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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

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ACRONYMS AND ABBREVIATIONS

Ac	Actinium
BFI	Browning-Ferris Industries
cm	Centimeter(s)
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	Department of Energy
EPA	Environmental Protection Agency
FBDU	Ford, Bacon, and Davis of Utah
FUSRAP	Formerly Utilized Sites Remedial Action Program
ft	Foot (feet)
g	Gram(s)
ICRP	International Commission on Radiological Protection
m	Meter(s)
µg	Microgram(s)
mg	Milligram(s)
mrem	Millirem(s)
NCRP	National Council on Radiation Protection and Measurements
NYSDEC	New York State Department of Environmental Conservation
Pa	Protactinium
pCi	Pico Curie(s)
PPE	Personal protective equipment
Ra	Radium
RESRAD	Residual radioactivity
RI	Remedial investigation
RME	Reasonable maximum-exposure
Rn	Radon
Th	Thorium
U	Uranium
UCL_{95}	Upper 95% confidence level
WL	Working level
yd	Yard(s)

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1. INTRODUCTION

In 1974, the Atomic Energy Commission, a predecessor to the U.S. Department of Energy (DOE), instituted the Formerly Utilized Sites Remedial Action Program (FUSRAP). 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 dose due to residual radioactivity within the Seaway Industrial Park landfill following implementation of alternatives considered for remediation.

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 I). 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 covers approximately 4 hectares (10 acres) and Areas B and C combined cover approximately 0.8 hectares (2 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. Only about 40% of Area A has been covered, because 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 Ashland.

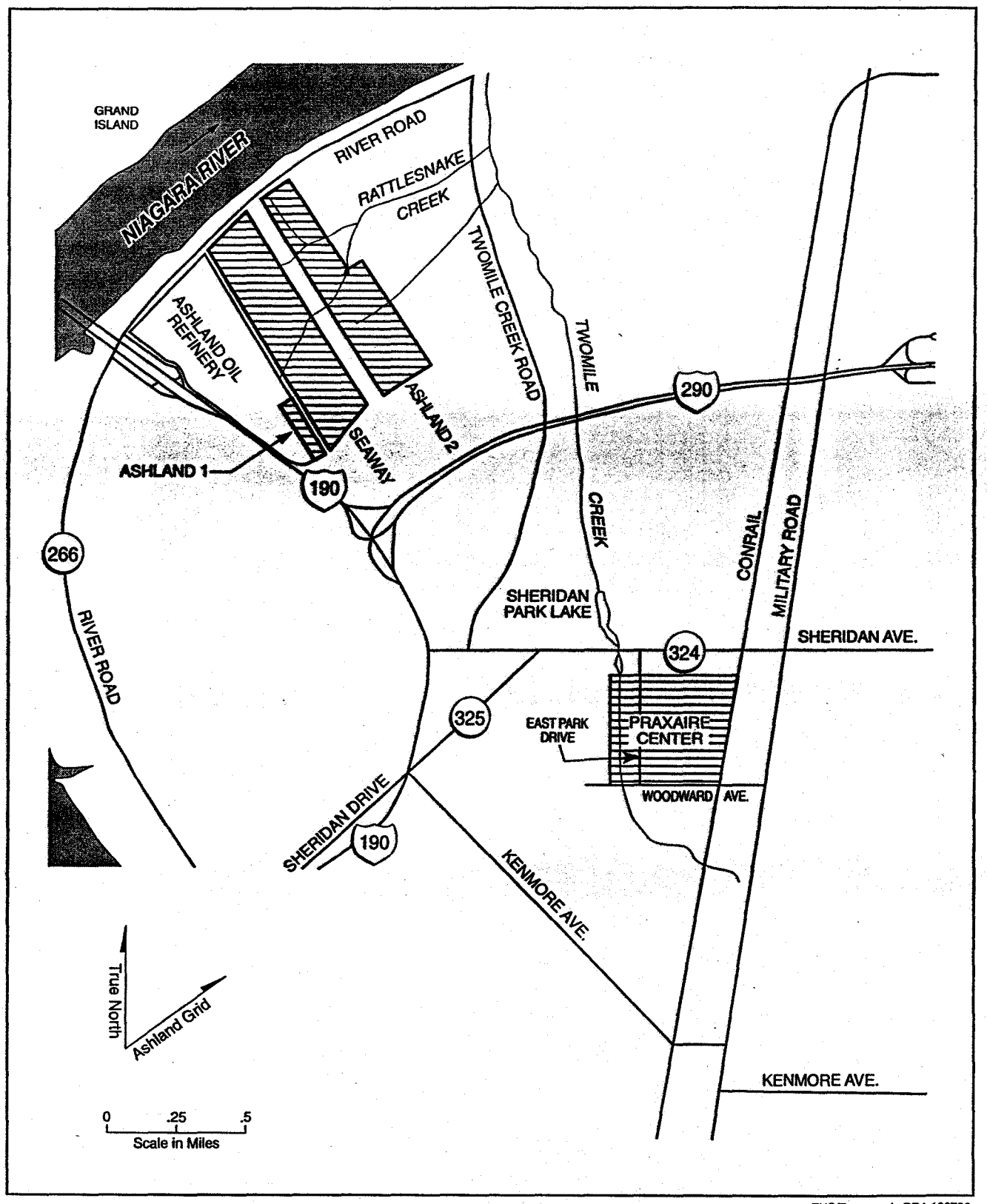

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Figure 1 Tonawanda Sites

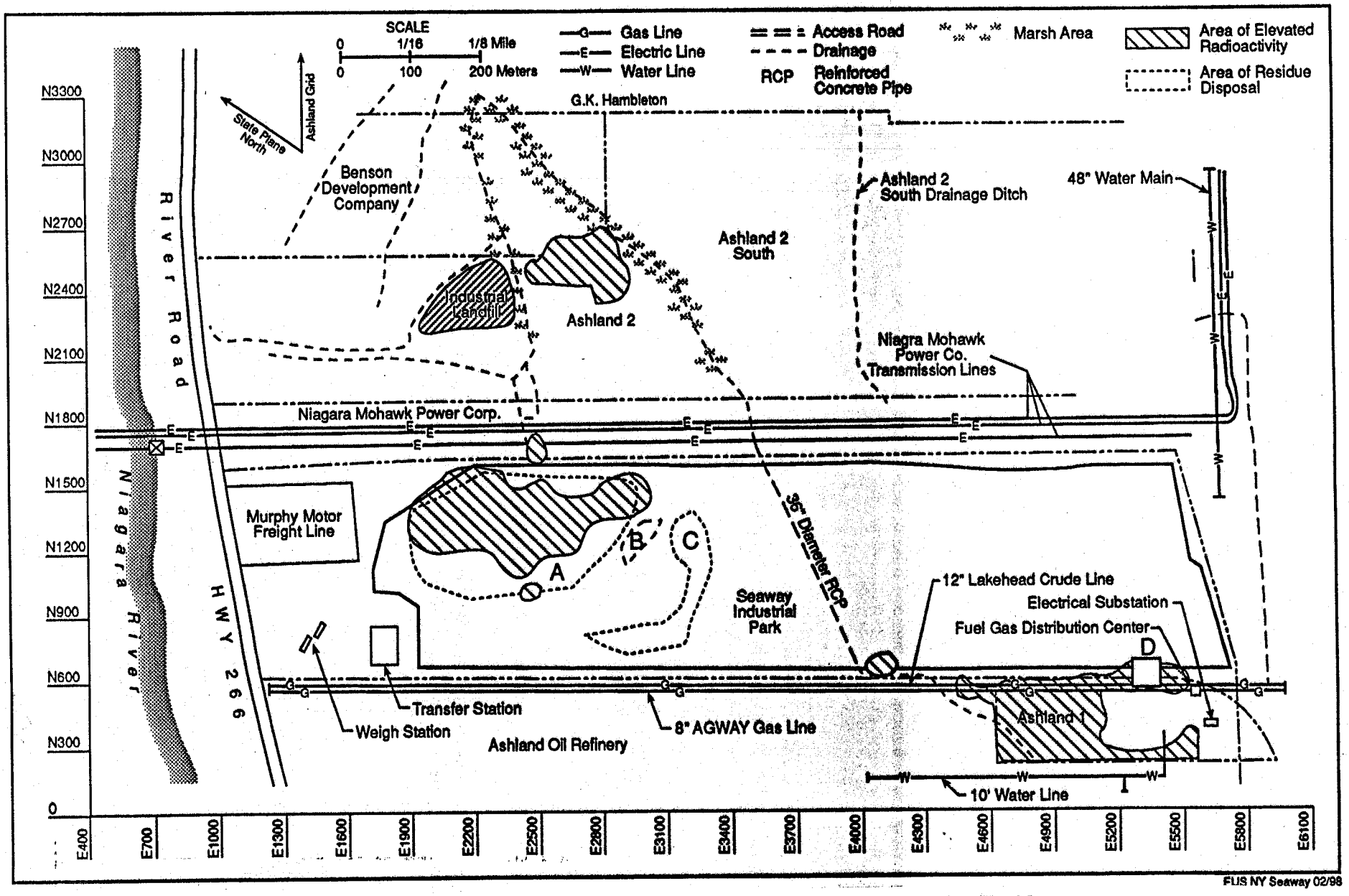

Figure 2. Areas Within Seaway Industrial Park Containing Radioactive Residues

1.2 SCOPE

The scope of this assessment includes evaluation of potential doses from Area A, and Areas B and C combined. Areas B and C were combined because their depositional history is similar, their current status (buried beneath fill) is the same, and Area B is very small relative to the other sites. Scenarios for these areas were constructed based on the remedial alternatives and potential future uses. Remedial worker scenarios were evaluated to establish short term effects of the remediation. Recreational and commercial or industrial exposures were evaluated as the most likely future uses consistent with the Town of Tonawanda Waterfront Region Master Plan. A resident living on top of the landfill was also considered as an extreme worst case future use. The remedial alternatives considered include No Action, Cap and Cover with no excavation, excavation of material exceeding 40 pCi/g Th-230 in Area A, and excavation of material exceeding 40 pCi/g Th-230 in Areas A, B, and C. The cap and cover alternative assumes the landfill is closed in concurrence with New York Regulations for an industrial landfill as specified in 6 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 Sections 2 through 3.

2. DOSE 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, and reports the results of the dose assessment. The calculations for the dose assessment were performed using the residual radioactivity (RESRAD) computer software, version 5.621 (Yu, et al. 1993a).

2.1 DATA EVALUATION

Data sets used for the evaluation of reasonable maximum exposure concentrations were taken from three 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 (FBDU) 1981], and the *Remedial Investigation Report for the Tonawanda Site* (DOE 1993a). 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 21 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 they had been covered by the time the RI took place. Consequently, no thorium data is available for Areas B and C. The RI frequently found Th-230 at concentrations 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 natural relative abundance. With no data available for Th-230 in Areas B and C, it was necessary to assume that the ratio of Th-230 to Ra-226 was the same in Areas A, B, and C. This assumption is reasonable because the material in Areas B and C is believed to have originated from the same source as the material in Area A.

An additional inconsistency in analytes was noticed during a review of the Ashland I 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 which is present at an activity of 4.6% of the U-238 activity. The Ashland I data indicated Ac-227 is present at much higher concentrations than would normally be expected. Because the concentrations of Ac-227 at Ashland I were high enough to contribute to dose, and the material at Seaway originated from Ashland I, it was decided the potential presence of Ac-227 could not be neglected even though no 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 I. A regression was performed on the Ashland I 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, it has 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. There was 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 Ac-227 value was 1500 pCi/g and the next highest Ac-227 value was 390 pCi/g). The data point was determined to be an outlier and was rejected. Thus, surrogate values for Ac-227 were generated for the Seaway data set based on the relationship of Ac-227 = 1.02 × Ra-226.

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 will exceed the mean concentration of a randomly drawn set of samples 95% of the time. The UCL_{95} values, after subtracting background, were used as the Reasonable Maximum Exposure (RME) concentrations for the assessment. A surrogate RME 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 (15.6) by the RME value for Ra-226 in Areas B and C. The results of this analysis are presented in Table 1.

Background concentrations were subtracted from the UCL_{95} because radiation protection guidelines 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 1993c). 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 results of this evaluation are presented in Table 1.

Table 1. Statistical Summary of Baseline Data

Analyte	Results > Detection Limit	Minimum	Maximum	Mean	UCL_{95}	RME[a]
			Area A			
Ac-227[b]	NA	0.12	72	7.26	8.41	8.27
Ra-226	214/217	0.12	72	7.26	8.41	7.31
Th-230	103/106	0.7	880	102	131	129.6
Th-232	82/106	0.5	21	1.5	1.83	0.63
U-238	69/146	0.33	63	11.3	12.9	9.8
			Areas B and C			
Ac-227[b]	NA	0.62	92.6	14.5	37.2	37.06
Ra-226	28/28	0.62	92.6	14.5	37.2	36.1
Th-230[c]	NA	NA	NA	NA	NA	562
U-238	15/15	0.77	102	15.1	62.8	59.7

[a] RME = UCL_{95} - background
[b] $^{227}Ac = 1.02^{226}Ra$
[c] ^{230}Th for Areas B and C approximated by taking ratio of ^{230}Th to ^{226}Ra UCL_{95}s in Area A (15.6) and multiplying by ^{226}Ra RME in Areas B and C

To obtain an estimate of residual concentrations following excavation of contaminated materials to the cleanup guideline of 40 pCi/g Th-230, all samples in the data set exceeding 40 pCi/g Th-230 were rejected and the remaining data were aggregated into a new data set. New UCL_{95}s for each isotope were calculated as described above for the baseline data set. The predicted post-remedial concentrations are given in Table 2.

Concentrations of long-lived decay products for which no analytical data were available were set equal to the 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 RME 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 15.6 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.

Table 2. Statistical Summary of Post Remedial Data

Analyte	Results > Detection Limit	Minimum	Maximum	Mean	UCL_{95}	RME[a]
			Area A			
Ac-227[b]	NA	0.12	4.9	1.48	1.67	1.53
Ra-226	109/112	0.12	4.8	1.45	1.64	0.54
Th-230	109/112	0.7	40	12	13.7	12.3
Th-232	57/68	0.5	4.0	1.31	1.48	0.28
U-238	28/92	0.33	19	5.75	6.5	3.4
			Areas B and C			
Ac-227[b]	NA	0.63	2.35	1.25	1.88	1.74
Ra-226	8/2	0.62	2.30	1.22	1.84	0.74
Th-230[c]	NA	NA	NA	NA	NA	27.4
U-238	6/6	0.77	13	3.25	65.6	9.9[d]

[a] RME = UCL_{95} - background
[b] $^{227}Ac = 1.02^{226}Ra$
[c] ^{230}Th for Areas B and C approximated by taking ratio of ^{226}Ra and ^{230}Th UCL_{95}s in Area A and multiplying by ^{226}Ra RME in Areas B and C
[d] Maximum detection used to calculater RME instead of UCL_{95}

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 3 presents the parameter values that are site specific (i.e. that were changed due to site specific characteristics). Table 4 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 uppermost aquifer containing usable quantities of groundwater is unpotable due to a high concentration of sulfate in the water.

Table 3. Site Specific Parameters Changed From RESRAD Version 5.621 Default Values

Parameter	Value A	Value B	Default	Basis
Area of Contaminated Zone, m^2	40,470	8,094	10,000	Actual area reported in the Pathways Analysis Document
Thickness of Contaminated Zone, m	0.58	2.07	2	Volume Divided by Area (A=23,656 m^3, B=16,830 m^3
Contaminated Zone Total Porosity	0.45	0.45	0.4	Baseline Risk Assessment
Contaminated Zone Hydraulic Conductivity, m/yr	123	123	10	Baseline Risk Assessment
Evapotranspiration Coefficient	0.46	0.46	0.5	Baseline Risk Assessment
Precipitation, m/yr	0.96	0.96	1.00	Remedial Investigation
Runoff Coefficient	0.25	0.25	0.2	Baseline Risk Assessment
Accuracy for Water/Soil computations	0	0	0.001	0 specifies 20 term Simpson's Rule instead of Romberg integration
Saturated Zone Total Porosity	0.45	0.45	0.4	Baseline Risk Assessment
Saturated Zone Hydraulic Conductivity, m/yr	123	123	100	Baseline Risk Assessment
Saturated Zone Hydraulic Gradient	0.00045	0.00045	0.02	Remedial Investigation
Water Table Drop Rate, m/yr	0	0	0.001	Little consumptive use of groundwater in the area
Distribution Coefficient Ac, cm^3/g	2400	2400	20	Data Conversion Handbook (DCH) Clay
Distribution Coefficient Pa, cm^3/g	2700	2700	50	DCH Clay
Distribution Coefficient U, cm^3/g	10	10	50	Remedial Investigation
Distribution Coefficients all other isotopes				DCH Clay
Livestock Water Fraction from Groundwater	0	0	1.0	No livestock present at site
Contamination Fraction of Household Water	0	0	1	Groundwater Pathway Suppressed
Depth of Soil Mixing Layer, m	0.05	0.05	0.15	15 cm based on agricultural till depth. 5 cm reasonable for non-agricultural setting, according to Argonne.

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Table 4. Scenario Specific Parameters Changed From RESRAD Version 5.621 Default Values

Parameter	Default	Remedial Worker	Recreation	Resident	Industrial	Basis
Inhalation Rate, m^3/yr	8,400	12,260	12,260	7,300	7,300	Resident, 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	0.0002	0.00018	0.00003	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	30	25	HHEM Reasonable maximum duration for resident and industrial, average duration for a resident at a single location for recreation. Remedial activities completed in less than 1 yr.
Time Fraction Indoors	0.5	0	0	0.62	0.20	EFH. Resident 108 hrs/wk indoors at home 50 wks/yr. Industrial 7 hr/day 250 days/yr. No indoor activities for recreation or construction.
Time Fraction Outdoors	0.25	Calculated	0.011	0.011	0.029	EFH. Resident, Recreation 3 hrs/wk, 50 wks/yr. Industrial 1 hr/day 250 days/yr
Soil Ingestion Rate g/yr	36.5	175.2	36.5	36.5	18.25	HHEM Industrial 50 mg/day in the workplace. 480 mg/day for construction activities
Erosion Rate, m/yr	.003	0	0.00006	0.00006	0	

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 1992

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2.2.1 Landfill Closure

To model the scenario for landfill closure, 6 NYCRR 360-2 was consulted to establish the minimum requirements for landfill closure. Landfill closure requires 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 required 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.

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 dose calculations were 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 dose received during construction of the gas venting layer, taking into consideration the shielding provided by the lower filter layer. The doses were added to give a total dose for the construction of the two layers. Each completed layer was added to the cover thickness for the next calculation until the cover became sufficiently thick that negligible dose was predicted during construction of a layer, or until all the layers had been modeled. The doses from each layer were then summed for a total dose during the project.

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 4-hectare (10 acre) Area A with 0.3 m (1 ft) of soil for the filter layer is

$$\frac{10\ acres \times 43{,}560\ ft^2 \times 1\ ft}{27\ ft^3/yd^3} \times \frac{0.016\ hr/yd^3 + 0.002\ hr/yd^3}{0.91 \times 0.63} = 507\ hrs \qquad (1)$$

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.

Similar calculations for Areas B and C gives

$$\frac{2\ acres \times 43{,}560\ ft^2/acre \times 1\ ft}{27\ ft^3/yd^3} \times \frac{0.016\ hrs/yd^3 + 0.002\ hrs/yd^3}{0.91} = 64 hrs \qquad (2)$$

in which the safety factor was dropped because the fill over the radioactive material eliminates the need for radiation precautions.

These results were used to calculate the onsite time fraction RESRAD variable by dividing the total time required for completion of the layer by the total number of hours in a year, 8,760 hours. The onsite time fraction for Area A is thus 0.058 and is 0.0073 for Areas B and C.

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), and 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.

2.2.2 Excavation

The volumes of soil to be excavated have been estimated at 23,700 m^3 (30,900 yd^3) in Area A and 16,800 m^3 (22,000 yd^3) in Areas B and C combined. 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 remediation for Area A and Areas B and C are

$$\frac{30{,}941\ yd^3 \times 1.2}{125\ yd^3/hr \times 0.91 \times 0.63} = 518\ hrs\ for\ A,\ and$$
$$\frac{22{,}013\ yd^3 \times 1.2}{125\ yd^3/hr \times 0.91 \times 0.63} = 369\ hrs\ for\ B\ and\ C \qquad (3)$$

The 1.2 factor accounts for 20% over excavation.

Based on 8,760 hours in a year, the fraction of time spent onsite is 0.059 for Area A and 0.042 for Areas B and C. Only the time spent within the zone containing radioactive material was considered. The time required to excavate the 12 m (40 ft) of overburden in Areas B and C was

neglected because the overburden would shield the workers from radiation exposure until it is removed.

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).

2.2.3 Residential, Industrial, and Recreational Scenarios

To model the resident, the fraction of time spent onsite was increased to 0.62 indoors, representing 108 hours per week indoors at the site for 50 weeks per year, and 0.017 outdoors, representing 3 hours per week outdoors, 50 weeks per year. Recreational use was assumed to be 2 hours per week (time onsite fraction of 0.011), 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 in Area A and 12.2 m (40 ft) in Area B for the No Action Alternative. For the Cap and Cover alternatives, depth was increased by 1.52 m (5 ft) representing the minimum depth if the landfill is closed in accordance with New York landfill closure regulations in Area A. Doses for the Cap and Cover Alternative in Areas B and C were not calculated because the No Action alternative indicated no dose with overburden in place. The filter layers were not included in the depth of cover because the regulations do not specify a depth for the filter layers. No cover was assumed for the excavation alternatives.

Dust loading was changed from the default to 0.00003 g/m^3 representing 100 mg/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 [Environmental Protection Agency (EPA) 1990] for the resident and 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 residential and recreational use. Soil ingestion was reduced to 18.25 g/year (50 mg/day) (EPA 1991) for the industrial worker. All other parameters were left the same as for the remedial worker

2.3 RESULTS

The doses and incremental lifetime cancer risks following implementation of the considered alternatives are shown in Table 5 and are discussed in detail in the following sections.

2.3.1 Area A

For the No Action Alternative, the doses to the recreational user, industrial worker, and resident were predicted to be 11.5, 93, and 251 mrem/yr, respectively. The doses reported in future use scenarios are the highest predicted doses in the 1,000 year period evaluated. The most significant pathway was gamma from Ra-226 built in from current concentrations of Th-230. Incremental lifetime cancer risk associated with these exposure levels are estimated at 4.2×10^{-3} for the resident, 1.3×10^{-3} for the industrial worker, and 5.6×10^{-6} for a recreational user.

Doses for the remedial workers are reported for current year evaluations. The worker constructing the lower filter layer was estimated to receive a dose of 24 mrem due primarily to dust inhalation during the project. This is a dose that occurs only during landfill closure and not a recurrent yearly dose. The exposure would increase the worker's likelihood of contracting cancer by 4.2×10^{-6} over the course of a lifetime. Ac-227 accounted for 39% of the total dose (9 mrem). Th-230 was the next largest contributor, accounting for 25% of the total dose (6 mrem), primarily through the inhalation pathway. With the filter layer in place, the second phase of construction, the gas venting layer, was modeled resulting in a predicted dose of 0.17 mrem. 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.

Table 5. Dose and Incremental Cancer Risk for Alternatives (radon not included in dose or risk)

Alternative		Remedial Worker		Recreational User		Residential (loss of control)		Industrial-Commercial	
		Dose mrem	Risk	Dose mrem/yr	Risk	Dose mrem/yr	Risk	Dose mrem/yr	Risk
No Action	A	NA	NA	11.5	5.6×10^{-6}	251	4.2×10^{-3}	93	1.3×10^{-3}
	B & C	NA	NA	0	0	0	0	0	0
Cover, No Removal	A	24.3	4.2×10^{-6}	«1	7.0×10^{-13}	«1	5.2×10^{-11}	«1	8.8×10^{-12}
	B & C	0	0	0	0	0	0	0	0
Remove A (No Cover), No Action B & C	A	24.7	4.3×10^{-6}	1.21	5.7×10^{-6}	26	4.2×10^{-4}	9.6	1.32×10^{-4}
	B & C	NA	NA	0	0	0	0	0	0
Remove All (No Cover)	A	24.7	4.3×10^{-6}	0.66	5.7×10^{-6}	26	4.2×10^{-4}	9.6	1.32×10^{-4}
	B & C	64.3	1.2×10^{-5}	1.31	6.3×10^{-6}	51.9	8.4×10^{-4}	19.12	2.7×10^{-4}
Remove and Cover A, No Action B & C	A	28.3	4.7×10^{-6}	«1	$<6 \times 10^{-12}$	«1	6.0×10^{-12}	«1	$<6 \times 10^{-12}$
	B & C	0	0	0	0	0	0	0	0
Remove and Cover All	A	28.3	4.7×10^{-6}	«1	$<6 \times 10^{-12}$	«1	6.0×10^{-12}	«1	$<6 \times 10^{-12}$
	B & C	64.8	1.2×10^{-5}	0	0	0	0	0	0

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RESRAD estimated negligible doses («.1 mrem/yr) to a resident, worker, or recreational user on top of the closed landfill.

The total dose to the remedial worker excavating Area A was predicted to be 14.9 mrem. The most significant pathway was gamma, contributing 43% of the total dose. The dominant radionuclides contributing to the dose were Ra-226 and Ac-227 at about 31% each. The remedial worker's incremental lifetime cancer risk was estimated at 4×10^{-6}.

2.3.2 Areas B and C

The total dose to the remedial worker is predicted to be 64.3 mrem for excavation of Areas B and C and 0 mrem for cap and cover. The 0 mrem is due to the protection provided by the deep fill in these areas. The inhalation pathway contributed most of the dose received during excavation. Ac-227 was the principal isotope accounting for 39% of the dose. Following excavation of material exceeding 40 pCi/g Th-230, the doses to the future users (no cover) are 1.3 mrem/yr for the recreational user, 19 mrem/yr for the industrial worker, and 52 mrem/yr for the resident.

The results of dose calculations with the 40-ft cover in place indicate that the dose to a resident, industrial worker, recreational user, or construction worker installing a cap on the landfill with the fill material in place is not measurable through the entire 1,000-year period of calculations.

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 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 3 and 4 when different from RESRAD default values. Exposure scenarios and parametrer 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 and no Th-230 data at all exist for Areas B and C. 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 Th-230 is its parent isotope, Th-230 must somehow be accounted for in order to predict future doses. 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 RME for Ra-226 in Areas B and C was multiplied by the Th-230:Ra-226 ratio in Area A to obtain an RME for Th-230 in Areas B and C. This factor was found to be 15.6. Other means of finding surrogate data for the Th-230 such as regression analyses with Ra-226 or U-238, and 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 felt to be more reasonable, especially in calculating future doses, than if other methods of approximating Th-230 were used.

Similarly, no Ac-227 data is available for Seaway in any of the areas. Ac-227 can be a significant contributor to dose, 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.

3.4 VOLUME

The volume estimates are based on spacial interpolation of the existing data points assuming steady concentration gradients between data points. Volume estimates calculated in this manner are highly dependent on the accuracy and quantity of data available for the site. The data gaps previously mentioned impact the accuracy of the volume calculations. The volumes used here are the volumes of material containing greater than 5 pCi/g Th-230, Ra-226, Th-232, or Ra-228 in the upper 15 cm (6 in), greater than 15 pCi/g at depths below 15 cm or greater than 30 pCi/g U-238 at any depth. There is a great deal of uncertainty associated with these volumes especially in Areas B and C where the materials have likely been mixed with the fill material placed over the contaminated areas.

The volume estimates are used to calculate the thickness of contamination and 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. The duration of exposure is probably overstated because the excavation would target material greater than 40 pCi/g Th-230, thus the estimated volume of contaminated material used in these calculations is likely larger than the volume that would actually be excavated.

3.5 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. This source 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.

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Attachment

Regression Analysis for Ra-226 vs. Ac-227 Concentrations

Statistical Analysis System (SAS)

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			

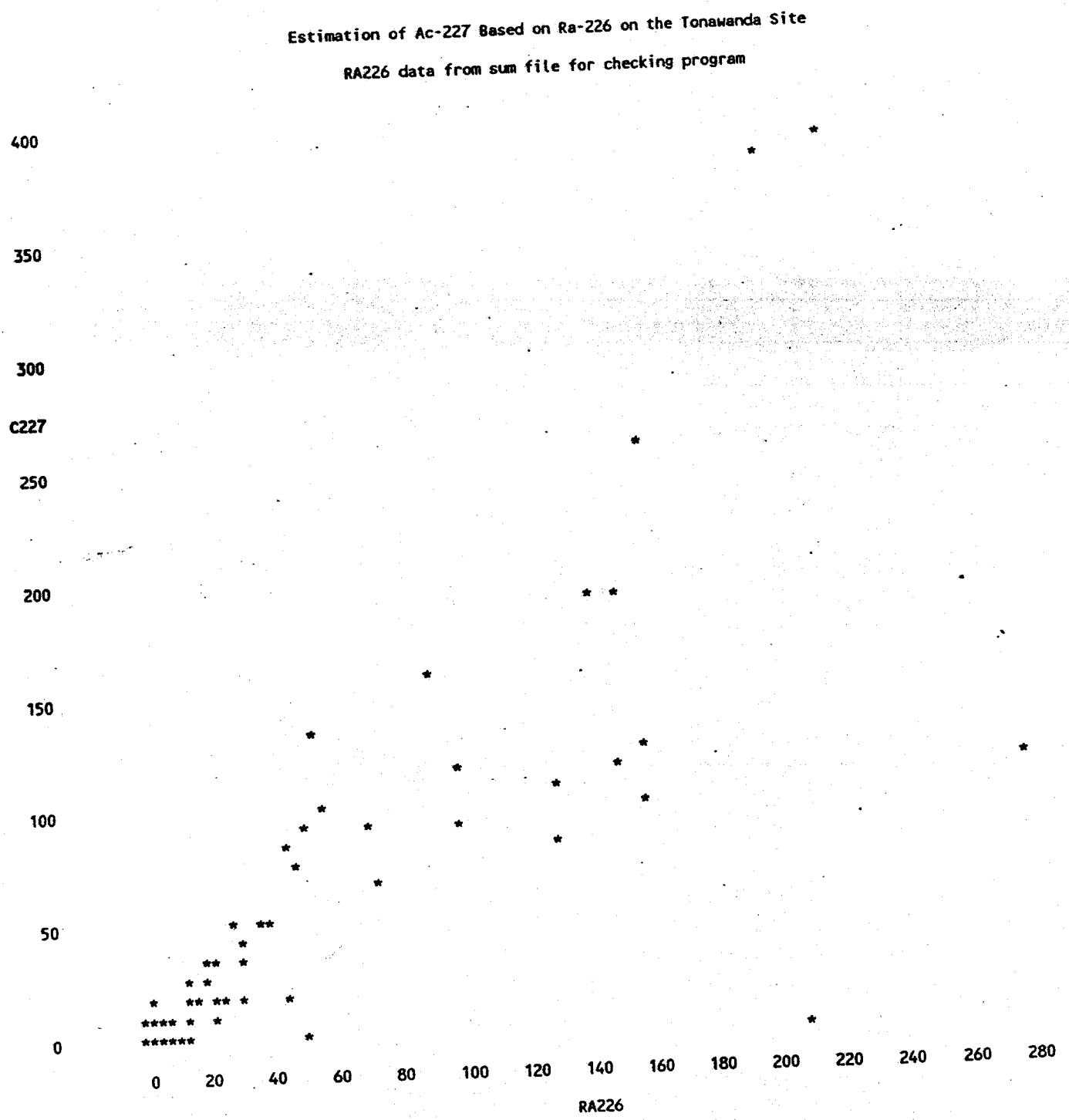
Root MSE	45.27854	R-square	0.7272
Dep Mean	44.74889	Adj R-sq	0.7241
C.V.	101.18361		

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.
&fnote2

SAS (continued)



Ashland 1 Data Set

^{226}Ra	^{238}U	^{227}Ac
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

^{226}Ra	^{238}U	^{227}Ac
23	7.3	31
45	150	87
150	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
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