

Including Below Detection Limit Samples in Decommissioning Soil Sample Analyses

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Introduction

Introduction

- Decommissioning is an emerging international issue in the nuclear industry.
- Termination of an NPP license, involves releasing the facility from regulatory control for either restricted or unrestricted use in the future.
- Current Domestic Research Focuses on;
 - Development of Clearance Standards
 - Evaluation of Exposure.

Introduction

NPP site soil analysis for license termination

- There are technical problems for finalizing regulations and standards.
 - Hot Spots
 - Observations reported as below the detection limits
- Observations reported as below the detection limits are caused by:
 - Inherent limitations of measurement methods (e.g. detectors)

Introduction

- Conventional methods for analyzing soil sampling data:
 - Only use values above detection limit (This ignores non-detects)
 - Replace non-detects with zero
 - Replace non-detects with half of the detection limit (DL)
 - Replace non-detects with DL
- However, these strategies have limitations:
 - Statistically biased estimate
 - Probabilistic Exposure Assessment is unreliable
 - Predicts a higher dose --- causing higher waste volumes and associated costs

Introduction

- To resolve these issues Statistical Techniques were used to analyze a case study
 1. Proposed methods for estimating summary statistics (Mean, STD DEV, PCT)
 - **Kaplan-Meier**
 - **Regression on Order Statistics (ROS)**
 - **Maximum Likelihood Estimation (MLE)**
 2. Proposed method for estimating confidence intervals
 - **Bootstrapping**
- These techniques are used by many researchers in the Environmental Science and Technology area.

Introduction – Kaplan-Meier

- The Kaplan-Meier method is a nonparametric technique which is the most commonly used for calculating the probability distribution to estimate summary statistics with censored data.
 - Kaplan-Meier is nonparametric, so it does not assume the data follow a known distribution.
 - Kaplan-Meier is well-suited for many environmental data sets because it is nonparametric.

Introduction – Kaplan-Meier

- Consider the following data set:

20, 20, 10, 1, <0.5, <0.5, <25, <2, <2, 1, 100, 30, 3, <3, 2, 1, 3, 5, <10, <0.5

- Order this data set in decreasing order (Efron's bias correction):

100, 30, <25, 20, 20, 10, <10, 5, 3, 3, <3, 2, <2, <2, 1, 1, 1, <0.5, <0.5, 0.5

- The probability of each data point is as below:

- The probability of getting a data point less than 100 is $19/20=0.95$
- The probability of getting a data point below 30 is $18/19=0.947$
The location of 30 on the PDF is calculated by $0.95*0.947=0.90$
- The probability of getting a data point below 20 is $15/17=0.882$
The location of 20 on the PDF is calculated by $0.90*0.882=0.794$

Introduction – Kaplan-Meier

Value	Probability
100	0.95
30	0.90
20	0.794
10	0.741
5	0.684
3	0.570
2	0.507
1	0.253
0.5	0

Table 1. Kaplan-Meier example data

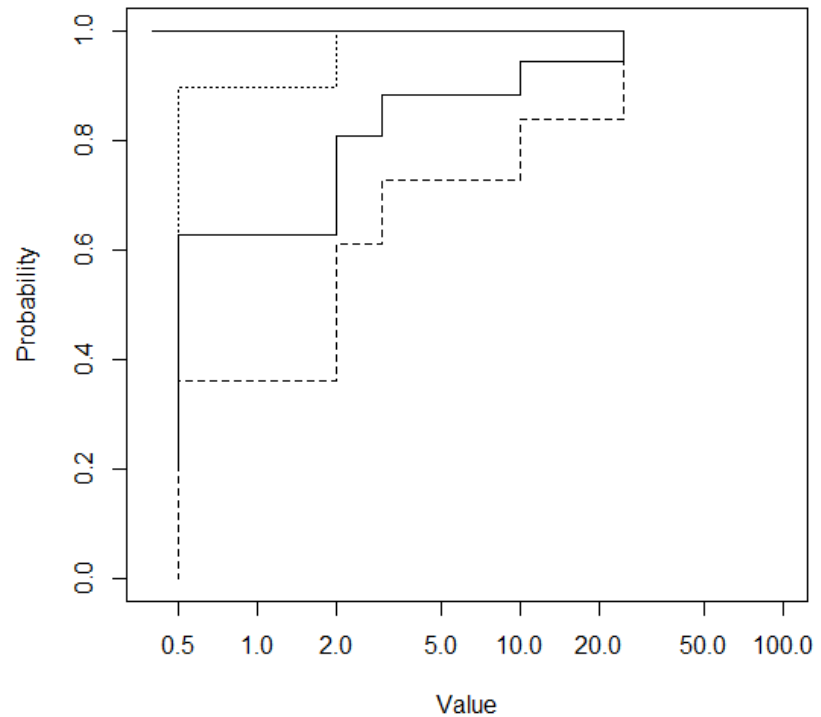


Fig. 1. Kaplan-Meier method example data plot

Introduction – ROS

- Robust regression on order statistics (ROS) is a semi-parametric method that can be used to estimate summary statistics with censored data. ROS plots the detected values on a probability plot and calculates a linear regression line in order to estimate the parameters.
 - ROS internally assumes that the underlying population is normal or lognormal. However, the assumption is applied to only the censored data set and not to the full data set.
 - It is necessary to fit a known distributional model to the detected values on a probability plot.

Introduction – ROS

Input Concentration	Probability	Estimated Concentration
3.2	0.972	3.2
2.8	0.944	2.8
<2	0.815	1.418
<2	0.713	1.143
<2	0.611	0.954
<2	0.509	0.807
<2	0.407	0.683
<2	0.306	0.572
<2	0.204	0.465
<2	0.102	0.349
1.7	0.873	1.7
1.5	0.829	1.5

Table 2. ROS final data

Introduction – MLE

- Maximum likelihood estimation (MLE) is a parametric, model-based method that can be used to estimate summary statistics with censored data. Probability plots and other goodness-of-fit techniques should be used to find matching distributions.
 - Nondetects are distributed in a manner similar to the detected values.
 - If the assumed model is incorrect, MLE may lead to misleading results.

Introduction – Bootstrap

- After generating 100 bootstrap samples, it is possible to find the confidence interval for the mean, calculating the difference between the mean of the original sample and the mean of bootstrap samples.

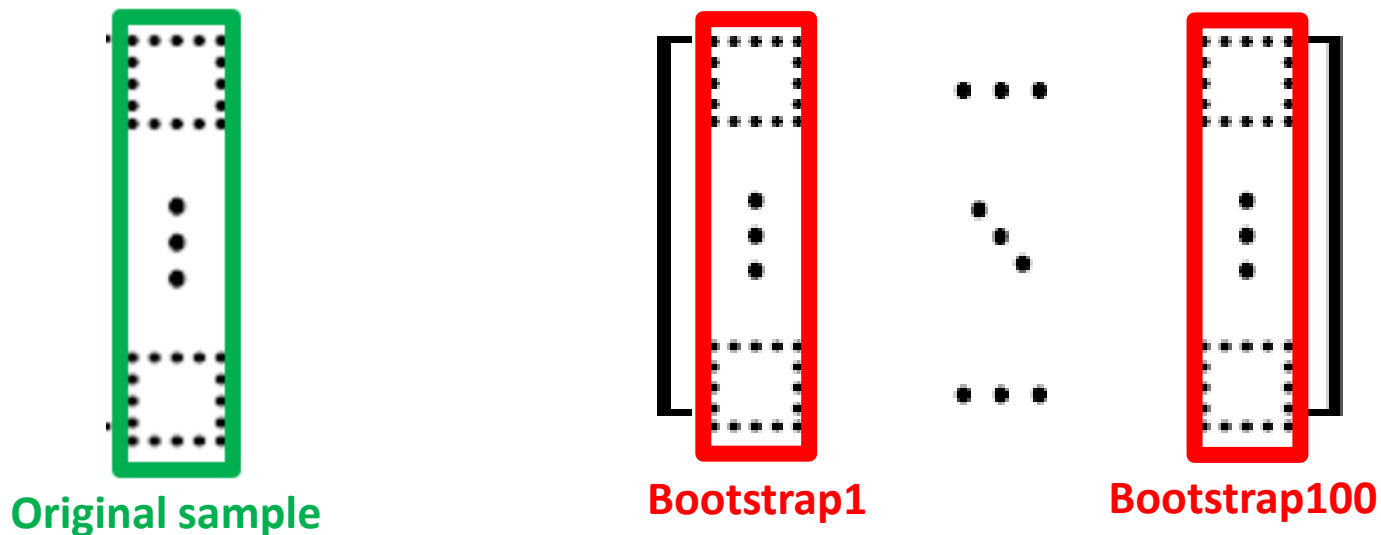


Fig. 2. Schematic matrix of original sample and bootstrap samples

Purpose of the research

“Develop a statistical approach that more accurately estimates the required site decontamination necessary to meet current cleanup criteria and validate that compliance.”

- The expected advantages are:
 - Better Probabilistic Exposure Assessment
 - More Cost Effective

Case study

Case study

- There is a monazite powder manufacturing plant.
- Some of the plant facilities and soil were contaminated during the manufacturing process.
- Facility soil was decontaminated and soil survey conducted.

Case study

- The survey consisted of Grid box No.1 and Grid box No.2, each having 30 data points measuring the concentration of U-238 and K-40, in the same area.
- In Grid box No.1, 8 data points are below the detection limit for U-238, and 17 for K-40.

Grid box No.1

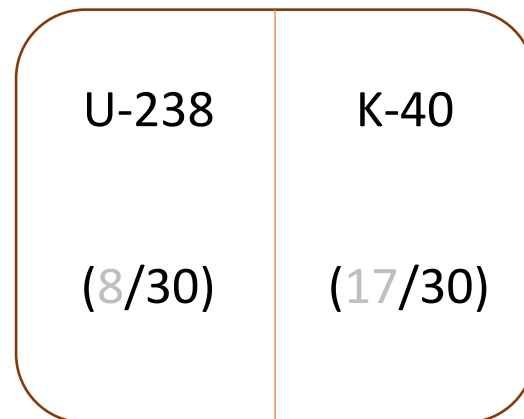


Fig. 3. Schematic diagram of Grid box No.1

Case study

- In Grid box No.2, 10 data points are below the detection limit for U-238, and 9 for K-40.

Grid box No.2

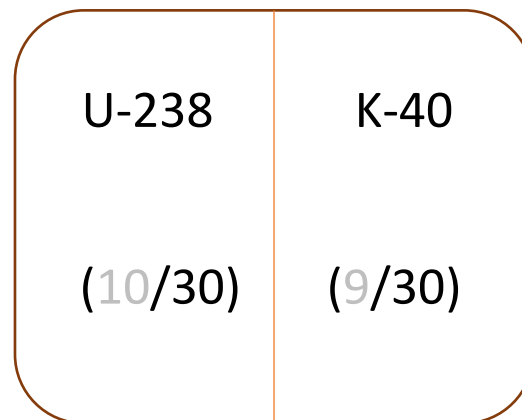


Fig. 4. Schematic diagram of Grid box No.2

Results

U-238 in Grid box No.1

	Mean (Bq/g)	STD DEV (Bq/g)	Pct25 (Bq/g)	Median (Bq/g)	Pct75 (Bq/g)
Ignoring	0.339	0.212	0.123	0.351	0.534
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 3. Summary statistics using several estimation methods – U-238 in Grid box No.1

K-40 in Grid box No.1

	Mean (Bq/g)	STD DEV (Bq/g)	Pct25 (Bq/g)	Median (Bq/g)	Pct75 (Bq/g)
Ignoring	0.092	0.042	0.072	0.094	0.110
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			0.091

Table 4. Summary statistics using several estimation methods – K-40 in Grid box No.1

U-238 in Grid box No.2

	Mean (Bq/g)	STD DEV (Bq/g)	Pct25 (Bq/g)	Median (Bq/g)	Pct75 (Bq/g)
Ignoring	0.492	0.274	0.228	0.408	0.7735
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		0.213	0.583

Table 5. Summary statistics using several estimation methods – U-238 in Grid box No.2

K-40 in Grid box No.2

	Mean (Bq/g)	STD DEV (Bq/g)	Pct25 (Bq/g)	Median (Bq/g)	Pct75 (Bq/g)
Ignoring	0.092	0.067	0.023	0.108	0.135
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		0.026	0.127

Table 6. Summary statistics using several estimation methods – K-40 in Grid box No.2

Confidence interval using MLE/Bootstrap

Cases	90% confidence interval for the mean (Bq/g)	95% confidence interval for the mean (Bq/g)
U-238 in Grid box No.1 (Mean : 0.263)	[0.189, 0.413]	[0.177, 0.450]
K-40 in Grid box No.1 (Mean : 0.043)	[0.025, 0.176]	[0.022, 0.233]
U-238 in Grid box No.2 (Mean : 0.353)	[0.256, 0.554]	[0.240, 0.604]
K-40 in Grid box No.2 (Mean : 0.067)	[0.043, 0.142]	[0.039, 0.165]

Table 7. Various confidence intervals for the mean using MLE/Bootstrap

Background - RESRAD

- RESRAD is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials.
- RESRAD code is used for determining regulatory compliance.
- Both the U.S Department of Energy and the U.S. Nuclear Regulatory Commission use 25 mrem/yr as the general limit or constraint for soil cleanup or site decontamination.
- RESRAD code has the basic models and parameters, but it can be modified to meet specific need.

Background - RESRAD

- RESRAD code can be used to :
 - Compute potential annual doses or lifetime risks to workers or members of the public resulting from exposures to residual radioactive material in soil
 - Support an ALARA analysis or a cost benefit analyses that can help in the cleanup decision-making process.

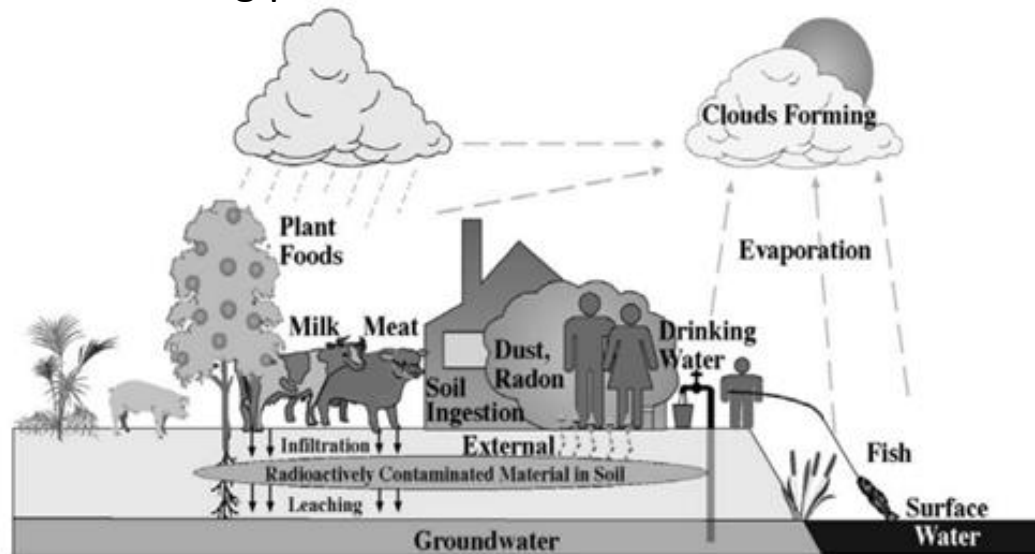


Fig. 5. Exposure pathways considered in RESRAD

Background - RESRAD

- Assumptions
 - Farmer scenario (Consider all pathways)
 - Municipal landfill
 - Climate data in Daejeon
 - National nutrition survey
 - Default value
 - Did not consider radon and C-14

Results

Cases	Maximum Total Dose (t) (mrem/yr)	Maximum Excess Cancer Risk (t)
Ignoring	29.11 (t=128.3yr)	1.127E-3 (t=100yr)
Zero	13.09 (t=128.4yr)	4.985E-4 (t=100yr)
1/2 DL	14.15 (t=128.4yr)	5.396E-4 (t=100yr)
DL	15.99 (t=128.3yr)	6.114E-4 (t=100yr)
MLE	14.13 (t=128.4yr)	5.388E-4 (t=100yr)

Table 8 Maximum Total Dose (t) and Maximum Excess Cancer Risk (t) for the several estimation methods in Grid box No.1

Conclusions

- Summary statistics and confidence intervals were compared to conventional methods.
- Proposed methods (MLE, ROS, K-M) were performed using the soil samples from the monazite powder manufacturing plant.
- The preliminary evaluation shows that the proposed method can be effectively used to provide
 - Best Estimate Radioactivity levels at decommissioned NPP site.
 - Estimates of uncertainty in the Mean Values
- RESRAD is used to estimate radiation doses and risks in each case.
- Cover thickness is calculated to show the difference between the each method.

Future work

- Get the soil data from real decommissioned NPP and conduct all of the above analyses (Contacted NRC).
- Benchmark the recommended guidance on site specific implications of available data.
- Economic analysis of the degree of savings using new methodology.
- Develop RESRAD input code that allows the inclusion of non-detects.

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Thank you
