
Th-230	12/12	0.78	3.1	1.8	2.1	0.70
Th-232	12/12	0.51	1.6	1.0	1.2	0.0
U-234	12/12	1.0	2.5	1.6	1.8	0.0
U-235	2/12	0.13	0.24	0.11	0.15	0.01
U-238	12/12	0.89	2.3	1.5	1.7	0.0
Area C Upper 2 ft (No Action)						
Ac-227	7/15	1.1	3.3	1.1	1.6	1.5
Pa-231	—	—	—	—	1.6	1.5
Pb-210	—	—	—	—	0.28	0.0
Ra-226	13/16	0.16	0.47	0.23	0.28	0.0
Ra-228	—	—	—	—	0.93	0.0
Th-228	—	—	—	—	0.93	0.0
Th-230	16/16	1.1	12	4.6	7.7	6.3
Th-232	16/16	0.39	1.3	0.83	0.93	0.0
U-234	16/16	1.1	16	4.3	7.8	4.7
U-235	7/16	0.21	0.55	0.19	0.26	0.12
U-238	16/16	0.78	14	4.1	8.1	5.0
Area C Upper 4 ft (Remove upper 4 ft)						
Ac-227	14/23	1.1	33	4.3	7.2	7.1
Pa-231	3/24	32	51	5.8	11	11
Pb-210	—	—	—	—	2.2	1.1
Ra-226	19/24	0.16	11	1.3	2.2	1.1
Ra-228	—	—	—	—	1.1	0.0
Th-228	—	—	—	—	1.1	0.0
Th-230	24/24	1.1	410	39	74	73
Th-232	24/24	0.39	2.5	0.90	1.1	0.0
U-234	24/24	1.1	47	9.0	14	11
U-235	11/24	0.21	1.6	0.34	0.49	0.35
U-238	24/24	0.78	44	9.0	14	11

[a] Where analytical results are not available: Pa-231 = Ac-227; Pb-210 = Ra-226, and Ra-228 = Th-228 = Th-232. All values rounded to two significant digits.

[b] Smaller of UCL_{95} and Maximum Detected Value minus background using the following background concentrations: Ac-227, Pa-231 and U-235 = 0.14 pCi/g; Pb-210 and Ra-226 = 1.1 pCi/g; Ra-228, Th-228 and Th-232 = 1.2 pCi/g, Th-230 = 1.4 pCi/g, and U-234 and U-238 = 3.1 pCi/g.

Table 3. Statistical Summary of Post Remedial Data

Analyte [a]	Results > Detection Limit	Minimum Detect (pCi/g)	Maximum Detect (pCi/g)	Mean (pCi/g)	UCL_{95} (pCi/g)	Net EPC (pCi/g) [b]	Average Th-230 = 40 pCi/g (pCi/g) [c]
Area A All Depths (Remove Th-230 > or = 40 pCi/g)							
Ac-227	—	—	—	—	1.5	1.4	8.8
Pa-231	—	—	—	—	1.5	1.4	8.8
Pb-210	—	—	—	—	1.5	0.40	2.6
Ra-226	125/128	0.12	4.4	1.3	1.5	0.40	2.6
Ra-228	—	—	—	—	1.4	0.20	0.20
Th-228	—	—	—	—	1.4	0.20	0.20
Th-230 [d]	127/128	0.0	40	6.2	7.6	6.2	40
Th-232	59/74	0.50	3.0	1.3	1.4	0.20	0.20
U-234	—	—	—	—	5.6	2.5	16
U-235	—	—	—	—	0.26	0.12	0.76
U-238	36/108	0.030	9.7	4.9	5.6	2.5	16
Area A All Depths (Remove upper 4 ft)							
Ac-227	—	—	—	—	4.3	4.2	—
Pa-231	—	—	—	—	4.3	4.2	—
Pb-210	—	—	—	—	4.2	3.1	—
Ra-226	49/51	0.15	17	2.6	4.2	3.1	—
Ra-228	—	—	—	—	2.1	0.9	—
Th-228	—	—	—	—	2.1	0.9	—
Th-230 [d]	50/51	0.0	220	22	34	33	—
Th-232	17/25	0.60	3.0	1.7	2.1	0.9	—
U-234	—	—	—	—	7.5	4.4	—
U-235	—	—	—	—	0.35	0.21	—
U-238	22/46	0.10	17	6.0	7.5	4.4	—
Areas B and C Combined Deep Soils (Remove Th-230 > or = 40 pCi/g)							
Ac-227	—	—	—	—	2.0	1.9	7.6
Pa-231	—	—	—	—	2.0	1.9	7.6
Pb-210	—	—	—	—	1.6	0.50	2.0
Ra-226	21/21	0.25	2.9	1.3	1.6	0.50	2.0
Ra-228	—	—	—	—	0.0	0.0	0.0
Th-228	—	—	—	—	0.0	0.0	0.0
Th-230	—	—	—	—	11	10	40
Th-232	—	—	—	—	0.0	0.0	0.0
U-234	—	—	—	—	2.1	0.0	0.0
U-235	—	—	—	—	0.10	0.0	0.0
U-238	18/18	0.13	3.7	1.7	2.1	0.0	0.0
Area B or C [e] (Remove upper 4 ft)							

[a] Where analytical results are not available: Ac-227 = 1.02 × Ra-226; Pa-231 = Ac-227; Pb-210 = Ra-226, Ra-228 = Th-228 = Th-232; U-234 = U-238, U-235 = 0.046 × U-238. All values rounded to two significant digits.

[b] Smaller of UCL_{95} and Maximum Detected Value minus background using the following background concentrations: Ac-227, Pa-231 and U-235 = 0.14 pCi/g; Pb-210 and Ra-226 = 1.1 pCi/g; Ra-228, Th-228 and Th-232 = 1.2 pCi/g, Th-230 = 1.4 pCi/g, and U-234 and U-238 = 3.1 pCi/g.

[c] Radionuclides (except Th-232 + D) scaled up to make Th-230 = 40 pCi/g.

[d] Includes combination of analytical data and estimated values using multiplication factor. Gross Th-230 = 20.188 × (Ra-226 – 1.1) + 1.4 based on regression analysis.

[e] Same as baseline values listed in Table 2.

Residual concentrations following implementation of the partial excavation alternative were estimated by removing all data from the top four feet and calculating new UCL_{95} values from the modified data set.

Concentrations of long-lived decay products for which no analytical data were available were set equal to the UCL_{95} concentration of the nearest parent radionuclide in the decay chain for which data were available. In addition, Pa-231 was set equal to the surrogate EPC for Ac-227. U-235 was set equal to 4.6% of the U-238 concentration. U-234 was set equal to U-238, Pb-210 was set equal to Ra-226, and for Areas B and C, Th-230 was set equal to 20.188 times the Ra-226 concentration. For Area A, additional data were available for Th-232, thus the Th-232 progeny Ra-228 and Th-228 were set equal to the Th-232 concentration, although the Th-232 concentration was very close to background. These surrogates were used only when analytical results are not available. That is, surrogates do not take the place of actual data.

2.2 EXPOSURE ASSESSMENT

In this section, the exposure scenarios are described in detail and the pathways for exposure are identified. Values of parameters used in RESRAD are presented and justified if they were different from the default values. Table 4 presents the parameter values that are site specific (i.e. that were changed due to site-specific characteristics). Table 5 presents the scenario specific parameters. Groundwater is not evaluated because the pathway is eliminated by the leachate collection system in the landfill and because the MED material is highly insoluble.

2.2.1 Landfill Closure (Containment)

To model the scenario for landfill closure, New York State regulation 6 NYCRR 360-2 was consulted to establish a reasonable scenario for landfill closure. Following this example, landfill closure would include construction of a gas venting layer bounded on the upper and lower surfaces with filter layers. A low permeability layer of not less than 46 cm (18 inches) is constructed over this. A 0.6-m (2-ft) thick barrier protection layer is placed over the low permeability layer to protect the low permeability layer from drying, freezing, and penetration by burrowing animals or roots. A vegetative layer is placed over the top. The actual design of the landfill cover may vary from this depending upon the contents of the landfill and specific requirements for closing out the FUSRAP-related areas. Using the state regulation as an example provides the best available basis for setting up the model.

Each of these layers will act as a shield to protect the workers from exposure during the construction of subsequent layers. To model the protection provided by layers that are in place during construction of subsequent layers, separate radiological risk calculations could be performed for each layer. The first calculation assumed no cover, representing conditions during construction of the lower filter layer. The second calculation assumed 0.3 m (1 ft) of cover to model the radiological risk incurred during construction of the gas venting layer, taking into consideration the shielding provided by the lower filter layer. However, the 0.3-m (1-ft) cover and subsequent layers of cover effectively shield the worker from significant additional dose and risk. The dose and risk estimates for the landfill closure scenarios therefore are limited to the exposures during

Table 4. Site Specific Parameters Changed From RESRAD Version 5.82 Default Values

Parameter	All Areas	Default	Basis
Area of Contaminated Zone, m^2	calculated	10,000	Separately computed for different remedial action alternatives based on USACE 1999b (Remove upper 4 ft: 17,800 m^2 for Area A, 2,600 m^2 for Area B, and 7,400 m^2 for Area C; All other scenarios: 36,700 m^2 for Area A, 2,600 m^2 for Area B, and 8,500 m^2 for Area C or 11,100 m^2 when combining Areas B and C).
Thickness of Contaminated Zone, m	2.0	2.0	Default
Contaminated Zone Total Porosity	0.45	0.4	Baseline Risk Assessment (DOE 1993b)
Contaminated Zone Hydraulic Conductivity, m/yr	123	10	Baseline Risk Assessment (DOE 1993b)
Evapotranspiration Coefficient	0.46	0.5	Baseline Risk Assessment (DOE 1993b)
Precipitation, m/yr	0.96	1.00	Remedial Investigation (DOE 1993a)
Runoff Coefficient	0.25	0.2	Baseline Risk Assessment (DOE 1993b)
Accuracy for Water/Soil computations	0	0.001	0 specifies use of 20 term Simpson's Rule instead of Romberg integration
Saturated Zone Total Porosity	0.45	0.4	Baseline Risk Assessment (DOE 1993b)
Saturated Zone Hydraulic Conductivity, m/yr	123	100	Baseline Risk Assessment (DOE 1993b)
Saturated Zone Hydraulic Gradient	0.00045	0.02	Remedial Investigation (DOE 1993a)
Water Table Drop Rate, m/yr	0	0.001	Little consumptive use of groundwater in the area
Distribution Coefficient U, cm^3/g	10	50	Remedial Investigation (DOE 1993a)
Distribution Coefficients all other isotopes	—	—	DCH* for Clay
Livestock Water Fraction from Groundwater	0	1.0	No livestock present at site
Contamination Fraction of Household Water	0	1	Groundwater Pathway Suppressed
Depth of Soil Mixing Layer, m	0.05	0.15	15 cm based on agricultural till depth. 5 cm reasonable for non-agricultural setting, according to Argonne representative.
Average Building Air Exchange Rate (1/hr)	1	0.5	Average value for single detached home as reported in Yu et al. 1993a.
Building Depth below Ground Surface (m)	0.0	-1	Slab on grade assumed

* DCH: *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil*, Yu et al. 1993b

Table 5. Scenario Specific Parameters Changed From RESRAD Version 5.82 Default Values

Parameter	Default	Remedial Worker	Recreation	Industrial	Basis *
Inhalation Rate, m^3/yr	8,400	12,300	12,300	7,300	Industrial-Human Health Evaluation Manual (HHEM) reasonable upper bound; Construction, Recreation-Exposure Factors Handbook (EFH) Average Outdoor Inhalation Rate assuming activity mix of 37% moderate, 28% at rest or light activity, 7% high activity level
Mass Loading for Inhalation, g/m^3	0.0001	0.00018	0.00003	0.00003	DCH, adjusted for 30% respirable fraction. Construction activities value is used for remedial worker; others average ambient conditions.
Exposure Duration, yr	30	1	9	25	HHEM Reasonable maximum duration for industrial worker, average duration for an individual at a single location for recreation. Remedial activities completed in less than 1 yr.
Time Fraction Indoors	0.5	0	0	0.20	EFH. Industrial Worker 7 hr/day 250 days/yr. No indoor activities for recreation or construction.
Time Fraction Outdoors	0.25	(See Eq. 1 and Eq. 2)	0.017	0.029	EFH. Recreation 3 hrs/wk, 50 wk/yr. Industrial 1 hr/day 250 days/yr
Soil Ingestion Rate g/yr	36.5	175.2	36.5	18.25	HHEM Industrial 50 mg/day in the workplace. 480 mg/day for construction activities
Erosion Rate, m/yr	0.001	0	0	0	Erosion assumed to be negligible during construction period and for a maintained landfill

*** References:**

DCH: *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil*, Yu et al. 1993b
EFH: *Exposure Factors Handbook*, EPA 1990.
HHEM: *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors*, EPA 1991

the placement of the lower filter layer. More details on the effects of cover thickness on exposure estimates are provided in Section 2.2.4.

For the first layer, the duration of exposure was estimated by using the backfill unit productivity rate in Mean's *Heavy Construction Cost Data* (Smit 1996) of 0.021 hour/m^3 (0.016 hour/yd^3) for a 200-horsepower dozer and a 90-m (300 ft) haul from the soil storage area. Compaction would be done with a wobbly wheel or sheepsfoot roller at a rate of 0.003 hr/m^3 (0.002 hr/yd^3). The time required to cover the impacted 36,750 m^2 (395,550 ft^2) Area A with 0.3 m (1 ft) of soil for the filter layer is

$$\frac{395{,}550\ \text{ft}^2 \times 1\ \text{ft}}{27\ \text{ft}^3/\text{yd}^3} \times \frac{0.016\ \text{hr/yd}^3 + 0.002\ \text{hr/yd}^3}{0.91 \times 0.63} = 460\ \text{hrs} \qquad \text{(Eq. 1)}$$

using a site productivity factor of 0.91 and a safety factor of 0.63. The productivity factor is used to adjust Means' rates to account for work interruptions, job sequencing, and site-specific requirements. The safety factor accounts for increased time to accomplish tasks due to the health and safety requirements when excavating radioactive materials. The onsite time fraction for the remediation worker in Area A was calculated by dividing the total time required for completion of the layer (460 hours) by the total number of hours in a year, 8,760 hours. The onsite time fraction for Area A is thus 0.053.

Similar calculations were performed for Areas B and C. In addition, separate areas were calculated for closure after partial and full excavation.

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. The mass loading of dust was set to 0.00018 g/m^3, adjusting the 0.0006 g/m^3 to account for a 30% respirable fraction (Paustenbach 1989). The incidental soil ingestion rate was set to 175.2 g/year (representing 480 mg/day) (Yu et al. 1993b). The respiration rate was set to 12,260 m^3/year, representing a typical mix of outdoor activities (Yu et al. 1993b). Cover depth was set to 0.0 m.

2.2.2 Excavation

Three potential excavation scenarios were evaluated; excavation to an average of 40 pCi/g of Th-230, excavation of everything exceeding 40 pCi/g of Th-230, and partial excavation. The volumes associated with the excavation of soil contaminated above 40 pCi/g Th-230 have been estimated at 57,900 m^3 (75,700 yd^3) in Area A, 5,000 m^3 (6,600 yd^3) in Area B and 22,000 m^3 (28,500 yd^3) in Area C. Excavation to an average of 40 pCi/g of Th-230 would excavate an estimated 54,600 m^3 (71,400 yd^3) in Area A, but no significant change in volume would be expected in Areas B and C. The partial excavation alternative would excavate only the top four feet. Volumes exceeding 40 pCi/g in the upper 4 feet are 37,200 m^3 (48,600 yd^3) in Area A and 3400 m^3 (4,500 yd^3) in Area C. No material exceeding the criteria was found in the upper four feet of Area B. These volume estimates are based on calculations performed using the Earth Vision® software (USACE 1999b). Using these volumes, the duration of the exposure was estimated. From Mean's *Heavy Construction Cost Data* (Smit 1996), a front end loader with a 2.3 m^3 (3 yd^3)

bucket can excavate 96 m^3/hour (125 yd^3/hour). After applying the site constraint and safety factors, the duration of exposure during excavation of all materials exceeding 40 pCi/g of Th-230 for Area A and Areas B and C are

$$\frac{75{,}700\ \text{yd}^3}{125\ \text{yd}^3/\text{hr} \times 0.91 \times 0.63} = 1{,}056\ \text{hrs for A, and}$$
$$\frac{35{,}100\ \text{yd}^3}{125\ \text{yd}^3/\text{hr} \times 0.91 \times 0.63} = 490\ \text{hrs for B and C} \quad \text{(Eq. 2)}$$

The time onsite for excavation to an average of 40 pCi/g was estimated by applying the ratio of volumes excavated in the two approaches to cleanup criteria to the time calculated for excavation of all material exceeding 40 pCi/g. That is, for Area A, time onsite for excavation to an average of 40 pCi/g is 71,400 yd^3/75,500 yd^3 = 0.94 of the time onsite for excavation of all materials exceeding 40 pCi/g and the dose and radiological risk to the remedial worker would be 94% of the dose and radiological risk to the remedial worker excavating all materials exceeding 40 pCi/g.

Based on 8,760 hours in a year, the fraction of time spent onsite to excavate everything exceeding 40 pCi/g of Th-230 is 0.12 for Area A and 0.056 for Areas B and C. Only the time spent within the zone containing radioactive material was considered. The time required to excavate the overburden in Areas B and C was neglected because the overburden would shield the workers from radiation exposure until it is removed. Similar calculations were performed for the partial excavation alternative.

The same assumptions for the cover depth, inhalation pathway and incidental ingestion of soil used for landfill closure were also used for the excavation scenario. Other non-default input parameters required by RESRAD are site specific rather than scenario dictated. These values were taken primarily from the RI (DOE 1993a). Results for dose and risk to the remediation worker while excavating and covering individual areas are presented in Table 6.

2.2.3 Commercial or Industrial and Recreational Scenarios

To model the recreational scenario, an individual was assumed to be present at the site for 3 hours per week for 50 weeks per year (time onsite fraction of 0.017), all outdoors. Industrial use assumed 7 hours indoors and 1 hour outdoors each day for 250 work days per year (fractions of 0.20 and 0.029, respectively).

Cover depth was set to 0.0 m for the No Action Alternative. For the Cap and Cover alternatives, depth was increased by 1.5 m (5 ft) assuming a depth consistent with New York landfill closure regulations. Both no cover and 1.5-m cover cases were analyzed for future use scenarios following partial or complete excavation. In addition, the radon model considered no cover, a 0.3-m cover, and a 1.5-m cover.

Dust loading was changed from the default to 0.00003 g/m^3 representing 100 μg/m^3 (Yu et al. 1993b) with a 30% respirable fraction (Paustenbach 1989). The inhalation rate was changed to 7300 m^3/year representing the average adult inhalation rate [U.S. Environmental

Table 6. Dose and Risk to Remediation Worker by Activity

Cover Results by Scenario (see Equation 1 for exposure times)							
Area	**Scenario**	**Surface Area (m^2)**	**Surface Area (ft^2)**	**Time (hrs)**	**Time Fraction**	**Dose (mrem/yr)**	**Risk ($lifetime^{-1}$)**
A	No Removal	36,700	395,000	460	0.053	12	4E-06
A	Excavate Top 4 ft	17,800	192,000	220	0.025	2.6	9E-07
A	Remove Th-230 > 40	36,700	395,000	460	0.053	1.3	3E-07
A	$Th\text{-}230_{avg} = 40$ [a]	36,700	395,000	460	0.053	7.2	2E-06
B Shallow	No Removal	2,600	28,000	33	0.0038	0.14	2E-08
B Shallow	Excavate Top 4 ft	2,600	28,000	33	0.0038	0.14	2E-08
B Shallow	Remove Th-230 > 40	2,600	28,000	33	0.0038	See B & C	
B Shallow	$Th\text{-}230_{avg} = 40$ [a]	2,600	28,000	33	0.0038	See B & C	
C Shallow	No Removal	8,500	91,500	110	0.013	0.23	3E-08
C Shallow	Excavate Top 4 ft	7,400	79,600	93	0.011	1.2	2E-07
C Shallow	Remove Th-230 > 40	8,500	91,500	110	0.013	See B & C	
C Shallow	$Th\text{-}230_{avg} = 40$ [a]	8,500	91,500	110	0.013	See B & C	
B & C Deep	Remove Th-230 > 40	11,100	119,000	140	0.016	0.54	1E-07
B & C Deep	$Th\text{-}230_{avg} = 40$ [a]	11,100	119,000	140	0.016	1.1	3E-07
Excavation Results by Scenario (see Equation 2 for exposure times) [b]							
Area	**Scenario**	**Surface Area (m^2)**	**Volumes (yd^3)**	**Time (hrs)**	**Time Fraction**	**Dose (mrem/yr)**	**Risk ($lifetime^{-1}$)**
A	No Removal	36,700	—	—	—	—	—
A	Excavate Top 4 ft	17,800	49,100	690	0.079	18	5E-06
A	Remove Th-230 > 40	36,700	75,700	1060	0.12	27	8E-06
A	$Th\text{-}230_{avg} = 40$ [a, c]	36,700	75,700	1060	0.12	27	8E-06
B Shallow	No Removal	2,600	—	—	—	—	—
B Shallow	Excavate Top 4 ft	2,600	0.0	0.0	0.0	—	—
B Shallow	Remove Th-230 > 40	2,600	6,600	92	0.011	See B & C	
B Shallow	$Th\text{-}230_{avg} = 40$ [a, c]	2,600	6,600	92	0.011	See B & C	
C Shallow	No Removal	8,500	—	—	—	—	—
C Shallow	Excavate Top 4 ft	7,400	4,500	63	0.0072	0.81	1E-07
C Shallow	Remove Th-230 > 40	8,500	28,500	400	0.046	See B & C	
C Shallow	$Th\text{-}230_{avg} = 40$ [a, c]	8,500	28,500	400	0.046	See B & C	
B & C Deep	Remove Th-230 > 40	11,100	35,100	490	0.056	21	6E-06
B & C Deep	$Th\text{-}230_{avg} = 40$ [a, c]	11,100	35,100	490	0.056	21	6E-06

[a] Conservatively assumes same surface area and volume as remove Th-230 > 40 scenario
[b] Only baseline data used to be conservative
[c] Conservatively assumes excavation doses and risks are the same as for remove Th-230 > 40 scenario

Protection Agency (EPA) 1990] for the commercial or industrial worker, and left at 12,300 for the recreational scenario. Incidental soil ingestion was set to 36.5 g/year (100 mg/day) (EPA 1991) for recreational use. Soil ingestion was reduced to 18.25 g/year (50 mg/day) (EPA 1991) for the commercial or industrial worker. All other parameters were left the same as for the remedial worker.

2.2.4 Cover Depth

The depth of material overlying areas of elevated radioactivity is one of the most important factors affecting dose and the associated radiological risk. Soil cover intercepts all pathways to potential receptors except gamma and radon, absorbs a portion of the gamma emissions, and delays radon release allowing attrition of the radon concentration through radioactive decay.

Figure 3 illustrates how dose decreases with depth of cover for cover depths of 20 cm (8 in), 30 cm (12 in), and 45 cm (18 in). For assessment purposes, all of Area A is assumed to be uncovered. However, historical information has indicated that subsequent to the placement of the contaminated materials in Areas B and C, up to 12 m (40 ft) of refuse was placed over the contamination. From beneath this depth of cover, the radioactive materials would have negligible effect on human health or the environment. However, computer modeling and additional characterization in December 1998 have suggested that some of this material (in Area C) may be near the side of the landfill. Thus, this material may not have a full 12 m of cover, although the 1998 data found there was at least 2 feet of cover.

The following is an evaluation of the impacts erosion to the initial cover depth would have on dose/risk to an industrial worker. The RESRAD code was used to complete the evaluation using the "Area A (No Action)" source term from Table 1, the "Area C Upper 4 ft (Remove upper 4 ft)" source term in Table 2, and the "Area A All Depths (Remove upper 4 ft)" source term from Table 3. The conservative RESRAD default erosion rate of 0.001 m/yr was used assuming the area is allowed to erode for 1000 year (1 meter erodes). Initial cover depths were varied from 1.0 m to 1.381 m to target a range of 1,000-year cover depths, but all other parameters from Tables 4 and 5 were used as shown. The resulting doses/risks using the range of cover depths are listed in Table 7. The results indicate that very little cover is required to produce dramatic reductions in residual dose/risk. Immediate reductions are observed even with very small cover depths due to the partial or complete elimination of the soil ingestion and dust inhalation pathways. Additional reductions in dose/risk are observed with increasing depth as the cover acts as a shield against penetrating gamma radiation. Results indicate that 0.305 m (12 inches) of residual cover or more would effectively reduce the residual dose to near 1 mrem/yr or less and residual risks to near 10^{-5} or less, especially considering that a conservative erosion rate of 0.001 m/yr was used. Results also indicate that a minimum initial cover depth of approximately 1.22 m (4 ft) would be necessary to achieve the CERCLA risk objectives if no material is removed. The initial cover depth would need to be approximately 1.22 m (4 ft) at a minimum to achieve the risk objectives if the upper 1.22 m (4 ft) of material is removed.

2.3 RESULTS

The doses and associated incremental lifetime cancer risks following implementation of the considered alternatives are shown in Table 8 and are discussed in detail in the following sections. Both the dose and cancer risks from the radioactive materials were calculated by the RESRAD computer software.

2.3.1 Area A

2.3.1.1 No Action

For the No Action Alternative, the doses to the recreational user and industrial worker were predicted to be 12 and 110 mrem/yr, respectively. The doses reported for future use scenarios are the highest predicted doses in the 1,000-year period evaluated. The most significant pathway was gamma from Ra-226 derived from decay of current concentrations of Th-230. Incremental lifetime cancer risk associated with these exposure levels are estimated at 2×10^{-3} for the industrial worker and 6×10^{-5} for a recreational user.

Figure 3. Sensitivity Analysis on Cover Depth

Dose (mrem/yr)

Cover Depth: M M M

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Table 7. Dose and Risk Verses Cover Depth

Initial Cover Depth [meters and (feet)]	Remaining Cover after 1,000 Years [meters and (inches)] [a]	Approximate Dose (mrem/year) [b]	Approximate Risk ($lifetime^{-1}$) [c]
Area A Baseline Source Term			
1.0 m (3.28 ft)	0.0 m (0.0 in)	110	2×10^{-3}
1.0763 m (3.53 ft)	0.0763 m (3.0 in)	42	7×10^{-4}
1.153 m (3.78 ft)	0.153 m (6.0 in)	16	3×10^{-4}
1.228 m (4.03 ft)	0.228 m (9.0 in)	6.3	1×10^{-4}
1.305 m (4.28 ft)	0.305 m (12 in)	2.4	4×10^{-5}
1.381 m (4.53 ft)	0.381 m (15 in)	0.93	2×10^{-5}
Area A Remove Top 4 ft			
1.0 m (3.28 ft)	0.0 m (0.0 in)	29	4×10^{-4}
1.0763 m (3.53 ft)	0.0763 m (3.0 in)	10	2×10^{-4}
1.153 m (3.78 ft)	0.153 m (6.0 in)	3.9	7×10^{-5}
1.228 m (4.03 ft)	0.228 m (9.0 in)	1.5	3×10^{-5}
1.305 m (4.28 ft)	0.305 m (12 in)	0.59	1×10^{-5}
1.381 m (4.53 ft)	0.381 m (15 in)	0.23	4×10^{-6}
Area C Remove Top 4 ft			
1.0 m (3.28 ft)	0.0 m (0.0 in)	52	7×10^{-4}
1.0763 m (3.53 ft)	0.0763 m (3.0 in)	20	3×10^{-4}
1.153 m (3.78 ft)	0.153 m (6.0 in)	6.9	1×10^{-4}
1.228 m (4.03 ft)	0.228 m (9.0 in)	2.7	4×10^{-5}
1.305 m (4.28 ft)	0.305 m (12 in)	1.0	2×10^{-5}
1.381 m (4.53 ft)	0.381 m (15 in)	0.40	7×10^{-6}

[a] Assumes an erosion rate of 0.001 m/yr.
[b] Two significant digits shown. All doses are from year 1,000 – the year of maximum exposure.
[c] One significant digit shown. All doses are from year 1,000 – the year of maximum exposure.

Table 8. Dose and Radiological Risk Estimates Summary

Alternative		Remediation Worker		Recreational User		Industrial/Commercial	
		Dose (mrem/yr)	Risk	Dose (mrem/yr)	Risk	Dose (mrem/yr)	Risk
No Action (No Cover)	A	NA	NA	12	6E-5	110	2E-3
	B	NA	NA	< 1	7E-7	2.0	2E-5
	C	NA	NA	< 1	2E-6	4.6	6E-5
Cover, No Removal	A	12	4E-6	< 1	< 1E-7	< 1	< 1E-7
	B	< 1	< 1E-7	< 1	< 1E-7	< 1	< 1E-7
	C	< 1	< 1E-7	< 1	< 1E-7	< 1	< 1E-7
Area A, Remove to Average of 40 pCi/g, No Cover, No Action B and C	A	27	8E-6	3.4	2E-5	33	5E-4
	B	NA	NA	< 1	7E-7	2.0	2E-5
	C	NA	NA	< 1	2E-6	4.6	6E-5
Area A, Remove to Average of 40 pCi/g, Cover A, No Action B & C	A	34	1E-5	< 1	< 1E-7	< 1	< 1E-7
	B	NA	NA	< 1	7E-7	2.0	2E-5
	C	NA	NA	< 1	2E-6	4.6	6E-5
Area A, Remove All Exceeding 40 pCi/g, No Cover, No Action B & C	A	27	8E-6	< 1	3E-6	5.6	8E-5
	B	NA	NA	< 1	7E-7	2.0	2E-5
	C	NA	NA	< 1	2E-6	4.6	6E-5
Area A, Remove All Exceeding 40 pCi/g, Cover A, No Action B & C	A	28	8E-6	< 1	< 1E-7	< 1	< 1E-7
	B	NA	NA	< 1	7E-7	2.0	2E-5
	C	NA	NA	< 1	2E-6	4.6	6E-5
Remove Top 4-ft from A, B and C, No Cover	A	18	5E-6	3.0	1E-5	29	4E-4
	B	NA	NA	< 1	7E-7	2.0	2E-5
	C	<1	1E-7	5.4	3E-5	52	7E-4
Remove Top 4-ft from A, B and C, Cover	A	21	6E-6	< 1	< 1E-7	< 1	< 1E-7
	B	< 1	< 1 E-7	< 1	< 1E-7	< 1	< 1E-7
	C	2.0	3E-7	< 1	< 1E-7	< 1	< 1E-7
Remove All Areas to Average of 40 pCi/g, No Cover	A	27	8E-6	3.4	2E-5	33	5E-4
	B	21	6E-6	3.2	2E-5	31	4E-4
	C	Included in estimate for Area B					
Remove All Areas to Average of 40 pCi/g, Cover	A	34	1E-5	<1	<1E-7	<1	<1E-7
	B	22	6E-6	<1	<1E-7	<1	<1E-7
	C	Included in estimate for Area B					
Remove All Exceeding 40 pCi/g in All Areas, No Cover	A	27	8E-6	< 1	3E-6	5.6	8E-5
	B	21	6E-6	< 1	4E-6	7.7	1E-4
	C	Included in estimate for Area B					
Remove All Exceeding 40 pCi/g in All Areas, Cover	A	28	8E-6	< 1	< 1E-7	< 1	< 1E-7
	B	22	6E-6	< 1	< 1E-7	< 1	< 1E-7
	C	Included in estimate for Area B					

2.3.1.2 Landfill Closure

Doses and associated radiological risks for the remedial workers are reported for current year evaluations. The worker constructing the lower filter layer in Area A was estimated to receive a dose of 12 mrem due primarily to dust inhalation during the project. This is a dose that occurs only during landfill closure and is not a recurrent yearly dose. The exposure would increase the worker's likelihood of contracting cancer over the course of a lifetime by 4×10^{-6}. Due to the large reduction in dose resulting from the installation of the first foot of cover, subsequent layers of the landfill cover following the second layer were not modeled. If the landfill were closed following partial removal (top 4 feet of material), then the dose would be reduced to only about 3 mrem.

RESRAD estimated negligible doses and associated radiological risks to an industrial worker or recreational user on top of the closed landfill.

2.3.1.3 Excavation

The total dose to the remedial worker excavating Area A (not including backfill) was predicted to be 27 mrem when removing soils to an average of 40 pCi/g Th-230 or when removing all soils exceeding 40 pCi/g Th-230. The dose estimate is 18 mrem for the partial excavation alternative. The dominant radionuclides contributing to the dose were Ra-226 and Ac-227. The remedial worker's incremental lifetime cancer risk was estimated at 8×10^{-6} for either removal to an average of 40 pCi/g Th-230 or removal of all soils exceeding 40 pCi/g, or 5×10^{-6} for excavation of the top four feet.

If the landfill is closed following excavation of radiological materials, the doses and risks to industrial workers or recreational users are negligible for any of the modeled residual concentrations. If Area A is not covered, the doses and radiological risks to the industrial worker were predicted to be 33 mrem/yr (5×10^{-4} radiological risk) when soils are removed to an average of 40 pCi/g, 29 mrem/yr (4×10^{-4} radiological risk) under the partial excavation alternative, and 5.6 mrem/yr (8×10^{-5} radiological risk) when all soils exceeding 40 pCi/g are removed. Corresponding recreational doses and risks are an order of magnitude lower than the industrial results.

2.3.2 Areas B and C

2.3.2.1 No Action

Doses and radiological cancer risk to the recreational user were predicted to be negligible in Area B. In Area C, the radiological risk was estimated at 2×10^{-6}, at the lower end of the CERCLA target risk range. For the industrial use scenario, the predicted doses were 2.0 mrem/yr in Area B and 4.6 mrem/yr in Area C. The radiological risk associated with these low doses is in the 10^{-5} range, which is the midpoint of the CERCLA target risk range. The low doses and risks in Areas B and C are due to the deep fill in these areas and lack of significant contamination in surface soils.

2.3.2.2 Landfill Closure

Doses and risks to industrial workers or recreational users after landfill closure were predicted to be negligible for all potential receptors due to the deep cover in these areas. The maximum remediation worker dose under any landfill closure scenario is 1.2 mrem/yr. The maximum remediation worker risk is on the order of 10^{-7}, or below the CERCLA target risk range.

2.3.2.3 Excavation

The total dose and associated radiological risk to the remedial worker excavating Areas B and C is predicted to be 21 mrem and 6×10^{-6} increased cancer risk when soils are removed to an average of 40 pCi/g or when all soils exceeding 40 pCi/g are removed. The dose is estimated to be less than 1 mrem (1×10^{-7} cancer risk) for partial excavation of Areas B and C. The low dose and cancer risk for partial excavation is due to the protection provided by the deep fill in these areas and lack of significant volumes of contamination in surface soils. Following excavation using 40 pCi/g as the average Th-230 residual concentration, the doses to an industrial worker assuming no cover is 31 mrem/yr (4×10^{-4} cancer risk) or 7.7 mrem/yr (1×10^{-4} cancer risk) for when all soils exceeding 40 pCi/g are removed. For the recreational scenario, the estimated dose is 3.2 mrem/yr (2×10^{-5} risk) when soils are removed to an average of 40 pCi/g Th-230 or less than 1 mrem/yr (4×10^{-6} cancer risk) for when all soils exceeding 40 pCi/g are removed. With the 1.5 m cover in place, the dose is reduced to < 1 mrem/yr and the associated radiological risk is reduced to $<10^{-7}$ for either approach.

Following partial excavation (top 4 feet) and no cover, the doses and associated cancer risk to the future recreational and industrial/commercial users in Area C are 5.4 mrem/yr (3×10^{-5} cancer risk) and 52 mrem/yr (7×10^{-4} cancer risk), respectively. With the 1.5-m cover, however, these doses and associated radiological risks drop to <1 mrem/yr ($<10^{-7}$ cancer risk) for both future uses.

2.3.3 Radon

Radon concentration and flux were estimated using the RESRAD code. Radon-related RESRAD default parameters values were used except slab-on-grade construction and one exchange per hour was assumed. Both no erosion and the RESRAD erosion rate of 0.001 m/yr was assumed when considering cover depths. Lastly, a range of cover depths was considered to evaluate the impacts of cover on radon concentration and flux results.

Predicted radon concentrations for years 0.0 and 1000 are shown in Table 9 for various alternatives. Doses and radiological risks from radon inhalation are normally reported separately from other pathways and not summed into the total. This is because significant exposures do not occur except inside buildings and the concentration inside buildings is highly variable depending upon how well the building floor is sealed, how well the building is ventilated, and the permeability of the soil underlying the building. Engineering controls can be used to remove radon from buildings or to reduce infiltration of radon into buildings. The predicted radon concentrations presented in Table 9 include the sum of Rn-220 and Rn-222. To calculate predicted radon concentrations following removal to an average of 40 pCi/g, the scaling factors (6.45 for Area A and 4.17 for

Table 9. Results of Radon Evaluation for the Seaway Site

			Indoor Radon pCi/L		Indoor Radon WL		Outdoor Radon Flux pCi/m²/s	
			Year 0	Year 1000	Year 0	Year 1000	Year 0	Year 1000
Scenario	**Area**	**Radon**			**No Cover**			
No Action	A	Rn-222	1.73	**11.87**	0.009	**0.063**	6.5	**44.8**
		Rn-220	0.01	0.01	0	0	60.5	58.8
		Total	1.74	11.88	0.009	0.063	67	103.6
	B	Rn-222	0.05	0.17	0	0.001	0.2	0.6
		Rn-220	0.01	0.01	0	0	42.7	41.5
		Total	0.06	0.18	0	0.001	42.9	42.1
	C	Rn-222	0.06	0.55	0	0.003	0.2	2.1
		Rn-220	0.01	0.01	0	0	33.1	32.2
		Total	0.07	0.56	0	0.003	33.3	34.3
Remove Top 4 ft	A	Rn-222	0.83	2.81	0.004	0.015	3.1	10.6
		Rn-220	0.02	0.02	0	0	74.7	72.6
		Total	0.85	2.83	0.004	0.015	77.8	83.2
	B	Rn-222	0.05	0.17	0	0.001	0.2	0.6
		Rn-220	0.01	0.01	0	0	42.7	41.5
		Total	0.06	0.18	0	0.001	42.9	42.1
	C	Rn-222	0.43	**5.26**	0.002	**0.028**	1.6	19.8
		Rn-220	0.01	0.01	0	0	39.1	38
		Total	0.44	5.27	0.002	0.028	40.7	57.8
Remove > 40 pCi/g	A	Rn-222	0.30	0.70	0.002	0.004	1.10	2.6
		Rn-220	0.01	0.01	0	0	49.8	48.4
		Total	0.31	0.71	0.002	0.004	50.9	51
	B	Rn-222	0.32	0.94	0.002	0.005	1.2	3.5
		Rn-220	0	0	0	0	0	0
		Total	0.32	0.94	0.002	0.005	1.2	3.5
	C	Rn-222	0.32	0.94	0.002	0.005	1.2	3.5
		Rn-220	0	0	0	0	0	0
		Total	0.32	0.94	0.002	0.005	1.2	3.5
Average = 40 pCi/g	A	Rn-222	0.73	3.22	0.004	0.017	2.7	12.2
		Rn-220	0.01	0.01	0	0	49.8	48.4
		Total	0.74	3.23	0.004	0.017	52.5	60.6
	B	Rn-222	0.63	3.16	0.003	0.017	2.4	11.9
		Rn-220	0	0	0	0	0	0
		Total	0.63	3.16	0.003	0.017	2.4	11.9
	C	Rn-222	0.63	3.16	0.003	0.017	2.4	11.9
		Rn-220	0	0	0	0	0	0
		Total	0.63	3.16	0.003	0.017	2.4	11.9
Scenario	**Area**	**Radon**			**0.3 m (1 ft) Cover**			
No Action	A	Rn-222	1.29	**8.81**	0.007	**0.046**	4.7	**32.3**
		Rn-220	0	0	0	0	0	0
		Total	1.29	8.81	0.007	0.046	4.7	32.3
	B	Rn-222	0.03	0.13	0	0.001	0.1	0.5
		Rn-220	0	0	0	0	0	0
		Total	0.03	0.13	0	0.001	0.1	0.5
	C	Rn-222	0.04	0.41	0	0.002	0.1	1.5
		Rn-220	0	0	0	0	0	0
		Total	0.04	0.41	0	0.002	0.1	1.5

Note: Values listed as "0" may be << limit (e.g., 0.00001 WL presented as 0)
Estimates exceeding the Rn-222 limits of 4 pCi/L, 0.02 WL, and 20 pCi/m²/s are bolded.
Initial cover depth of 1.7 m would limit worst case flux in a 1,000-year period to no more than 20 pCi/m²/s assuming a 0.001 m/yr erosion rate.

Table 9. Results of Radon Evaluation for the Seaway Site (continued)

			Indoor Radon pCi/L		Indoor Radon WL		Outdoor Radon Flux pCi/m²/s	
			Year 0	**Year 1000**	**Year 0**	**Year 1000**	**Year 0**	**Year 1000**
Remove Top 4 ft	A	Rn-222	0.61	2.09	0.003	0.011	2.2	7.7
		Rn-220	0	0	0	0	0	0
		Total	0.61	2.09	0.003	0.011	2.2	7.7
	B	Rn-222	0.03	0.13	0	0.001	0.1	0.5
		Rn-220	0	0	0	0	0	0
		Total	0.03	0.13	0	0.001	0.1	0.5
	C	Rn-222	0.32	3.9	0.002	**0.021**	1.2	14.3
		Rn-220	0	0	0	0	0	0
		Total	0.32	3.9	0.002	0.021	1.2	14.3
Remove > 40 pCi/g	A	Rn-222	0.22	0.52	0.001	0.003	0.8	1.9
		Rn-220	0	0	0	0	0	0
		Total	0.22	0.52	0.001	0.003	0.8	1.9
	B	Rn-222	0.23	0.7	0.001	0.004	0.9	2.6
		Rn-220	0	0	0	0	0	0
		Total	0.23	0.7	0.001	0.004	0.9	2.6
	C	Rn-222	0.23	0.7	0.001	0.004	0.9	2.6
		Rn-220	0	0	0	0	0	0
		Total	0.23	0.7	0.001	0.004	0.9	2.6
Average = 40 pCi/g	A	Rn-222	0.54	2.39	0.003	0.013	2.0	8.8
		Rn-220	0	0	0	0	0	0
		Total	0.54	2.39	0.003	0.013	2.0	8.8
	B	Rn-222	0.47	2.35	0.002	0.012	1.7	8.6
		Rn-220	0	0	0	0	0	0
		Total	0.47	2.35	0.002	0.012	1.7	8.6
	C	Rn-222	0.47	2.35	0.002	0.012	1.7	8.6
		Rn-220	0	0	0	0	0	0
		Total	0.47	2.35	0.002	0.012	1.7	8.6
Scenario	**Area**	**Radon**			**1.5 m (5 ft) Cover**			
No Action	A	Rn-222	0.38	2.61	0.002	0.014	1.3	9.2
		Rn-220	0	0	0	0	0	0
		Total	0.38	2.61	0.002	0.014	1.3	9.2
	B	Rn-222	0.01	0.04	0	0	0	0.1
		Rn-220	0	0	0	0	0	0
		Total	0.01	0.04	0	0	0	0.1
	C	Rn-222	0.01	0.12	0	0.001	0	0.4
		Rn-220	0	0	0	0	0	0
		Total	0.01	0.12	0	0.001	0	0.4
Remove Top 4 ft	A	Rn-222	0.18	0.62	0.001	0.003	0.6	2.2
		Rn-220	0	0	0	0	0	0
		Total	0.18	0.62	0.001	0.003	0.6	2.2
	B	Rn-222	0.01	0.04	0	0	0	0.1
		Rn-220	0	0	0	0	0	0
		Total	0.01	0.04	0	0	0	0.1
	C	Rn-222	0.1	1.16	0.001	0.006	0.3	4.1
		Rn-220	0	0	0	0	0	0
		Total	0.1	1.16	0.001	0.006	0.3	4.1

Note: Values listed as "0" may be << limit (e.g., 0.00001 WL presented as 0)
Estimates exceeding the Rn-222 limits of 4 pCi/L, 0.02 WL, and 20 pCi/m²/s are bolded.
Initial cover depth of 1.7 m would limit worst case flux in a 1,000-year period to no more than 20 pCi/m²/s assuming a 0.001 m/yr erosion rate.

Table 9. Results of Radon Evaluation for the Seaway Site (continued)

			Indoor Radon pCi/L		Indoor Radon WL		Outdoor Radon Flux pCi/m²/s	
			Year 0	**Year 1000**	**Year 0**	**Year 1000**	**Year 0**	**Year 1000**
Remove > 40 pCi/g	A	Rn-222	0.06	0.15	0	0.001	0.2	0.5
		Rn-220	0	0	0	0	0	0
		Total	0.06	0.15	0	0.001	0.2	0.5
	B	Rn-222	0.07	0.21	0	0.001	0.2	0.7
		Rn-220	0	0	0	0	0	0
		Total	0.07	0.21	0	0.001	0.2	0.7
	C	Rn-222	0.07	0.21	0	0.001	0.2	0.7
		Rn-220	0	0	0	0	0	0
		Total	0.07	0.21	0	0.001	0.2	0.7
Average = 40 pCi/g	A	Rn-222	0.16	0.71	0.001	0.004	0.6	2.5
		Rn-220	0	0	0	0	0	0
		Total	0.16	0.71	0.001	0.004	0.6	2.5
	B	Rn-222	0.14	0.69	0.001	0.004	0.5	2.5
		Rn-220	0	0	0	0	0	0
		Total	0.14	0.69	0.001	0.004	0.5	2.5
	C	Rn-222	0.14	0.69	0.001	0.004	0.5	2.5
		Rn-220	0	0	0	0	0	0
		Total	0.14	0.69	0.001	0.004	0.5	2.5

Note: Values listed as "0" may be << limit (e.g., 0.00001 WL presented as 0)
Estimates exceeding the Rn-222 limits of 4 pCi/L, 0.02 WL, and 20 pCi/m^2/s are bolded.
Initial cover depth of 1.7 m would limit worst case flux in a 1,000-year period to no more than 20 pCi/m2/s assuming a 0.001 m/yr erosion rate.

Areas B and C) were applied to the Rn-222 concentrations calculated for removal of everything exceeding 40 pCi/g and summed with the Rn-220 concentrations. The factors are not used for Rn-220 because Th-232 (parent of Rn-220) is very close to background concentrations following remediation and applying the factors would multiply the Rn-220 due primarily to background Th-232.

Radon concentration limits used in this assessment are taken from the Uranium Mill Tailings Radiation Control Act. Subpart A of the mill tailings regulations prescribe that controls shall be designed to provide reasonable assurance that releases of Rn-222 from residual radioactive material to the atmosphere will not exceed an average release rate of 20 pCi/m^2/s. In addition, remedial actions shall make a reasonable effort to achieve an annual average radon decay product concentration (including background) not to exceed 0.02 working levels (WL) in any habitable building and in any case shall not exceed 0.03 WL. As shown in Table 9, only the no action scenarios fail to meet the Rn-222 flux standards for Seaway Area A. Indoor concentrations exceed 0.02 WL in the very long term (within 1,000 years) for only a few alternatives as indicated in Table 9.

Estimates of outdoor radon flux for 30 years and 100 years are shown in Table 10 for use in assessing potential radon flux in landfill gas. It was also estimated that an initial cover of 1.7 m (approximately 5.5 ft) would limit radon flux to no more than 20 pCi/m^2/s over the 1,000-year period even using the conservative RESRAD default erosion rate of 0.001 m/yr. In other words, radon flux estimates are modeled to be below 20 pCi/m^2/s in Areas A, B, and C as long as at least 0.7 m (2.3 ft) of cover is in place throughout the 1,000-year period.

Table 10. Years 30 and 100 Outdoor Radon Flux Estimates

	Outdoor Radon Flux (pCi/m^2/s)*					
	Year 30	**Year 100**	**Year 30**	**Year 100**	**Year 30**	**Year 100**
	No Cover		**1 ft (0.3 m) Cover**		**5 ft (1.5 m) Cover**	
No Action Area A						
Rn-222 Total	8.0	11.3	5.8	8.1	1.6	2.3
Rn-220 Total	60.4	60.3	0.0	0.0	0.0	0.0
No Action Area B						
Rn-222 Total	0.2	0.2	0.1	0.2	0.0	0.0
Rn-220 Total	42.6	42.6	0.0	0.0	0.0	0.0
No Action Area C						
Rn-222 Total	0.3	0.4	0.2	0.3	0.1	0.1
Rn-220 Total	33.1	33.0	0.0	0.0	0.0	0.0
Remove to 4 ft Area A						
Rn-222 Total	3.4	4.0	2.5	2.9	0.7	0.8
Rn-220 Total	74.6	74.5	0.0	0.0	0.0	0.0
Remove to 4 feet Area B						
Rn-222 Total	0.2	0.2	0.1	0.2	0.0	0.0
Rn-220 Total	42.6	42.6	0.0	0.0	0.0	0.0
Remove to 4 feet Area C						
Rn-222 Total	2.3	3.9	1.7	2.8	0.5	0.8
Rn-220 Total	39.1	39.0	0.0	0.0	0.0	0.0

* Initial cover depth of 1.7 m would limit worst case flux in a 1,000-year period to no more than 20 pCi/m^2/s assuming a 0.001 m/yr erosion rate.

3. UNCERTAINTIES

3.1 PARAMETER ASSUMPTIONS

Exposure parameters were selected to provide a conservative, yet reasonable, estimate of potential radiological dose and risk to each receptor. Site-specific data were used, when 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 dose and radiological risk with preferential use of parameter values from the Baseline Risk Assessment or standard default values recommended by EPA or other authorities. Sources of parameter values were given in Tables 4 and 5 when different from RESRAD default values. Exposure scenarios and parameter values have been consistently chosen to provide conservative, yet reasonable, estimates of potential radiation risk in accordance with the principle of keeping radiation exposures "As Low As Reasonably Achievable" (ALARA).

3.2 LIMITATIONS ON AVAILABLE DATA

The primary radionuclide of concern in Tonawanda soils is Th-230. However, early investigations did not include this isotope in the analyses. A review of the database indicated that many samples that excluded Th-230 analysis contain elevated concentrations of Ra-226. It is likely that the Th-230 concentration in these samples is elevated as well, but Th-230 was not quantified. Because Ra-226 is a primary contributor to dose and associated radiological risk, and Th-230 is the parent isotope of Ra-226, Th-230 must somehow be accounted for in order to predict future radiological risk. The ratio of Th-230 to Ra-226 should be the same in Areas B and C as in Area A due to the common source of radioactive materials. Therefore, the source term for Ra-226 in Areas B and C was multiplied by the Th-230:Ra-226 ratio in Area A to obtain a source term for Th-230 in Areas B and C. This factor was found to be 20.188 through linear regression forced through the point (0,0). Other means of finding surrogate data for the Th-230 such as inclusion of data from Ashland 1 as well as Area A generally yield factors for Th-230: Ra-226 from 10 to 20. Although there is high uncertainty associated with this value, the results are within the range of other MED waste sites within the Tonawanda area and comparable to other areas where uranium was extracted from ore. The r^2 value for the regression was 0.77. The 95% confidence limits of the slope are 18.4046 and 21.9717. These statistics suggest that the calculated value of the slope provides a good fit with the data.

Similarly, no Ac-227 data was available for Seaway in the early data sets. Ac-227 can be a significant contributor to dose and associated radiological risk, especially through the inhalation pathway. To account for Ac-227, a regression analysis was performed on Ashland 1 data and the results were applied to the Seaway data set. The regression line was forced through (0,0) to avoid negative values for Ac-227 at low values of Ra-226. One outlier data point was rejected as probably not being representative of the data set changing the coefficient from 1.8 to 1.02. This was based on both a standard outlier test (Younger 1985) and experience at similar sites where Ac-227 has been found to be approximately equal to Ra-226. Limited Ac-227 data was obtained in the limited surface characterization efforts of Areas B and C in 1998 (USACE 1999a). This data was used in the scenarios involving the upper 4 feet of Areas B and C. The regression analysis results were used for all other scenarios.

3.3 VOLUME

Volume estimates are used to calculate the exposure duration of the remedial worker. The thickness of the contamination does not have a large impact on dose below about 15 cm for the pathways analyzed in this assessment, therefore the thickness was left at the default value of 2 m. Volume estimates for Seaway were developed based on historical data and recent sampling activities (USACE 1999b). These volumes were used for establishing the exposure durations in this assessment.

3.4 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 pathway, so reduction in groundwater concentration as a result of using clay values does not understate risk.)

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ATTACHMENT

REGRESSION ANALYSIS FOR RA-226 VS. AC-227 CONCENTRATIONS

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Estimation of Ac-227 Based on Ra-226 on the Tonawanda Site

RA226 data from sum file for checking program

Descriptive Statistics

Variables	Sum	Mean	Uncorrected SS	Variance	Std Dev
INTERCEP	90	1	90	0	0
RA226	3668.5	40.761111111	467334.83	3570.8167853	59.756311677
AC227	4027.4	44.748888889	668855.1	5490.263201	74.096310306

Results less than the detection limit were set to 1/2 the reported detection limit except for radioisotopes.
Dist. Codes: L-distribution most similar to lognormal. (Land statistic used for UCL.)
N-distribution most similar to normal. (t-distribution used for UCL.)
X-distribution significantly different from normal and lognormal.
(t-distribution used for UCL.)
D-distribution not determined because fewer than 5 detects or less than
50% detects.(t-dist)
Z-distribution with negative results and therefore treated as normal.
Generated by program tonest01 on 24OCT96 at 17:33 using dataset tonrad10.

Estimation of Ac-227 Based on Ra-226 on the Tonawanda Site

RA226 data from sum file for checking program

Model: MODEL1
NOTE: No intercept in model. R-square is redefined.
Dependent Variable: AC227

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	486392.08896	486392.08896	237.248	0.0001
Error	89	182463.01104	2050.14619		
U Total	90	668855.10000			

Root MSE	45.27854	R-square	0.7272
Dep Mean	44.74889	Adj R-sq	0.7241
C.V.	101.18361		

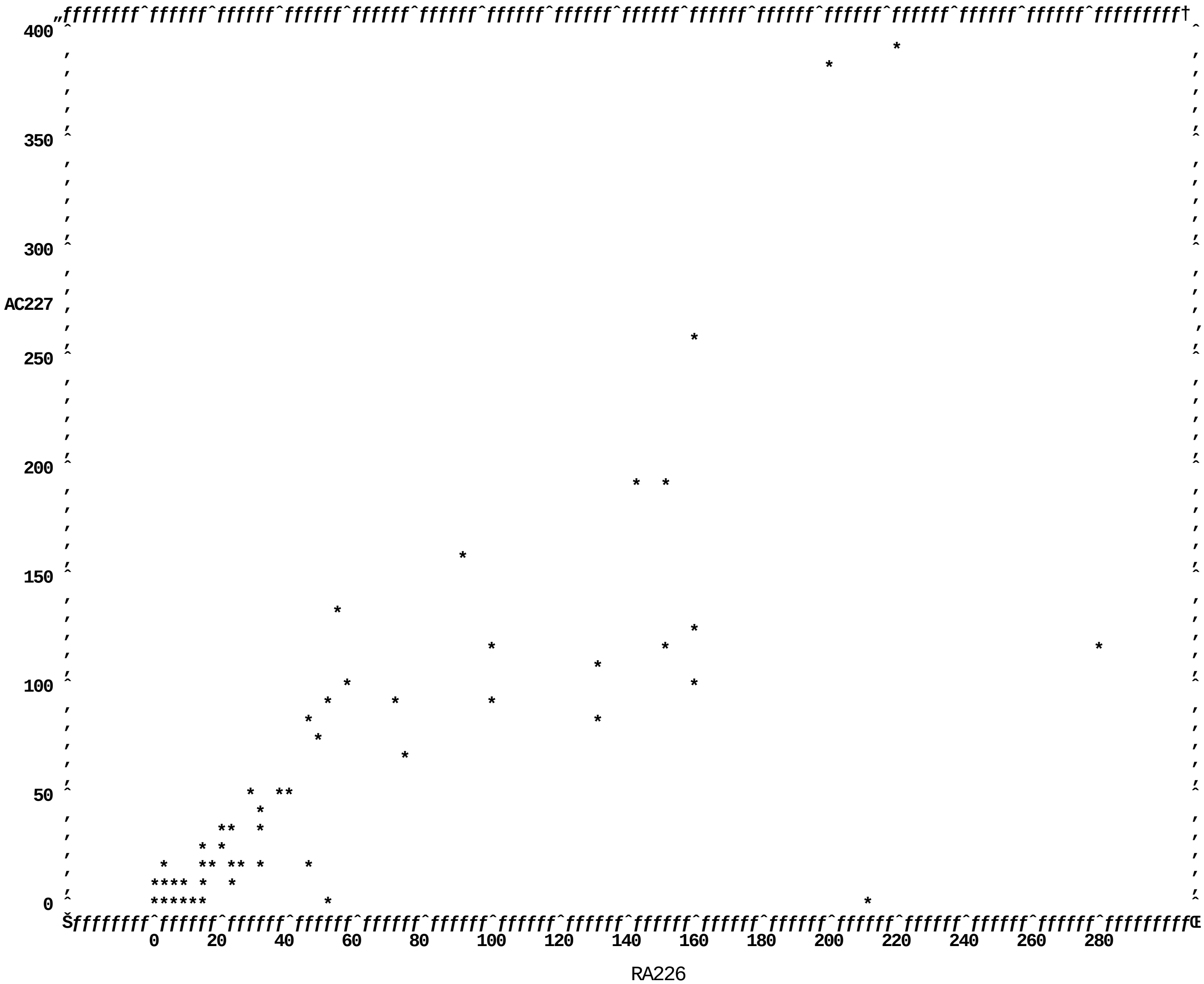
Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
RA226	1	1.020186	0.06623360	15.403	0.0001

Results less than the detection limit were set to 1/2 the reported detection limit except for radioisotopes.
Dist. Codes: L-distribution most similar to lognormal. (Land statistic used for UCL.)
N-distribution most similar to normal. (t-distribution used for UCL.)
X-distribution significantly different from normal and lognormal.
(t-distribution used for UCL.)
D-distribution not determined because fewer than 5 detects or less than 50% detects.(t-dist)
Z-distribution with negative results and therefore treated as normal.
Generated by program tonest01 on 24OCT96 at 17:33 using dataset tonrad10.

Estimation of Ac-227 Based on Ra-226 on the Tonawanda Site

RA226 data from sum file for checking program



Results less than the detection limit were set to 1/2 the reported detection limit except for radioisotopes.

Dist. Codes:
- L-distribution most similar to lognormal. (Land statistic used for UCL.)
- N-distribution most similar to normal. (t-distribution used for UCL.)
- X-distribution significantly different from normal and lognormal. (t-distribution used for UCL.)
- D-distribution not determined because fewer than 5 detects or less than 50% detects.(t-dist)
- Z-distribution with negative results and therefore treated as normal.

Generated by program tonest01 on 24OCT96 at 17:33 using dataset tonrad10.

Data Set Used to Derive Regression Coefficient for Seaway Actinium

Radium-226	Uranium-238	Actinium-227
55	890	130
1.2	2.9	0.5
1.3	ND	1.5
280	2100	120
100	710	120
50	150	0.5
5.0	20	1.7
210	ND	0.1
530	2900	1500
3.6	40	3.5
1.0	26	0.4
1.5	2.6	0.6
1.9	ND	2.3
6.5	28	11
220	1100	390
160	820	260
13	ND	0.2
1.2	13	0.6
1.5	4.4	2.3
4.5	ND	0.1
19	58	30
23	85	33
3.9	6.5	4.2
30	170	45
90	370	160
29	170	52
23	7.3	31
45	150	87
9	370	120
2.6	6.5	2.4
73	510	66
100	550	91
29	68	49
37	70	50
9.0	21	3.4
71	210	92
143	230	190
2.0	11	1.3
2.3	ND	4.5
24	32	20
160	200	122
31	81	31
160	200	100
130	210	81
58	290	100
1.3	6.7	0.7
1.4	8.1	0.5
52	120	94
21	ND	31
7.0	32	11

Data Set Used to Derive Regression Coefficient for Seaway Actinium (continued)

Radium-226	Uranium-238	Actinium-227
92	330	160
13	ND	16
1.1	ND	1.7
1.1	3.4	2.0
150	960	190
20	580	25
200	ND	380
48	90	77
14	39	16
2.6	6.0	1.4
4.5	ND	2.6
130	4300	110
31	1300	18
26	560	19
5.6	18	4.0
5.6	11	4.5
15	48	23
7.3	27	5.4
47	ND	13
13	9.7	4.2
12	6.1	2.2
1.8	4.6	0.8
3.5	ND	1.9
1.8	ND	17
39	ND	47
23	110	33
36	750	47
18	820	18
13	840	13
5.3	60	3.9
1.1	2.5	0.8
1.5	2.6	0.7
1.6	1.5	3.8
6.1	58	1.9
1.0	ND	0.1
22	150	7.9
1.9	25	0.4
1.2	ND	0.4

ND = Not Determined

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