RADIOLOGICAL DOSE ASSESSMENT

1 INTRODUCTION

Stepan Company holds U.S. Nuclear Regulatory Commission (NRC) Materials License STC-1333, Docket 40-8610, authorizing possession of thorium tailings in three burial pits on its property at 100 West Hunter Avenue, Maywood, New Jersey. Under the Formerly Utilized Sites Remedial Action Program (FUSRAP), the US Army Corps of Engineers (USACE) excavated and disposed of offsite the thorium tailings in those burial pits. The USACE then backfilled the excavated areas with clean fill. Remedial excavation and backfilling activities for the three burial pits are now complete.

Following excavation, but prior to backfilling, the USACE performed a final status survey (FSS) of each area, collecting measurements in accordance with protocols set forth in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), to identify any residual contamination levels. The USACE issued a Post-Remedial Action Report for each of the three burial areas detailing the results of their remediation and the FSSs [1, 2, 3].

Of interest to the NRC is whether the former burial areas satisfy the NRC radiological dose criterion of 25 mrem/yr in 10 CFR Part 20, subpart E, such that the NRC can terminate the Materials License STC-1333. As provided by NRC guidance,[4] Stepan has performed a radiological dose assessment using the RESRAD environmental simulation program [5] to assess compliance directly. As inputs, Stepan used the data from the Corps' FSSs. The dose assessment methodology, inputs, and results are reported herein. In sum, even with significantly conservative assumptions, Stepan's dose assessment confirms that the residual radioactivity remaining in the three former burial pits is well below the NRC's 25 mrem/yr dose criterion.

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1 USACE, *Post-Remedial Action Report (PRAP), Burial Pit No. 1 (NRC License STC-1333) 100 West Hunter Avenue, Block 124, Lots 39 through 44, Borough of Maywood New Jersey.* Formerly Utilized Sites Remedial Action Program (FUSRAP) Maywood Superfund Site (Aug. 2011).

2 USACE, *PRAP, Burial Pit No. 2 (NRC License STC-1333) 100 West Hunter Avenue, Block 124, Lot 47, Borough of Maywood New Jersey.* FUSRAP Maywood Superfund Site (July 2011).

3 USACE, *PRAP, Burial Pit No. 3 (NRC License STC-1333) 100 West Hunter Avenue, Block 124, Lots 31 and 33, Borough of Maywood New Jersey.* FUSRAP Maywood Superfund Site. (Aug. 2011).

4 Schmidt, D.W., *et.al., Consolidated Decommissioning Guidance,* NUREG-1757. vol. 2, rev. 1, §2.5 (Sept. 2006).

5 Yu, C. *et.al., User's Manual for RESRAD v.6.,* ANL EAD-4, Argonne National Laboratory, Environmental Assessment Division (July 2001).

2 FINAL STATUS SURVEY

Following excavation, the Corps performed radionuclide measurements as part of a final status survey (FSS) in each burial area in order to identify any residual contamination.

The FSS methodology was based on the MARSSIM.[6] Stepan previously submitted copies of the Corps' FSS within Post-Remedial Action Reports (PRAR) to the NRC as Appendix A [on DVD] to Stepan's request for license termination dated August 15, 2014. The Corps' reports demonstrate that final status radiation surveys, and analyses of the data collected by the final radiation status surveys, were performed in accordance with the MARSSIM.

Systematic soil sampling locations were on a triangular grid, beginning at a random starting location, to satisfy the MARSSIM model for systematic sampling.

Additional *bias samples* were collected, as necessary, to address gamma walkover survey (GWS) measurements exceeding a reading greater than three standard deviations above the mean reading and also at the discretion of the FSS field team.

The GWS identified an area of elevated, residual, radioactivity in post-remedial soil within the excavation of burial pit 1 (in survey unit SU 10A-30). Subsequent sampling confirmed residual activity within an area of about 30 m^2, and an elevated measurement concentration (EMC) evaluation was performed for combined Ra-226 and Th-232. The product of elevated measurements and a factor accounting for the small area of the elevated measurements demonstrated conformance to the MARSSIM methodology.

Systematic, biased, and EMC measurements reported in the PRAR become a representative source term to perform this dose assessment. Appendix A, Tables A1 through A3 herewith list the final status survey measurements of indicator radionuclides reported in the PRAR.

3 SOURCE TERM

Radioactive waste in the burial pits primarily included soil contaminated with the radionuclides related to the past thorium processing by the former Maywood Chemical Works. Source ore included natural thorium series, natural uranium series, and actinium

6 MARSSIM Committee. *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)*, NUREG-1575 (Dec. 1997).

series. The indicator radionuclides-of-concern measured by the USACE are Thorium 232 (Th^{232}), Radium 226 (Ra^{226}), Uranium 238 (U^{238}), and their decay progeny.[7, 8, 9]

3.1 Measurements

Arithmetic averages of the indicator radionuclides measured during final status surveys, giving equal weight to each systematic, bias, and EMC measurement, are in Table 1. As the FSS measurements represent soil after remediation and before backfilling, dose assessment based on these data also conservatively represents exposure to the bare surface before backfilling; whereas after thorium residue removal, the burial pits were backfilled with clean earth.

The thorium series is represented in RESRAD by indicator radionuclide, Th-232, with the long-lived Th^{232} + Ra^{228} + Th^{228} in equal concentration, with shorter-lived radionuclides in the series implicitly in secular equilibrium.

Table 1. Post-remediation Radionuclide Concentration

Burial Pit	Total Survey Area (sq m)	Average Concentration (pCi/g)		
		Ra 226	Th 232	U 238
1	2621	1.55	5.13	1.24
2	2069	1.11	1.35	0.94
3	6147	1.30	2.69	0.96
1+2+3	10837	1.37	3.46	1.06

Indicator radionuclide U-238 is represented in RESRAD with the long-lived U^{238} + U^{234} in equal concentration, and with shorter-lived radionuclides in the series through U^{234} implicitly in secular equilibrium. The actinium (U^{235}) series is included in its natural concentration relative to U^{238}, representing the uranium series.

Indicator radionuclide, Ra-226 is represented in RESRAD as the long-lived Th^{230} + Ra^{226} + Pb^{210} nuclides in equal concentration with shorter-lived radionuclides in the series implicitly in secular equilibrium.

3.2 Rationale

Thorium. Thorium series nuclides will have grown or decayed within near radioactive equilibrium. Especially for future estimation, the shorter radioactive half-lives of Ra^{228}, 6.7 yr, and of Th^{228}, 1.9 yr, imply that Th^{232} parent concentration is controlling. Thorium series radionuclides will be assumed to be in radioactive equilibrium and will be represented by

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7 ANL & Bechtel, *Work Plan-Implementation Plan for the Remedial Investigation/Feasibility Study/ Environmental Impact Statement for the Maywood Site, Maywood, New Jersey* (MISS-036) (Nov. 1982).

8 USACE, *Record of Decision for Soils and Buildings at the FUSRAP Maywood Superfund Site.* (MISS-182) (Aug. 2003).

9 USACE PRAP for Burial Pits 1, 2, & 3.

measurement of parent Th^{232} in the series. Thus, equal concentrations of principal radionuclides, Th^{232}, Ra^{228}, and Th^{228}, are entered into RESRAD.

Uranium. Since the residue includes natural uranium, it would be logical to consider U^{238} through U^{234} in radioactive equilibrium since both isotopes are long-lived and intervening progeny are short-lived. The actinium, or U^{235}, series exists in its naturally-occurring proportion to the uranium series. Shorter-lived radionuclides in the series are modeled as being in secular equilibrium with their longer-lived parents. When these radionuclides are the source in a RESRAD probabilistic simulation, the peak of the mean annual dose occurs in the first year of exposure because that is when the source near the surface is maximum.

Radium. Radium-226 and its progeny, including Pb^{210}, will be assumed to be in radioactive equilibrium and will be referenced to the measured Ra^{226} concentration. A subseries beginning with Th^{230} and including Ra^{226}, Pb^{210}, and their short-lived progeny is a logical grouping. Th^{230} is the long-lived parent of Ra^{226}; progeny of Ra^{226} and Pb^{210} are short-lived. In soil, it would be reasonable to assume Th^{230}, Ra^{226}, Pb^{210}, and their short-lived progeny are in radioactive equilibrium. The relatively short half-life of Pb^{210}, 21 years, and its lower dose factor than of Ra^{226} justifies compositing the contributions of Ra^{226}, Pb^{210}, and their short-lived progeny to radiological dose.

Th^{230} will be associated with Ra^{226} and Pb^{210} because the Ra^{226}, to which it decays, presents the dominant dose factor. Since Th^{230} transmutes into Ra^{226}, and since the dose factor of Ra^{226} and its progeny, including Pb^{210}, exceed other radionuclides in the uranium series, it is logical to associate Th^{230} and Ra^{226} in dose estimation.

3.3 Naturally-occurring Background Radioactivity

The regulatory standard for decommissioning applies to "... the residual radioactivity that is distinguishable from background radiation ...".[10] Studies of local and regional background radioactivity appropriate for such accounting have been reported.[11]

3.3.1 Locally.

A grassy area of Saddle River County Park, located in Rochelle Park, New Jersey, located in close proximity to the site, was selected for the local background survey because it was considered to be non-impacted. Table 2 summarizes the findings of that survey.

Statistics for U-238 in this study indicate U-238 is not normally distributed about the mean. However, the mean (1.34 pCi/g) and the median (1.33 pCi/g) values are virtually identical indicating a relative level of confidence in the measure of central tendency. In this case, central tendency and relative data dispersion is best assessed via the median, U-238 = 1.33 pCi/g bounded by the 25th and 75th percentile of the sample observations = 0.47 to 2.06 pCi/g.

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[10] 10 CFR 20.1402.

[11] Shaw Environmental, *Background Study Investigation Report, NY District, FUSRAP, Maywood Superfund Site*, Draft Final, rev. 1 (May 2004).

Table 2. Natural Background Radionuclide Concentration in Soil Near the Site

Designation	Ra-226 (pCi/g)	Th-232 (pCi/g)	Ra226+Th232 (pCi/g)	U-238 (pCi/g)
Number of Samples	31	35	30	36
Mean Concentration	0.897	0.711	1.641	1.340
Std. Deviation (1 σ)	0.0450	0.3035	0.5633	0.8354
95% confidence	0.732 to 1.063	0.606 to 0.815	1.430 to 1.851	1.057 to 1.622
Median	0.950	0.630	1.715	1.330

3.3.2 Regionally.

Table 3 summarizes previous studies of indicator radionuclide concentration occurring naturally in land in New Jersey. The basis data include measurements by ORNL[12], by ORAU[13], and by Bechtel[14].

Table 3. Regional Natural Background Radioactivity in Soil

Designation	Ra-226 (pCi/g)	Th-232 (pCi/g)	Ra-226 + Th-232 (pCi/g)	U-238 (pCi/g)
Number samples	30	30	29	26
Mean	0.82	0.89	1.73	0.87
Std. Dev (1σ)	0.32	0.31	0.57	0.36
Median	0.84	0.89	1.80	0.98
95% mean confidence interval	0.70 to 0.94	0.77 to 0.1.01	1.52 to 1.94	0.72 to 1.02

3.3.3 Influence of Background

Ore processed by the Maywood Chemical Works included the same radionuclide series that exist in natural soil. The radionuclide concentrations measured and reported in the PRAR are the gross concentrations in the soil samples, *i.e.*, of natural background plus residual burial pit material. Evaluation of radiological dose reported herein is based on the gross concentrations reported in the PRAR, thereby including contribution from residuals and from natural background. This is conservative. For example, if the concentration of

12 Oak Ridge National Laboratories (ORNL), *State Background Radiation Levels: Results of* Measurements Taken During 1975-1979, (Nov. 1981).

13 Oak Ridge Associated Universities, *Radiological Assessment of Ballod and Associates Property*, (July 30, 1981(prepared under USDOE Contract No. DE-AC05-760R00033).

14 Bechtel National, Inc., *Remedial Investigation Report for the Maywood Site* (Dec. 1992) (prepared for USDOE).

naturally-occurring radionuclides were removed from this source term, then the concentration of indicator radionuclides, Ra^{226} and Th^{232}, which affect radiological dose the most, would be about two-thirds of the Ra^{226} and Th^{232} source terms that were entered into the RESRAD simulation. Having based the evaluation of dose estimation on the gross radionuclide concentrations, substantial conservatism is incorporated into estimates of dose when compared to a standard for the residual burial pit material alone.

4 LAND USE

The Stepan property in Maywood is in an urban industrial area. Manufacturing and support buildings cover a large portion of the 19-acre Stepan property, and much of the remainder of the area is paved with asphalt or concrete. A manufacturing facility has operated continuously on the property for more than 100 years. Stepan has operated a manufacturing plant on the property since 1959, continues to invest in operations on the property and intends to continue industrial operation on the property during the foreseeable future.

The Borough of Maywood is a settled, stable township established in 1894. The Maywood Chemical Company began manufacturing in Maywood in 1895.[15] The Maywood Chemical Company grew to encompass approximately 63 acres of land, which include and surround the Stepan property.[16] Additional chemical manufacturing was conducted adjacent the Maywood Chemical Company facilities by Citro Chemical (now Pfizer, Inc.). Significant filling was conducted in the area, including in connection with the construction of State Route 17. As a consequence, soil borings conducted on the property generally indicate urban fill to a depth of 5 to 10 feet.[17]

Stepan's site is in an area whose zoning by the Borough of Maywood is for light industrial use[18, 19] consistent with historical use. Current land use surrounding the site reflects a mixture of commercial and industrial uses and by transportation corridors.[20] The 27-acre Sears warehousing property is located to the south of the Stepan property. The 11-acre Federal Maywood Interim Storage Site is located to the northwest of the Stepan property. Mixed commercial and industrial operations are located to the east and

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[15] USEPA, *Record of Decision, Maywood Chemical Company Superfund Site, Operable Unit 1, Non-FUSRAP Soil and Source Areas, Boroughs of Maywood & Lodi and Township of Rochelle Park, Bergen County, New Jersey* (Sept. 2014) ("USEPA ROD, OU-1").

[16] *Ibid.*

[17] CH2MHill, *Final Remedial Investigation Report, Stepan Company and Sears and Adjacent Properties, Maywood, New Jersey* (Nov. 1994).

[18] Neglia Engr. Assoc., Zoning Map, Borough of Maywood, N.J., Bergen County, N.J (Mar 14, 2014) (available at http://www.maywoodboro.org/forms/MAP.pdf .

[19] USACE, *Proposed Plan for Soils and Buildings at the FUSRAP Maywood Superfund Site, Maywood, New Jersey*, Fig. 1, at 5 (Aug. 2000).

[20] *Id.* (map).

southeast. The nearest residential use is located to the north, across the railroad right of way and tracks operated by New York, Susquehanna & Western Railroad. The Maywood Master Plan recommends maintaining the light industrial zoning classification for these industrial and commercial properties[21] except for the MISS, where a commercial, high rise zoning designation has been recommended. Limitations on available industrial property in the area are likely to result in continued industrial use of these properties.[22] No cultural resources, environmental justice issues, wetlands, floodplains, or critical habitats of endangered or threatened species have been identified that would impact the current limited light industrial zoning.[23]

Residential use of the Stepan property is not reasonably foreseeable because of historical and current land use, and because of municipal government zoning restrictions. Agricultural usage also is not reasonably foreseeable because of the prevailing land use in the area, consequent displacement of topsoil by excavation, buildings, and pavement by industrial and commercial activity, and impact from historical use.

Consistent with the foregoing, the Army Corps of Engineers, the United States Department of Energy and the United States Environmental Protection Agency set cleanup standards for chemical and radiological remedial actions on the Stepan property and the neighboring Sears property, the MISS and the railway property for nonresidential uses.[24]

Thus, the reasonably foreseeable future use of Stepan's site is for continued industrial use.

5 CRITICAL GROUP

As a result of the land use scenario described in section 4, industrial workers are potentially subject to the most exposure in the foreseeable future. Stepan limits access to its facilities to employees, construction workers, and authorized visitors, and maintains 24-hour security at the property. Labor laws prohibit employment of minors. The maximum exposure could occur to a typical industrial worker who spends most of their time in a building and some time out-of-doors onsite. Thus, an industrial worker scenario is the most exposed group for radiological dose modeling.

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21 Borough of Maywood, N.J. Master Plan. Maywood Land Use Plan Element. Commercial Land Use Plan. Limited Light Industry Borough of Maywood, N.J. Master Plan. Maywood Land Use Plan Element. Commercial Land Use Plan. Limited Light Industry.

22 USACE, *Feasibility Study for Soils and Buildings at the FUSRAP Maywood Superfund Site, Maywood, New Jersey*, at 5-21 (Aug 2002).

23 USACE ROD for Soils and Buildings, at 17, § G.2.1. (Aug. 2003).

24 USEPA ROD, OU-1 at 15, 19, 54-57; USACE ROD for Soils and Buildings at 18, 80.

6 ENVIRONMENTAL EXPOSURE PATHWAYS

6.1 Pathways to an Industrial Worker

In the expected industrial use scenario, the substantial pathways of potential radiological exposure are irradiation directly from the source in ground, ingestion of soil from contact, and inhalation of dust suspended in air. Such exposure would only occur proximate to the source. According to RESRAD modeling of a U series + Th series source in an industrial land use scenario, about 0.9 of radiological dose would be caused by irradiation directly from the ground, less than 0.1 of dose would be caused by ingestion of soil, and less than 0.01 of dose would be caused by inhalation of airborne dust. Thus, essentially all of the radiological exposure occurs from the source in the ground. In reality, all exposure pathways will be mitigated because the USACE placed clean fill in all of the former burial areas. Also, after backfilling, remediated burial pits 2 and 3 were covered with macadam.

The exposure-by-inhalation model assumes dust of contaminated soil becomes suspended as airborne dust where it could be inhaled. Atmospheric dispersion would dilute it and deposition would deplete it as wind blows it away from the survey unit.

Dose modeling assumes a member of the critical group wanders randomly on the area being modeled during their time on-site. Since a person can be in but one place at a time, they cannot be on a former burial area and another place on-site at the same time. Reciprocally, sources of exposure in the separate areas cannot be in the same area, *i.e.,* coincident. If exposure were to be apportioned by location, time of exposure, *e.g.*, a nominal 2000 hour work year, would be apportioned, thereby diminishing duration of exposure on each former burial pit area.

6.2 Pathways Not Present

6.2.1 Surface Water

There is no surface stream or lake on the Stepan property, and industrial or commercial use would not be conducive to creation of either. This eliminates any reasonable anticipation of surface water use on-site to become a potential exposure pathway.

6.2.2 Groundwater

The groundwater beneath the site is not a current source of drinking water, nor is it expected to be a source of drinking water in the future since the region is served by municipal water supply. Further, a search for wells in the area indicates there is no public water supply well within a five-mile radius of the site.[25] This may be because bedrock is shallow in the vicinity of the site and, accordingly, the perched water on top of the bedrock is insufficient to serve as a water supply.

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[25] USACE Groundwater ROD at 29; *see also* USEPA ROD, OU-1 at 15.

Furthermore, known chemical contamination in the bedrock aquifer up-gradient of the site would also prohibit the use of groundwater at the site as a potential source of drinking water.[26] As dictated by its Record of Decision, land use control against wells on-site and downgradient off-site will be implemented by the USACE to preclude potable use of groundwater.[27] Based on groundwater data and feedback from the USEPA, similar prohibitions are anticipated to be a requirement of the CERCLA remedy addressing chemical contamination in the groundwater.

7 MATHEMATICAL SIMULATION MODELS

The RESRAD computer program implements mathematical models that calculate total effective dose equivalent to an average member of the critical group from residual radionuclides in soil. RESRAD models simulate environmental pathways including transport in air, water, and biological media to an exposed person. Exposure is translated to radiological dose with ICRP models (ICRP 26, 30, and 48) for estimating total effective dose equivalent, which are the bases of NRC regulations. Mathematical models implemented in RESRAD v.6 have been described.[28] RESRAD v.6 includes the best available set of mathematical models to describe the environmental scenario and exposure pathways that might be anticipated after remediation.

8 INPUT PARAMETERS

Default values of parameters in RESRAD v. 6 have been developed and described.[29] Unless described herein, default values of parameters in RESRAD v.6 have been retained in this assessment. Where appropriate, values of parameters most pertinent to the industrial worker scenario have been used.

8.1 <u>Area of Contaminated Zone</u>

A larger assumed potential area increases dose by airborne dust inhalation. Thus, it would be conservative, *i.e.*, estimate greater dose, to model an overestimate of the contaminated area. These areas are tabulated in Table 4.

One scenario evaluated assumes the areas of FSS units covering the 3 burial areas are contiguous, thereby conceptually posing exposure on 12000 m^2 of the 3 survey units together.

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[26] Environmental Strategies & Applications, Inc., *RI Report Addendum for Dixo Company, Inc.*, (April 11, 2008).

[27] USACE Groundwater ROD, § 1.D, at 2-3; and § K.1 at 43-45. (May 2012).

[28] Yu, C., *et.al.*, User's Manual for RESRAD v.6 .

[29] Biwer, B.M., *et. al.*, *Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes*, attachment C in *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes*, NUREG/CR-6697 (Dec. 2000).

Table 4. Area of Contaminated Zone

Burial Pit	Total Survey Area (sq m)	Area Assigned in RESRAD (sq m)
1	2621	4000
2	2069	4000
3	6147	8000
1+2+3	10837	12000

8.2 Thickness of Contaminated Zone

The thickness of the contaminated zone is the vertical depth distance between the uppermost and lowermost soil samples that have radionuclide concentration above background.

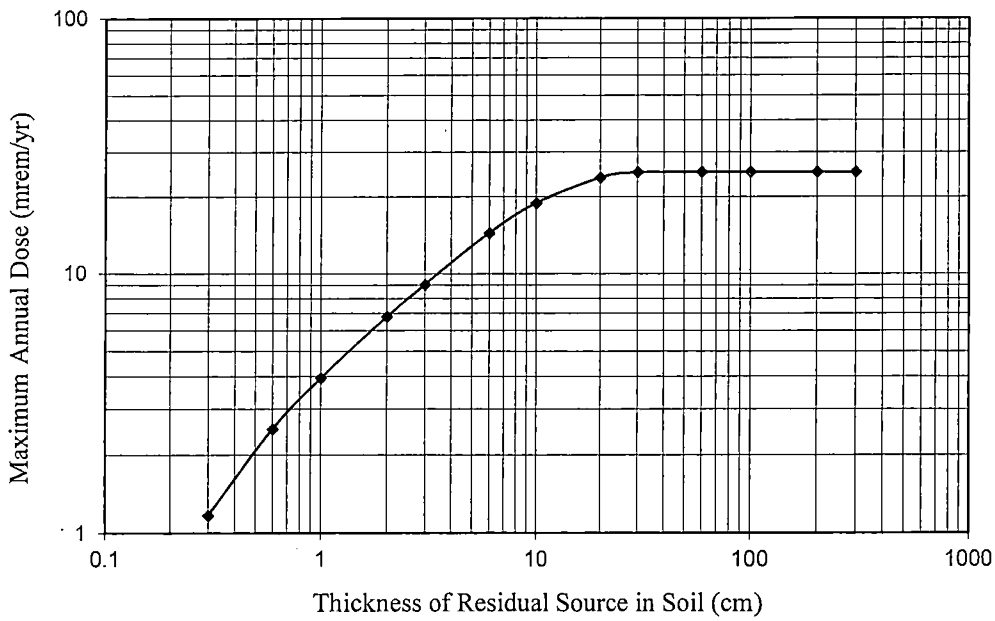
Probabilistic. An analysis of the effect of contaminated zone thickness on radiological dose to an industrial worker was performed to interpret the depth beyond which additional contribution from a representative source in soil to irradiation dose to a person would become negligible. Essential features of modeling to perform this analysis were:

- a reasonably representative source ratio of 3 U series, 0.0455 x 3 actinide (U^{235}) series, and 1 Th series together.
- bare land in which residual source contamination extends from land surface downward into the soil;
- indoor time fraction = 0.0 in order to simulate effect of irradiation from bare land;
- the industrial land use scenario modeled, except no ingestion of soil and inhalation of dust, because the origin of inadvertently ingested dust and of dust suspended into air is surficial topsoil; and
- deterministic simulation using RESRAD to derive the effect of increasing contamination depth in soil on exposure to direct irradiation.

The result of this analysis is summarized graphically in Figure 1. It determined that, in representative simulation, maximum dose rate by direct irradiation is reached asymptotically when the depth of the contaminated zone reaches about 30 cm. Additional source thickness would not produce a significantly greater dose rate.

As a result of this analysis, the thickness-of-contaminated-zone parameter will be represented as a variable in probabilistic dose modeling. It is being represented as a uniform distribution ranging from 0 to 1 meter thick. A maximum depth of 1 meter is more than sufficient to be a conservative representation insofar as direct irradiation is concerned.

Figure 1. Maximum Annual Radiological Dose Versus Source Depth in Soil
(infinitely-thick source ratio 3 U series + 1 Th series produces 25 mrem/yr)



Deterministic. While maximum dose rate by irradiation from ground is demonstrated to be reached within about 0.3 meters thickness of a contaminated zone, a conservative thickness of 1 meter is entered as a deterministic value in RESRAD modeling.

8.3 Cover Depth

Cover depth is the distance from ground surface to the contaminated zone. The default value in RESRAD is zero meters. Although former burial pits were backfilled with clean fill and burial pits 2 and 3 were then paved over, when evaluating potential exposure to contaminated soil, Stepan conservatively modeled exposure assuming there was no backfill or pavement and the land were bare.

8.4 Soil Mixing Layer Thickness

The soil mixing layer thickness is the thickness of the uppermost soil layer in which radioactive residue might be mixed. It affects the fraction of resuspendable soil particles at ground surface that are assumed contaminated. The soil mixing layer is estimated[30] to range from 0 to 0.6 meter deep, with the most likely thickness being 0.15 m. Since 0.15 m assures contaminated airborne dust for inhalation and is also the default value in RESRAD, Stepan used it in the dose modeling, even though there is no expectation that mixing of contaminated soil will ever occur, because the surface soil in the former burial pits are now clean backfill.

[30] *op. cit.,* Biwer, B.M., *et. al.*, pp. 3-42 & 3-43.

8.5 Occupancy Time

Occupancy times are described as the fraction of a year spent indoors and the fraction of a year spent outdoors in an area on-site that contains residual radionuclides. That would be the fraction of an 8766 hour year spent by an industrial worker within an affected area of the plant or where the burials had been located.

An industrial work year is estimated to be 50 weeks x 40 hr/wk = 2000 hrs. 0.8 of that time is estimated to be indoors and 0.2 is estimated to be out-of-doors. These amount to 0.1825 of total time in an 8766 hour year time indoors at the industrial site, and 0.04566 of the total time out-of-doors at that same site. These fractions, 0.1825 of total time in an 8766 hour year indoors and 0.04566 of total time in a year out-of-doors, are entered into RESRAD as deterministic estimates of indoor and outdoor time fractions of 8766 hr/yr.

These RESRAD inputs are reasonable. By comparison, the ANL staff estimated industrial worker occupancy indoors to be 0.17 of the time and occupancy out-of-doors to be 0.06 of the time in an 8766 hour year.[31]

8.6 Inhalation Rate

It is necessary to estimate the volume of air inhaled by a worker while in an area on-site that contains residual radionuclides in order to estimate potential radiological dose to an industrial worker after decommissioning. That volume is the product of occupancy time and inhalation rate. Resource data on inhalation rate have been reviewed.[32]

For the purpose of soil concentration-to-dose modeling, industrial workers are assumed to spend time out-of-doors on affected land as well as indoors. The RESRAD model accepts a single inhalation rate, which should be weighted to represent both circumstances. The USACE[33] estimated that an industrial worker breathes at an average rate of 1.2 m^3/hr. The ANL staff estimates that an industrial worker breathes at an average rate of 1.3 m^3/hr.[34] Short-term inhalation rates of adults[35] at 1.0 m^3/hr during light activity 1/3 of the time and at 1.6 m^3/hr during moderate activity 2/3 of the time produce a time and activity weighted inhalation rate of 1.4 m^3/hr. Similarly, if an outdoor worker[36] breathes 1.1 m^3/hr during slow activity 0.25 of the time and 1.5 m^3/hr during moderate activity 0.75 of the time, the weighted inhalation rate would also be estimated to be 1.4 m^3/hr. An inhalation rate of 1.4 m^3/hr has also been recommended as the default rate for

31 Yu, C., *et. al.*, User's Manual for RESRAD v.6, ANL/EAD-4, at 2-22 (Table 2-3).

32 Biwer, B.M., *et. al.*, attachment C, at 5-1 thru 5-5, in NUREG/CR-6697.

33 USACE, Post-Remedial Action Report for the St. Louis Downtown Site Plant 2 Property, Table B-3 (June 2001).

34 Yu, C., *et. al.*, User's Manual for RESRAD v. 6, ANL/EAD-4. at 2-22.

35 Biwer, B.M., *et. al.*, at 5-4 (Table 5.1-2).

36 *Ibid.*

commercial or industrial building occupancy.[37] An inhalation rate representing an industrial worker who spends some time out-of-doors and the majority indoors is represented by 1.4 m^3/hr in the industrial worker scenario.

8.7 Mass Loading for Inhalation

Estimation of intake by inhalation depends on the airborne concentration of contaminated airborne particulate matter, *i.e.*, soil that is respirable. Respirable particles are those less than 10 μm in diameter. About 0.28 to 0.33 of airborne particles have been found to be respirable.[38, 39, 40, 41] The mass loading of respirable particulate in air may be estimated as the product of the total mass loading of airborne dust and the respirable fraction.

Deterministic. The total mass loading of airborne dust in an urban area has been estimated to range from 60 to 220 μg/m^3 by USHEW[42] and 33 to 254 by Gilbert, *et.al.*[43] A geometric estimate from these two studies is about 115 μg/m^3. Thus, a reasonable estimate of respirable mass loading for inhalation in an urban, industrial area is 0.3 x 115 μg/m^3 = 35 μg/m^3. (This is about the upper 90^{th} percentile recommended for use in RESRAD in a residential environment.[44] Long-term measurements of mass loading in ambient air are 23 μg/m^3 at the 50^{th} percentile.)

Probabilistic. The model of radionuclides in outdoor air subject to inhalation is the product of the radionuclide concentration in surface soil and the airborne density of particulates of respirable size in ambient air. Biwer, *et.al.*,[45] summarized the distribution

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37 Biwer, B.M., *et. al.*, attachment C, at 5-3 in NUREG/CR-6697.

38 USEPA, *Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment*, EPA 520/4-77-016, at 31-32 (Sept. 1977).

39 Chepil, W.S., "*Sedimentary Characteristics of Dust Storms: III Composition of Suspended Dust*," Am. J. Sci., vol. 225, at 206 (1957) (in EPA 520/4-77-016, at 57)

40 Sehmel, G.A., *Radioactive Particle Resuspension Research Experiments on the Hanford Reservation*, BNWL-2081 (1977).

41 Willeke, K. *et.al.*, *Size Distribution of Denver Aerosols - A Comparison of Two Sites*, Atm. Env., vol. 8, at 609 (1974).

42 USHEW, *Air Quality Criteria for Particulate Matter* (1969), in *Residual Radioactive Contamination From Decommissioning*, NUREG/CR-5512, vol. 1, at 6.11 (Sept. 1992) ("USHEW, in NUREG/CR-5512").

43 Gilbert, T.L., *et.al.*, *Pathways Analysis and Radiation Dose Estimates for Radioactive Residues at Formerly Utilized MED/AEC Sites*, ORO-832 (Jan. 1984), in Yu, C. *et.al.*, *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil*, ANL/EAIS-8, at 110-111 (Apr. 1983) ("ORO-832").

44 Biwer, *et.al.*, attachment C, at C4-16, in NUREG/CR-6697.

45 *Op.cit.*, Biwer, *et.al.* "Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes." attachment C, at C4-15, C4-16, in NUREG/CR-6697.

of respirable particulate in ambient air reported by the EPA[46] for about 1790 air monitoring stations in a range of environments. At cumulative probability = 0.50, the most frequent respirable particulate density in the EPA distribution occurs at about 23 μg/m³ air.[47]

Three other sources of data were examined to get more comprehensive information about airborne particulate density in urban air. As discussed above, the total mass loading of airborne dust in an urban area has been estimated to range from 60 to 220 μg/m³ by USHEW[48] and 33 to 254 by Gilbert, *et.al.*[49] Their respective geometric means are approximately 115 and 92 μg/m³. Airborne particulates measured in 14494 urban and 3114 non-urban air samples in the National Air Sampling Network exhibited a geometric mean of 98 μg/m³.[50] A best geometric estimate of those is about 102 μg/m³.

Estimating intake by inhalation depends on the airborne concentration of contaminated airborne particulate matter, *i.e.*, soil, that is respirable. Again, as described above, about 0.28 to 0.33 of airborne particles have been found to be respirable, *i.e.,* less than 10 μm in diameter.[51, 52, 53, 54] The mass loading of respirable particulate in air may be estimated as the product of the total mass loading of airborne dust and the respirable fraction. Thus, a reasonable estimate of the geometric mean of respirable mass loading for inhalation in an urban, industrial area is about 0.3 x 102 μg/m³ = 31 μg/m³.

A distribution representing airborne particulate loading in urban air may be estimated by the shape of the distribution in NUREG/CR-6697, Table 4.6-1. Stepan has shifted this distribution upward by an increment representing the increase in dust in urban air relative to all ambient air. The result, in Figure 2, becomes the probabilistic distribution to replace the default distribution in RESRAD v. 6.3. This distribution

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46 USEPA, *Aerometric Information Retrieval System*, (1999) (described at https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7B44ECD47F-B6A5-4927-A42B-E6805DB0CEF5%7D).

47 Biwer, *et.al.*, Table 4.6-1 and Fig. 4.6-1, in NUREG/CR-6697.

48 USHEW. *Air Quality Criteria for Particulate Matter.* vol. 1, p. 6.11, NUREG/CR-5512, (1969).

49 Gilbert, T.L., *et.al., "Pathways Analysis and Radiation Dose Estimates for Radioactive Residues at Formerly Utilized MED/AEC Sites."* ORO-832, rev. Jan 1984. in Yu, C. *et.al.*, *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil.* ANL/EAIS-8. At pp. 110-111. (Jan 1984).

50 Stern, A.C., ed. *Air Pollution*, 2nd ed, Academic Press, NY (1968).

51 USEPA. *Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment.* EPA 520/4-77-016, at pp. 31-32 (Sept. 1977).

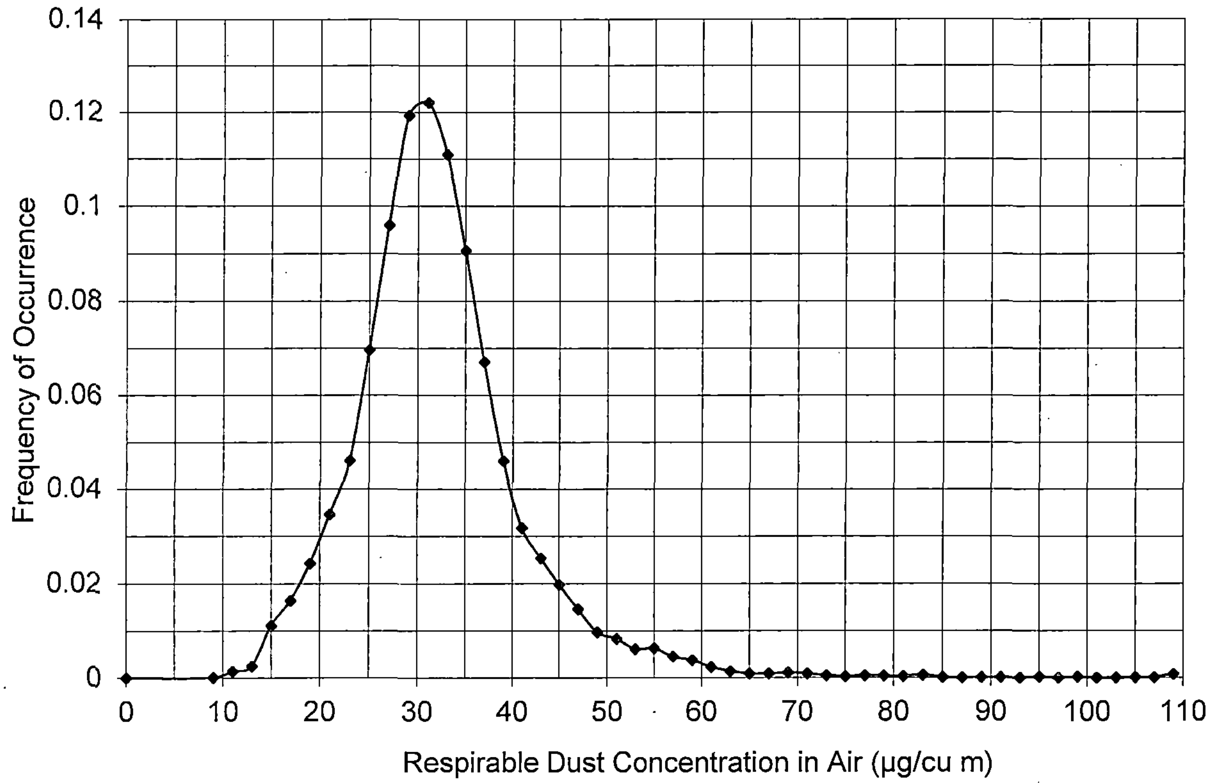
52 Chepil, W.S., *Sedimentary Characteristics of Dust Storms: III Composition of Suspended Dust,* Am. J. Sci., vol. 225, at 206, 1957, in EPA 520/4-77-016, at 57.

53 Sehmel, G.A., *Radioactive Particle Resuspension Research Experiments on the Hanford Reservation,* BNWL-2081 (1977).

54 Willeke, K. *et.al., Size Distribution of Denver Aerosols - A Comparison of Two Sites,* Atm. Env., vol. 8, at 609 (1974).

represents careful, reasonable appraisal of values of airborne mass loading in an urban environment.

Figure 2. Frequency Distribution of Respirable Dust in Urban Air
(EPA AIRS PM-10 data normalized to urban environment)



This shifted distribution is represented in RESRAD as a continuous distribution with entries in Table 5.

Table 5. Respirable Particulate in Urban Air

Respirable Particulate Concentration (μg/m³)	Cumulative Frequency Distribution (cfd)
0.	0.0
15.	0.0151
23.	0.1365
37.	0.8119
47.	0.9495
67.	0.9937
83.	0.9983
107.	0.9992

8.8 Soil Ingestion Rate

The quantity of contaminated soil ingested incidentally from outdoor activities annually is estimated to range from 0 to 36.5 g/yr.[55] The most likely amount is estimated to be 18.3 g/yr.[56] The recommended default value[57], 36.5 g/yr, which is the most conservative, is entered into RESRAD to represent an industrial worker.

8.9 Building Shielding Against Gamma Radiation

The floor and walls of a building shield an occupant against some gamma rays entering from soil outside. Buildings on the Stepan site have concrete slab floors and brick or concrete block walls with few windows.

Probabilistic. An analysis of the effect of radiation attenuation by a building, especially floor thickness, on radiological dose for the portion of time a worker spends indoors during industrial occupation has been performed. This analysis assumed:

- a source ratio of 3 U series, 0.0455 x 3 actinide (U^{235}) series, and 1 Th series together;
- residual source contamination conservatively extends from land surface downward one meter into the soil;
- outdoor time fraction = 0.0 in order to conservatively simulate effect of irradiation indoors;
- deterministic simulation using RESRAD to derive the fraction of gamma dose rate as a function of concrete floor thickness; and
- combination of probable distribution of floor thickness and indoor gamma shielding factor to derive a probability distribution of indoor gamma shielding factor.
- The result of this analysis is summarized in Table 6, where indoor gamma shielding factor probability distribution is tabulated.

On the premise that a floor construction is likely to be specified in an integer thickness in units of inches, a *discrete cumulative* probability distribution of these data has been specified in RESRAD. Table 6 depicts the cumulative probability and indoor gamma shielding factor data entered into RESRAD for probabilistic evaluation of the effect of this parameter on radiological dose rate.

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[55] Biwer, *et.al.* attachment C, at C5-19 thru C5-25, in NUREG/CR-6697.

[56] *Ibid.*

[57] Yu, C., *et. al.*, NUREG/CR-6697, at 18 (Table 2.1).

Table 6. Indoor Gamma Shielding Factor Distribution

Shielding Thickness (cm)	(in)	Shielding Factor ("value")	Fractional Occurrence	Cumulative Distribution Indoor Only (cfd)
25.4	10	0.0084	0.01	0.01
20.3	8	0.022	0.08	0.09
17.8	7	0.035	0.12	0.21
15.2	6	0.055	0.18	0.39
12.7	5	0.088	0.24	0.63
10.2	4	0.14	0.25	0.88
7.6	3	0.23	0.07	0.95
0	0	1.0	0.05	1.0

Deterministic. A floor slab of an industrial building is likely to be concrete in a range of 4 to 6 inches-thick. A conservative representation for deterministic modeling would be three-inch-thick concrete. According to Table 6, a corresponding single-valued, deterministic shielding factor for 3-inch-thick concrete would = 0.23 and is assigned herein for deterministic assessment. By comparison, a shielding factor = 0.17 was recommended for a brick house with a 6-inch thick concrete slab floor.[58]

8.10 Indoor Airborne Dust Filtration

The fraction of airborne dust out-of-doors that is available indoors has been reviewed.[59] When considering outdoor sources of respirable particulate indoors, Wallace[60] estimated the indoor-to-outdoor fraction to be close to 0.5. For conservatism, a value of 0.6 will be assumed when computing dose for an industrial worker.

8.11 Wind Speed

The annual average wind speed reported for Newark, New Jersey[61] is 10.2 mi/hr (4.56 m/s), and was entered into RESRAD to compute radiological dose.

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58 Yu, C., *et.al., Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes.* NUREG/CR-6697. attach C, Biwer, *et.al.*, attachment C in NUREG/CR-6697, §7.10 (External Gamma Shielding Factor).

59 *Op.cit.*, Biwer, *et.al.* attachment C, at pp. 7-1 thru 7-4.in NUREG/CR-6697.

60 Wallace, L., *Indoor Particles: A Review,* J. Air & Waste Mgt. Assoc., vol. 46, at 98-126 (1996) discussed in Biwer, *et.al.* attachment C, at pp. 7-1 thru 7-4 in NUREG/CR-6697.

61 NOAA, *Comparative Climate Data for the United States through 1995,* Newark, NJ. (available at www.erh.noaa.gov/er/gyx/climo/avgwind.html).

8.12 Precipitation

The annual average precipitation reported for northern New Jersey[62] is 46.6 inches/yr (1.18 meters). This was entered into RESRAD for the dose modeling.

8.13 Geology

Soil type on-site is generally silt-sand. Values of geological and hydrological parameters were estimated among similar soil types tabulated in the data handbook for RESRAD [63].

Parameter	Value	Basis
Dry density of soil	1.5 g/cm^3	in range of sand and sandy loam
Soil porosity	0.4	in range of sand and silt
Saturated hydraulic conductivity	100 m/yr	in range of silty sand, silty loam, sandy loam, and loamy sand
b parameter	4.65	in range of loamy sand and sandy loam

9 Radiological Dose Estimation

9.1 Radiological Dose Modeling

Models simulating environmental exposure pathways to estimate potential radiological dose to people are coded in the RESRAD computer program. With the aid of RESRAD, probabilistic modeling has been done to derive dose factors and DCGL at the *peak of the mean* dose as NRC guidance suggests.[64]

RESRAD is able to compute and tabulate the time of peak mean dose rate and the peak mean dose rate (mrem/yr). One may derive a composite dose factor for a related series of radionuclides by summing the average dose of each source radionuclide in the series at the time of the peak of the mean dose. Then one may derive the dose factor as the quotient of that sum and the concentration of the radionuclides to which it is referenced. For example, the composite dose factor of the thorium series would be the sum of doses of the principal radionuclides, including their short-lived progeny, at the time of the peak of the mean dose divided by the initial concentration of the reference, or parent, *e.g.,* Th^{232}.

In the probabilistic total dose summary, one can read the contribution by each long-lived radionuclide entered in the source term column corresponding to the time of peak

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[62] NOAA, National Center for Environmental Information (*available at* www.ncdc.noaa.gov/cag/time-series home>climate monitoring>climate at a glance>US precipitation annual.

[63] Yu, C., *et.al.*, *Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil*, ANL, Environ Assess & Info Sci Div. (April 1993).

[64] *Op.cit.,* NUREG-1757, vol. 2, §5.

mean dose. The *average* dose of each source radionuclide at the time of peak mean dose, summed over all of the source radionuclides, equals the peak of the mean dose. Having identified the contribution of each source radionuclide to the peak of the mean total dose, one may derive an appropriate probabilistic dose factor (mrem/yr per pCi/g) as the quotient of the average dose of each source radionuclide at the time of peak mean total dose and the concentration of that radionuclide entered into the source term in RESRAD.

9.2 Results of Dose Modeling

9.2.1 Probabilistic Modeling

Annual radiological dose was computed by RESRAD for an industrial worker scenario with probabilistic treatment of thickness of the residual source in soil, of respirable dust concentration in air, and of gamma shielding by building floor and walls. Results of the computations are summarized in Table 7. If an industrial worker were to spend a work year (*i.e.*, 2,000 hours) on the area represented by the FSS encompassing a remediated burial pit (assuming indoor and outdoor environments within a former burial pit's footprint), the potential radiological dose would be as represented for that burial pit.

The burial pits identified as 1 + 2 + 3 represents conceptual, contiguous placement of the FSS units of the three burial pits. The source term is the arithmetic average of measurements of all soil samples in the FSS units. That is, if an industrial worker occupied the contiguous area, the potential radiological dose would be estimated to be 4.7 mrem/yr.

Table 7. Radiological Dose Computed Probabilistically

Burial Area	Radiological Dose (mrem/yr)
1	6.5
2	2.2
3	3.8
1 + 2 + 3	4.7

9.2.2 Deterministic Modeling

Radiological dose was also computed by RESRAD with single-valued inputs. Resulting dose estimates by this deterministic modeling are in Table 8.

Table 8. Radiological Dose Computed Deterministically

Burial Area	Radiological Dose (mrem/yr)
1	8.7
2	3.0
3	5.1
1 + 2 + 3	6.3

APPENDIX A
FINAL RADIATION STATUS SURVEY DATA

Table A1. Final Status Survey Data for Burial Pit Area 1

Concentration (pCi/g)		
Ra 226	Th 232	U-238
SU 10A-29 systematic		
3.26	11.94	1.62
2.12	4.36	1.26
1.05	0.95	1.00
1.71	3.57	1.09
1.58	2.88	0.76
2.80	5.64	1.07
1.23	1.14	0.99
0.85	0.96	0.62
1.61	1.68	0.55
1.09	1.06	0.68
1.00	0.89	0.60
1.33	1.18	0.27
2.05	5.74	0.83
1.01	1.09	0.56
0.77	1.01	0.98
SU 10A-29 bias		
2.14	11.82	3.80
3.60	9.91	1.70
2.04	5.12	0.82
2.93	9.47	1.53
1.84	9.52	1.40
2.72	9.72	0.72
2.01	9.69	1.35
2.42	8.61	1.75
1.55	3.38	0.91
1.51	1.79	1.61
1.12	2.14	0.68
1.35	1.68	1.21
2.51	2.20	2.64
1.76	1.69	1.31
0.92	0.86	0.96
1.17	1.04	1.33
1.70	5.47	0.82
2.20	4.50	1.22
1.00	1.13	0.53

SU 10A-30 systematic		
0.96	0.77	0.39
2.89	5.71	1.30
1.31	1.86	0.50
1.84	2.92	0.79
1.02	1.23	0.84
0.93	0.93	0.12
2.27	7.67	2.73
1.05	1.03	0.87
1.85	3.98	0.89
1.94	2.49	1.02
1.34	1.49	0.86
1.13	1.12	0.97
1.96	3.50	1.01
1.63	2.68	1.19
SU 10A-30 bias		
2.21	5.03	1.30
1.54	1.96	0.77
2.81	5.61	0.57
1.99	3.47	2.10
1.02	6.28	1.47
1.47	5.43	1.06
1.95	3.09	2.21
1.12	1.18	0.77
1.18	1.06	1.51
1.72	0.85	1.84
1.14	1.02	0.97
1.46	3.19	0.17
1.29	1.32	0.51
1.06	1.35	1.19
1.11	1.19	1.07
1.03	1.36	1.16
0.62	1.35	0.59
0.65	1.21	0.29
1.09	1.01	0.99
1.19	1.51	0.61
2.10	3.79	1.60
1.20	1.54	0.30
SU 10A-30 EMC		
1.05	0.82	0.95
1.02	2.87	1.19
1.40	24.69	4.05
0.88	74.00	6.81

	1.44	3.20	1.23
	0.93	17.42	4.64
	0.34	4.41	0.66
	1.03	10.89	1.53
	1.30	31.94	1.45
average	1.55	5.13	1.24

Table A2. Final Status Survey Data for Burial Pit Area 2

	Concentration (pCi/g)		
	Ra 226	Th 232	U-238
	SU 10A-16 systematic		
	1.57	1.75	1.53
	1.38	2.85	1.49
	1.03	1.20	0.55
	1.02	1.16	0.58
	0.98	0.80	1.04
	1.02	0.91	0.77
	0.87	0.99	0.98
	0.97	0.98	0.75
	0.97	0.93	0.88
	1.08	1.04	0.57
	1.23	1.26	0.38
	1.42	2.22	2.37
	1.13	1.05	1.08
	0.92	0.88	0.79
	SU 10A-16 bias		
	0.91	1.05	1.02
	0.94	0.94	1.01
	0.93	1.21	1.20
	1.30	2.02	0.40
	1.34	1.91	1.00
	1.23	2.15	0.75
	1.51	2.02	0.60
	1.04	0.98	0.93
	0.90	0.80	0.72
	0.99	1.24	1.06
average	1.11	1.35	0.94

Table A3. Final Status Survey Data for Burial Pit Area 3

Concentration (pCi/g)		
Ra-226	Th-232	U-238
SU 10A-17 systematic		
0.96	0.90	0.73
0.64	0.69	0.60
2.58	11.07	2.01
0.94	2.05	0.79
1.75	7.24	2.38
0.92	0.79	0.71
0.94	0.81	0.49
0.94	2.09	0.85
0.88	0.83	0.70
1.11	1.00	1.32
0.89	0.99	0.63
0.99	1.45	1.17
0.87	0.80	0.74
1.00	1.36	1.11
1.06	1.09	0.25
0.89	0.92	0.43
SU 10A-17 bias		
0.82	1.15	0.23
1.20	2.60	1.09
1.37	5.18	2.44
2.23	12.25	1.26
1.01	1.11	0.56
1.19	1.32	1.28
4.33	2.55	3.59
1.37	5.03	1.06
1.03	0.84	0.46
1.45	4.55	0.58
1.48	3.39	0.84
2.22	1.52	1.77
SU 10A-19 systematic		
1.02	0.86	0.58
1.20	1.51	0.94
1.26	3.57	0.74
1.50	3.12	0.82
0.75	0.68	0.74
0.74	0.59	0.58
1.06	0.90	0.54

0.70	0.61	0.35
0.87	0.77	0.94
0.85	0.79	0.72
1.04	1.02	0.60
1.15	1.00	0.59
1.00	0.85	0.79
1.72	5.92	1.98
0.98	0.95	0.07

SU 10A 19 bias

1.17	1.87	0.58
1.33	4.58	0.97
1.38	1.34	1.29
1.36	3.72	1.43
1.89	8.27	1.92
1.60	4.14	0.59
1.47	3.75	1.25
0.91	2.52	0.64
1.78	4.22	1.05
2.26	3.02	0.94
1.94	6.69	1.56
0.99	1.05	0.42
1.71	6.17	0.97
1.85	6.24	2.08
1.89	6.98	1.30

SU 10A-22 systematic

0.94	0.88	0.95
1.54	2.01	1.24
1.59	1.59	0.54
1.14	1.04	0.83
1.20	1.28	1.16
1.16	1.32	1.04
0.98	1.21	0.58
1.00	1.00	0.48
1.16	1.04	0.37
1.10	1.41	0.99
1.15	1.80	0.60
1.56	2.35	1.13
1.07	0.94	0.35
1.14	2.60	0.62
0.91	1.06	0.80
1.81	4.59	0.90

SU 10A -22 bias

2.21	4.95	1.36
1.09	1.09	0.70
1.46	1.66	1.28
2.07	9.66	1.62
1.06	1.20	1.06
1.04	0.95	0.28
1.27	3.44	0.75
1.03	1.19	1.16
1.47	6.59	2.07
2.32	9.67	1.44
1.22	2.40	0.53

SU 10A-23 systematic

0.93	1.82	0.42
1.05	2.79	0.41
1.09	0.82	0.82
1.13	0.99	0.56
0.93	0.69	0.30
1.14	0.42	0.59
1.04	0.77	0.68
1.04	0.78	0.74
0.98	0.64	0.68
1.32	0.91	1.01
1.27	2.68	0.65
1.02	1.22	0.49
1.26	1.01	0.94
0.98	0.94	0.83

SU 10A-23 bias

	1.21	5.58	0.73
	1.71	7.88	1.66
	1.40	4.47	2.04
	1.74	8.30	1.36
	1.56	6.04	1.28
	1.80	1.88	1.67
Average	1.30	2.69	0.96

APPENDIX B

RECORD OF RESRAD COMPUTATIONS

{ computer files here }