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The Impact of Including Below Detection Limit Samples in Post Decommissioning Soil Sample Analyses

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1. Introduction

Decommissioning is an emerging international issue in the nuclear industry. Termination of the decommissioning authorization involves releasing the facility from regulatory control for restricted or unrestricted use in the future.

Prior to releasing the facility from regulatory control, it must be shown that the site has been sufficiently cleaned up to meet either restricted or unrestricted use in the future. To meet the required standards the site owner has to show that the soil at the facility has been sufficiently cleaned up. To do this one must know the contamination of the soil at the site prior to clean up. This involves sampling that soil to identify the degree of contamination. However there is a technical difficulty in determining how much decontamination should be done. The problem arises when measured samples are below the detection limit. Regulatory guidelines for site reuse after decommissioning are commonly challenged because the majority of the activity in the soil at or below the limit of detection.

Using additional statistical analyses of contaminated soil after decommissioning is expected to have the following advantages: a better and more reliable probabilistic exposure assessment, better economics (lower project costs) and improved communication with the public. This research will develop an approach that defines an acceptable method for demonstrating compliance of decommissioned NPP sites and validates that compliance

2. Conventional Methods used to analyze Environmental Censored Data Sets

Censored values are reported as less than or greater than some value, or as an interval between some values. Left censored values are known to be less than some values and right censored values are known to be more than some values, respectively. By definition, environmental data with below the detection limit observations are an example of left censored data.

The main approaches for handling censored data are simple replacement and extrapolation. The most common and easiest strategy is simple replacement, where censored values are replaced with zero, or some fraction of the detection limit (usually 1/2 of the detection limit), or the detection limit itself. The extrapolation strategies, on the other hand, use regression or probability plotting techniques to calculate the mean and standard deviation based on the regression line of the observed values that are, above limit of detection values. Commonly used methods for dealing with environmental data sets that contain the detection limits are statistically biased and limited in their usefulness.

According to National Human Exposure Assessment Survey (NHEXAS) database, 30 to 70% of the observations are below the detection limits for many pollutants [1]. There is an impact on society due to uncertainties in technical factors. Costs for decommissioning are based on decommissioning strategies and final disposition of the site [2]. Therefore, these biased results use of the detection limits in the analysis can affect public communication and economics which directly impact the nuclear industry.

3. Additional Methods and Results

After decommissioning soil samples, representative radioactivity is determined by sampling analysis and the properties of residues or suspicious material from a monazite manufacturing factory. From Grid box No.1 and Grid box No.2, it is possible to get data points of U-238 and K-40, with data points below the detection limits.

Implementing goodness of fit tests demonstrate all nuclides in each Grid box follow both normal distribution and lognormal distribution.

Conventional methods, replacing censored values with zero, or 1/2 of the detection limit, or the detection limit, used to analyze censored data sets.

By applying additional methods, Cohen's table adjustment method, maximum likelihood estimation (MLE), Kaplan-Meier, and regression on order statistics (ROS), censored data sets are analyzed more accurately using Nondetects And Data Analysis (NADA) for R package and MATLAB [3,4].

Table I: Summary statistics using several estimation methods – U-238 in Grid box No.1

	Mean	STD DEV	Pct25	Median	Pct75
Zero	0.249	0.236	0.012	0.148	0.460

1/2 DL	0.261	0.223	0.048	0.148	0.460
DL	0.274	0.211	0.095	0.148	0.460
MLE(ln)	0.263	0.221	0.065	0.148	0.486
ROS(ln)	0.267	0.218	0.085	0.148	0.460
K-M	0.263	0.221	0.051	0.148	0.486

Table II: Summary statistics using several estimation methods – K-40 in Grid box No.1

	Mean	STD DEV	Pct25	Median	Pct75
Zero	0.040	0.054	0	0	0.087
1/2 DL	0.043	0.051	0.006	0.006	0.087
DL	0.046	0.049	0.012	0.012	0.087
MLE(ln)	0.043	0.051	0.003	0.012	0.091
ROS(ln)	0.046	0.049	0.012	0.012	0.087
K-M	0.054	0.044	NA	NA	0.091

Table III: Summary statistics using several estimation methods – U-238 in Grid box No.2

	Mean	STD DEV	Pct25	Median	Pct75
Zero	0.328	0.324	0	0.242	0.561
1/2 DL	0.346	0.305	0.055	0.242	0.561
DL	0.364	0.288	0.109	0.242	0.561
MLE(ln)	0.353	0.299	0.102	0.242	0.604
ROS(ln)	0.358	0.294	0.109	0.242	0.561
K-M	0.379	0.277	NA	0.213	0.583

Table IV: Summary statistics using several estimation methods – K-40 in Grid box No.2

	Mean	STD DEV	Pct25	Median	Pct75
Zero	0.064	0.070	0	0.026	0.124
1/2 DL	0.066	0.069	0.006	0.026	0.124
DL	0.068	0.067	0.013	0.026	0.124
MLE(ln)	0.067	0.068	0.011	0.026	0.128
ROS(ln)	0.067	0.068	0.012	0.026	0.124
K-M	0.068	0.067	NA	0.026	0.127

Table V: Summary statistics using several estimation methods – U-238 in Grid boc NO.1 and Grid box No.2

	Mean	STD DEV	Pct25	Median	Pct75
Zero	0.288	0.284	0	0.202	0.502
1/2 DL	0.305	0.267	0.055	0.202	0.502
DL	0.321	0.253	0.109	0.202	0.502
MLE(ln)	0.306	0.266	0.077	0.202	0.518
ROS(ln)	0.311	0.262	0.095	0.202	0.502
K-M	0.307	0.267	0.085	0.191	0.494

Table VI: Summary statistics using several estimation methods – K-40 in Grid boc NO.1 and Grid box No.2

	Mean	STD DEV	Pct25	Median	Pct75
Zero	0.052	0.063	0	0.018	0.105
1/2 DL	0.055	0.061	0.006	0.018	0.105
DL	0.058	0.059	0.013	0.018	0.105
MLE(ln)	0.055	0.061	0.006	0.018	0.107
ROS(ln)	0.054	0.060	0.011	0.015	0.103
K-M	0.058	0.059	NA	0.016	0.104

The mean appears to be underestimated for all cases except replacing values below DL with DL

Table VII: Various confidence interval for the mean using MLE/Bootstrap

Cases	90% confidence interval for the mean	95% confidence interval for the mean
U-238 in Grid box No.1 (Mean : 0.263)	[0.106, 0.336]	[0.068, 0.348]
K-40 in Grid box No.1 (Mean : 0.043)	[-0.107, 0.060]	[-0.179,0.064]
U-238 in Grid box No.2 (Mean : 0.353)	[0.140, 0.448]	[0.086, 0.465]

Table VIII: Maximum Total Dose (t) and Maximum Total Excess Cancer Risk (t) for the several estimation methods in Grid box No.1

Cases	Maximum Total Dose (t) (mrem/yr)	Maximum Excess Cancer Risk (t)
Ignoring	7.112 (t=0)	1.713E-4 (t=0)
Zero	4.693 (t=1000yr)	8.544E-5 (t=0)
1/2 DL	4.919 (t=1000yr)	9.114E-5 (t=0)
DL	5.077 (t=1000yr)	9.694E-5 (t=0)
MLE	4.957 (t=1000yr)	9.135E-5 (t=0)

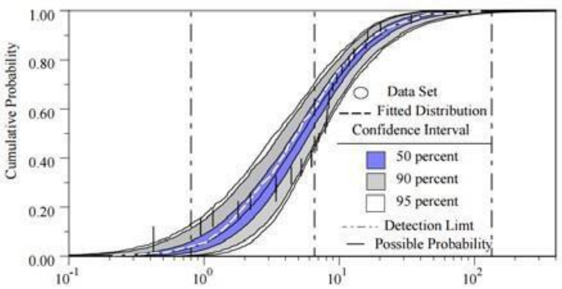

Fig. 1. Uncertainty of U-238 in Grid box No.1 estimated based upon a lognormal distribution.

4. Summary

Soil samples from NPP often contain censored data. Conventional methods for dealing with censored data sets are statistically biased and limited in their usefulness. In this research, additional methods are performed using real data from a monazite manufacturing factory.

Using additional statistical analyses of contaminated soil before or after decommissioning is expected to have a better and more reliable probabilistic exposure assessment, better economics and improved communication with the public.

REFERENCES

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