Methodology for Determination of Exposure Point Concentration Using both Systematic and Biased Samples for Radiological Risk and Dose Assessments – 11488

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ABSTRACT

Residual radiological dose and risk assessments are performed as a part of Baseline Risk Assessment and/or as a part of the Final Status Survey to assess the dose and risk due to the presence of residual contaminants at the Site. Determination of source term or exposure point concentrations (EPCs) for each of the radiological contaminants present at the Site is one of the major steps during the determination of residual radiological dose and risk. Both systematic and biased sampling results are utilized during the determination of EPC for each of the radiological contaminants present at the Site. When the sampling results collected from the site are either random or systematic, the methods for computing the mean and confidence limits around the mean are relatively straightforward. However, in most cases, the sample results available are not strictly random or systematic; instead they include biased sample results as well. Biased samples are collected from areas with presumed higher concentrations. Inclusion of sampling results for both biased and systematic samples can result in erroneous statistics. Giving an equal weight to both systematic and biased samples will generally lead to an over estimation of EPCs and therefore increased dose and risk for the site, which can lead to unnecessary additional cleanup costs. However, ignoring the biased samples from the sampling results can lead to an under estimation of the EPCs which can lead to ineffective cleanup resulting in added risk to current and future receptors. By incorporating both systematic and biased sample results with their corresponding impacted area information, the problems related to both over and under estimation can be minimized and a more accurate estimation of dose and risk can be obtained.

INTRODUCTION

Residual radiological dose and risk assessments are performed as a part of a Baseline Risk Assessment to determine whether remedial action is required due to the presence of unacceptable dose and risk at the Site. Residual radiological dose and risk assessments are also performed in conjunction with Final Status Surveys to verify that the selected remedy meets the remedial action objectives regarding established dose and risk criteria. The first major step during the residual radiological dose and risk assessment process is the determination of the source term or EPC in the environmental medium to which a receptor may be exposed, for each of the radiological contaminants of concern (COCs) present at the Site. EPCs for various radiological COCs are determined by calculating the 95% upper confidence limit (UCL) of the mean following the procedures presented in the Environmental Protection Agency's (EPA) 2002 guidance document, *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites (OSWER 9285.6-10*) (EPA 1992) [1]. USEPA issued the ProUCL program to assist in the determination of UCLs following the methodology described in their 2002 guidance. The ProUCL program version 4.0 was utilized during the determination of appropriate UCL in this paper.

The EPA's *Risk Assessment Guidance for Superfund* (RAGS) (EPA 1989) [2] discusses procedures for acquiring reliable chemical release and exposure data for quantitative human health risk assessment at hazardous waste sites. Section 4.6.2 in Volume 1, Part A of the RAGS guidance document summarizes three general strategies for establishing sample locations. They include purposive (or biased), completely random, and systematic (e.g., sampling on a grid). RAGS states that purposive sampling should not be conducted if the data are to be used to provide defensible information for a risk assessment, but rather random or systematic/grid sampling is preferred. Systematic sampling is preferable to other types of sampling if the objective is to search for small areas with elevated concentrations. However, during the remedial investigation for radiological contaminated sites, the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) guidance is used to develop soil sampling strategies. The MARSSIM provides information on planning, conducting, evaluating, and documenting building surface and surface soil final status radiological surveys for demonstrating compliance with dose or risk-based regulations or standards. The MARSSIM is a multi-agency consensus document that was developed collaboratively by four Federal agencies having authority and control over radioactive materials: Department of Defense (DOD), Department of Energy (DOE), EPA, and Nuclear Regulatory Commission (NRC). Under the MARSSIM based sampling strategy, a gamma walkover survey is initially conducted to map areas of potential radiological impact. Both biased and systematic soil samples are collected as a part of the sampling strategy. Since RAGS advises against using biased sample results when conducting dose and risk assessments and implementing the MARSSIM sampling strategy usually generates biased sample results, the objective of this paper is to present and compare several approaches for calculating EPCs using MARSSIM generated data during a RAGS-based dose and risk assessment and provide a discussion of that comparison.

This paper presents four different approaches for calculating EPCs for radiological COCs when both systematic and biased sampling results are available. The approaches include – (1) Site EPC based on area weighted Representative Area EPCs; (2) Area weighted Site EPC based on separate Systematic EPCs and Biased EPCs; (3) Non-area weighted Site EPCs based on both Systematic and Biased Samples; and (4) Site EPCs based on only Systematic Samples. The paper also provides an example radiologically contaminated Site to present the results of the four EPC approaches for radiological COCs present at the Site and their corresponding effect on dose and risk.

METHODOLOGIES FOR DETERMINING EPCs

Four different methodologies for calculating EPC for each radiological COC present at the Site are presented in the following section. The sampling results for each radiological COC include both systematic and biased samples.

1. Determination of the Site EPCs Based on Area Weighted Representative Area EPCs – Under this methodology, the total site area is divided into a number of representative areas (RAs) that may include both systematic and biased samples. Each RA area is equal to the total area divided by the number of systematic sampling locations. An area-weighted average concentration for each radionuclide COC for each RA is determined based on the area and

concentration results of both systematic and biased samples within that RA. Area weighting of samples for each representative area was calculated using the following equation (Eq. 1).

$$C_{RA} = \frac{\sum\left(\frac{C_S \, x\left(R_A - \sum A_B\right)}{N_S}\right) + \sum\left(C_B \, x \, A_B\right)}{R_A} \qquad \text{(Eq. 1)}$$

Where;

C_{RA} = Concentration of the representative area
C_S = Concentration of the systematic sample
R_A = Representative area value
C_B = Concentration of the biased sample
A_B = Area of the biased sample
N_S = Number of samples per systematic sample location (e.g., samples at different depths)

In this area-weighting equation, the sample concentration results from the systematic sample location are multiplied by the area associated with the RA minus the area of the biased samples associated with the RA and then divided by the total number of systematic samples. These concentration-area values are then summed. The biased sample concentration results are then multiplied by the biased sample area, summed, and added to the previously calculated systematic concentration-area value sum. The total concentration-area value sum is then divided by the area of the RA to yield an area-weighted concentration for the RA. This process is repeated for each RA. The area-weighted average concentrations for each radiological COC within each RA will then be utilized to determine the EPC for each radiological COC present at the site.

2. Determination of Area Weighted Site EPCs Based on Separate Systematic EPCs and Biased EPCs – Under this methodology, two EPCs for each radiological COC are calculated separately for systematic and biased samples. Those EPCs are then area-weighted to determine the EPC for each COC at the site.

3. Determination of Non-Area Weighted Site EPCs Based on Both Systematic and Biased Samples – Under this methodology, the EPCs for each radiological COC are calculated by providing equal weighting to the sampling results for both systematic and biased samples.

4. Determination of Site EPCs Based on Only Systematic Samples - Under this methodology, the EPCs for each radiological COC are calculated by utilizing the sampling results for only systematic samples.

DETERMINATION OF EPCs USING FOUR METHODOLOGIES

Prior to determining EPCs using the four different methodologies, a hypothetical area of concern (AOC) of 1,000 square meters (m^2) was established with seven systematic sampling locations. Based on a walkover survey, twelve additional biased sampling locations were established. Table I presents the impacted area for each biased sample.

Table I. Biased Sample Areas

Biased Sample Location	A_B (m^2)
B-1	10
B-2	5
B-3	1
B-4	5
B-5	1
B-6	1
B-7	10
B-8	10
B-9	1
B-10	5
B-11	1
B-12	1

The radiological COCs associated with the AOC are actinium (Ac)-227, protactinium (PA)-231, radium (Ra)-226, Ra-228, thorium (Th)-228, Th-230, Th-232, U-235, and U-238. Both systematic and biased sampling results for all COCs are presented in Table II. Each systematic sample location had sample results from different depths which are annotated in Table II with a small letter behind the sample location.

Table II. Laboratory Sample Data for AOC

Sample Location	Ac-227	Pa-231	Ra-226	Ra-228	Th-228	Th-230	Th-232	U-235	U-238
S-1a	0.02	0.03	1.44	0.60	1.02	0.86	0.32	0.25	2.64
S-1b	0.00	0.00	0.95	0.56	0.86	0.71	0.22	0.15	2.95
S-1c	0.00	0.03	0.35	0.60	1.13	0.30	0.39	0.16	1.81
S-1d	0.03	0.15	0.14	0.63	2.68	0.12	1.77	0.07	1.21
S-2a	0.05	0.01	0.00	0.11	0.20	0.50	0.00	0.00	0.81
S-2b	0.07	0.46	1.26	0.82	1.36	1.71	1.01	0.46	3.00
S-2c	0.04	0.00	0.00	0.36	0.47	0.00	0.00	0.26	0.89
S-2d	0.05	0.00	0.00	0.42	0.81	0.30	0.00	0.15	0.39
S-3a	0.05	0.06	0.00	0.14	0.28	0.66	0.00	0.25	0.95
S-3b	0.00	0.17	2.10	0.73	1.04	2.03	0.32	0.25	2.69
S-3c	0.20	0.26	3.82	1.11	1.56	4.26	0.78	0.45	7.58
S-3d	0.07	0.29	0.53	0.65	0.85	0.41	0.29	0.08	1.13
S-4a	0.18	0.45	0.68	0.52	0.45	0.52	0.12	0.00	1.43
S-4b	0.00	0.00	0.00	0.35	0.35	0.29	0.02	0.16	0.62
S-5a	0.07	0.00	1.75	0.63	0.70	1.44	0.15	0.23	2.80
S-5b	0.01	0.04	1.11	0.44	0.54	1.49	0.22	0.20	1.76
S-6a	0.00	0.00	1.18	0.72	0.97	1.57	0.21	0.39	2.84
S-6b	0.00	0.26	0.48	0.83	0.95	1.04	0.35	0.00	1.66
S-7a	0.27	0.49	2.04	0.83	0.88	2.34	0.89	0.12	3.67
S-7b	0.24	0.45	2.19	0.93	1.04	1.73	0.58	0.28	3.06
B-1	0.23	0.40	1.79	0.62	0.99	2.00	0.65	0.03	2.46
B-2	0.38	1.16	5.25	1.10	1.62	5.99	1.01	0.20	6.40
B-3	0.26	0.74	6.39	1.48	2.03	6.49	1.59	0.19	8.03
B-4	0.03	0.71	5.26	1.22	1.51	4.20	1.12	0.37	4.95
B-5	0.00	0.15	0.00	0.32	0.24	0.00	0.00	0.00	0.42
B-6	0.00	0.00	2.58	1.09	1.79	1.43	0.35	0.42	3.15
B-7	2.70	3.00	2.62	0.96	0.55	6.21	0.32	1.58	25.00
B-8	1.25	1.29	1.46	0.81	0.79	2.82	0.17	0.55	8.29
B-9	0.21	0.00	16.30	1.43	1.49	3.71	1.06	0.48	4.12
B-10	0.15	0.39	1.88	0.96	1.61	1.90	0.39	0.10	2.65
B-11	0.00	0.47	3.23	1.67	1.60	2.17	0.96	0.07	3.71
B-12	2.89	2.56	3.14	1.19	1.87	8.32	0.81	1.15	18.40

Determination of Site EPCs Based on Area Weighted Representative Area EPCs

Under this methodology, the total site area was divided into a number of representative areas (RAs) that may include both systematic and biased samples. For this example, the AOC area of 1,000 m^2 was divided by seven sampling locations giving each RA an area of 142.9 m^2. The sampling locations and RAs are represented in Figure 1.

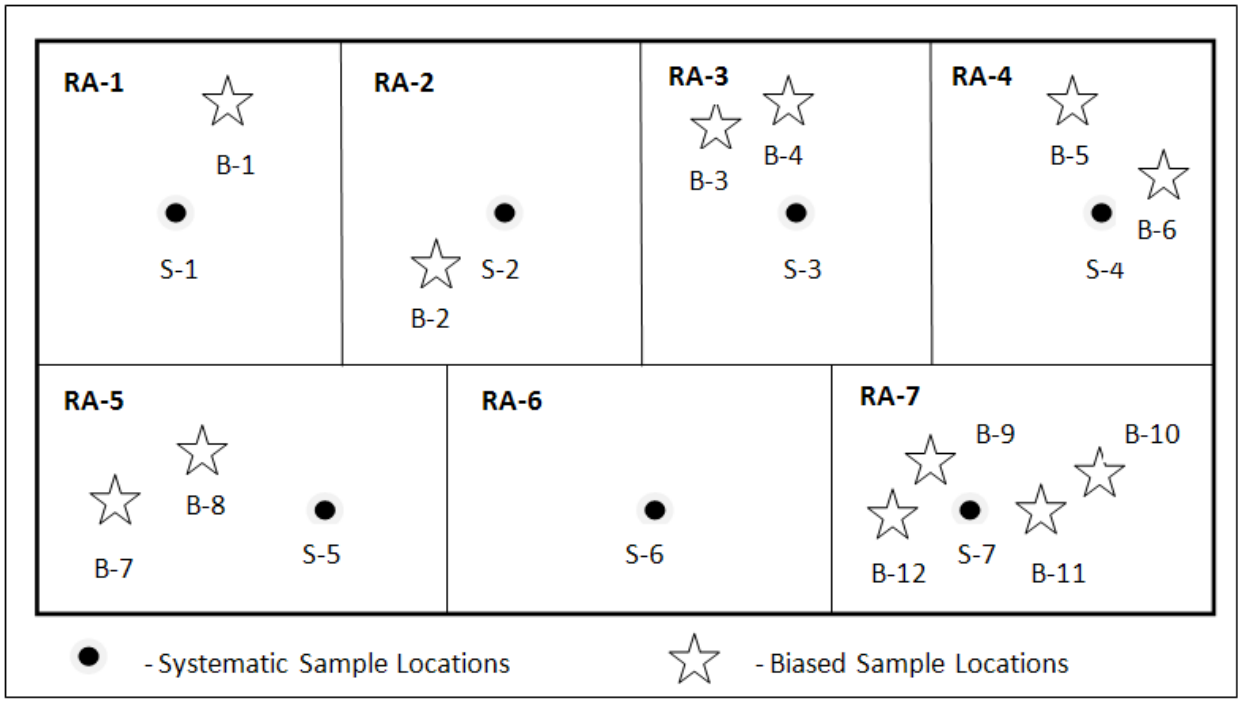

Fig. 1. AOC Sample Locations and RAs.

The EPCs for each radiological COCs were determined for each RA. The EPCs results for each RA and the ProUCL software were then utilized to determine the Site EPC for each radiological COC for the Site. The results for Site EPCs are listed in Table III.

Determination of Area Weighted Site EPCs Based on Separate Systematic EPCs and Biased EPCs

Under this methodology, ProUCL software and all systematic sample results were used to calculate the EPC for each radiological COC present at the Site. A separate EPC for each radiological COC was calculated for all biased sample results. The systematic and biased EPC values were then area weighted by multiplying the biased EPC value by the sum of the biased sample areas; multiplying the systematic EPC value by the total AOC area minus the sum of the biased sample areas; and then dividing the sum of those two results by the total AOC area. The sum of the biased sample areas was 51 m^2 therefore the area associated with the systematic samples was 949 m^2. The EPCs for each radiological COC are listed in Table III.

Determination of Non-Area Weighted Site EPC Based on both Systematic and Biased Samples

Under this methodology, the EPCs for each radiological COC were calculated by providing equal weighting to the sampling results for both systematic and biased samples. The EPCs for each radiological COC are listed in Table III.

Determination of Site EPCs Based on Only Systematic Samples

Under this methodology, the EPCs for each radiological COC were calculated by using the sampling results for only systematic samples. The EPCs for each radiological COC are listed in Table III.

Table III. Results of EPCs for Radiological COCs

Methodologies	Ac-227	Pa-231	Ra-226	Ra-228	Th-228	Th-230	Th-232	U-235	U-238
Site EPC based on Area Weighted RA EPCs	0.32	0.45	2.30	0.75	1.19	2.44	0.77	0.26	3.79
Area Weighted Site EPC based on Systematic EPC and Biased EPC	0.24	0.43	2.37	0.73	1.17	2.25	0.82	0.29	3.39
Non-Area Weighted Site EPC based on both Systematic and Biased Samples	0.83	0.98	6.83	0.95	1.42	4.53	1.04	0.53	9.35
Site EPC based on only Systematic Samples	0.15	0.34	1.98	0.70	1.15	2.10	0.81	0.25	2.90

DETERMINATION OF RESIDUAL DOSE AND RISK ASSESSMENTS

The human health radiological dose and risk assessment for radiological COCs were conducted by utilizing the residual radioactivity computer code (RESRAD) Version 6.5 (ANL. 2009) [3] and the derived EPCs under four methodologies, as presented in Table III. The RESRAD default receptor scenario, the default assigned values for exposure parameters, and the external, inhalation, and soil ingestion pathways were used to determine radiological dose and risk. The results of the residual dose and risk assessments are presented in Table IV.

Table IV. Results of Residual Dose and Risk Assessments

Methodologies	Dose (mrem/yr)	Risk
Site EPC based on Area Weighted RA EPCs	25	5.2E-4
Area Weighted Site EPC based on Systematic EPC and Biased EPC	25	5.1E-4
Non-Area Weighted Site EPC based on both Systematic and Biased Samples	60	1.2E-3
Site EPC based on only Systematic Samples	22	4.6E-4

The results presented in Table IV showed that EPCs derived using the non-area weighting methodology resulted in the highest dose and risk whereas the EPCs derived from the systematic only EPC methodology produced the smallest dose and risk. The table also showed that EPCs derived using the two area weighting methodologies produce approximately the same amount of dose and risk for the receptor and slightly higher than the systematic only EPCs and lower than the non-area weighted EPCs.

Depending on the release criteria for the site, the dose and risk values presented in Table IV could play a vital role in determining if additional costly cleanup is required. Failing to account for the biased sample data in the risk assessment could result in a lack of cleanup and subsequent property release resulting in over exposure to human health and the environment.

References

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