Establishing Conservative Limits through a Statistical Approach for Low-Level Waste (LLW) from Decommissioning

Jeongwook Moon*, Geun- Ho Kim and Jongjin Kim
Korea Atomic Energy Research Institute (KAERI), 111 Daedeok-daero Yuseong-gu, Daejeon
*jwmoon@kaeri.re.kr

1. Introduction

- At KAERI, the decommissioning of two research reactors that have been operating since 1962 and 1972, respectively, is currently taking place.
- As the national policy related to decommissioning changes frequently, the reclassification of waste had to be conducted again. Multiple rounds of reclassification, however, make the waste records more diverse and complex, which may cause difficulty in confirming the radioactive concentration of the decommissioning waste.
- Countries that have already performed decommissioning have developed and applied a scaling factor using the correlation between nuclides for reactive waste that have the same generation history in order to find the concentration of radioactive nuclides that are difficult to detect; however, such a method is not applicable to CV stream waste. Applying a detailed analysis or conservative limiting value to such radioactive waste is recommended in IAEA TECDOC-1357.
- Therefore, 23 samples were selected among the entire 120 tons (343 drums) of concrete waste for the destructive analysis, and a conservative limiting value was deduced by using a statistical method on the analysis results.

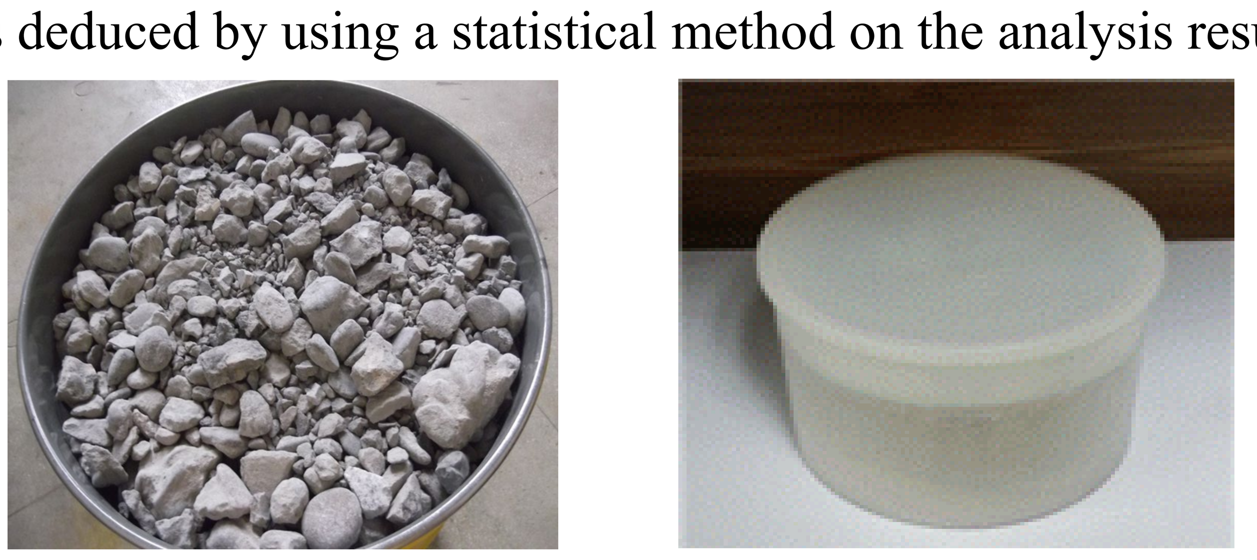

Figure1. Decommissioning Concrete Waste Drum & Sampling material

2. Methods and Results

2.1 Setting a Statistical Unit of Decommissioning Waste

- The entire waste to be disposed of is included in the evaluation unit or the population, while the samples being made for a nuclide analysis among the entire waste are included in the sample unit. In the measurement unit, the measured samples that are extracted for actual measurements are included. Hence, this indicates that all the generated samples have been measured if the sample and the measurement units are identical.
- The concrete waste generated in the KRR can be considered the evaluation unit, or the population, of the 343 drums (120 tons) of the decommissioning waste; 343 samples extracted from each drum can be considered the sample unit, while the 23 samples that were actually used in the measurement can be considered the measurement unit.

2.2 Setting the Conservative Limiting value Using a Statistical Approach

- The distribution of the population (the entire waste) was first determined to estimate the conservative limiting value using a statistical method.
- To reduce the risk of underestimating the population mean, the cumulative probability density function (CDF) 99.99%, or the maximum value of the normal distribution, was selected as the population mean instead of the two-sigma that is commonly used in statistical estimation.
- Subsequently, the population distribution was estimated using the deviation of the sample in order to correct the distribution of the estimated mean value.
- Finally, the conservative limiting value of the concentration of the nuclides that are difficult to extract from the ultra-low-level waste was determined by combining the estimated population variance with the induced population mean.

2.3 Estimation of the Population Mean and Maximum Cumulative Probability Density Function

- The probability density function (PDF) was calculated based on the values of the 23 samples that were measured, and the CDF was calculated by integrating the PDF. When the sample distribution follows a normal distribution, the PDF and the CDF can be represented in the following equations.

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma_x} \cdot \exp\left(-\frac{(x-\mu_x)^2}{2\sigma_x^2}\right)$$

$$F(x) = \frac{1}{2} \cdot \left(1 + erf\left(\frac{x-\mu_x}{\sqrt{2}\sigma_x}\right)\right)$$

- Here, F(x) is the cumulative probability density function of x. Subsequently, the nuclide concentration at CDF 99.99% can be set as the population mean.

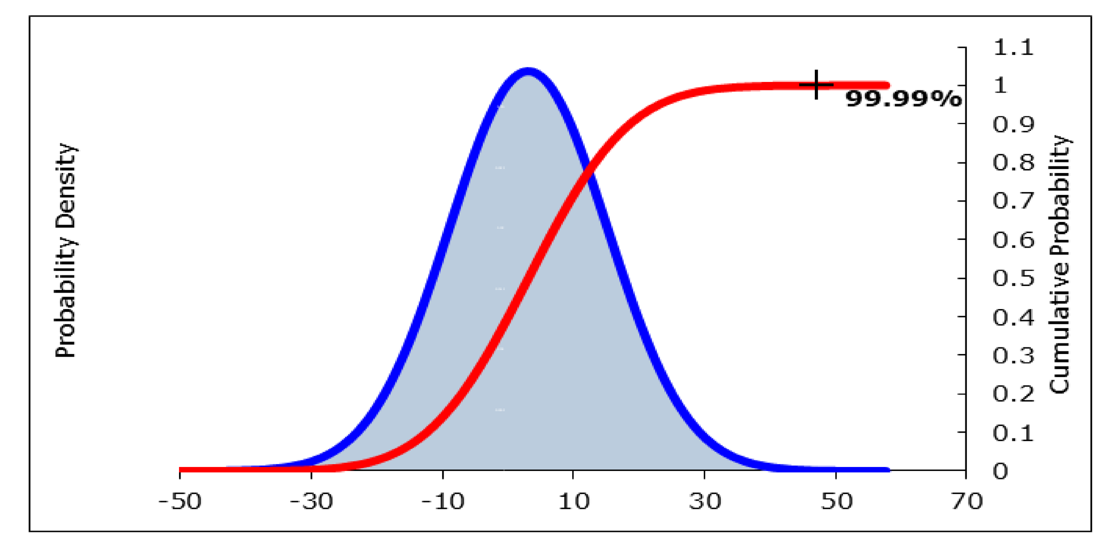

Figure2. Estimated population mean (CDF 99.99%)

2.4 Estimation of Population Standard Deviation

- The standard deviation of the sample was calculated to estimate the population distribution in order to correct the distribution of the estimated mean value. The chi-squared distribution, which is commonly used for estimating the distribution, was used for the population standard deviation, and the PDF of the χ^2 distribution can be represented in the following equation.

$$f(x,\nu) = \begin{cases} 0, & x < 0 \\ \frac{1}{2^{\frac{\nu}{2}} \cdot \Gamma\left(\frac{\nu}{2}\right)} \cdot x^{\frac{\nu}{2}-1} \cdot e^{-\frac{x}{2}}, & x \geq 0 \end{cases} \quad \text{(Eq. 3)}$$

2.5 Setting the Conservative Limiting Value

- Among the 343 drums generated from the decommissioning, the concentration of the nuclides for which a detailed analysis is difficult to conduct was determined by combining the estimated population mean with the population standard deviation calculated by estimating the population variance
- When the same approach was applied for the nuclide Co-60 for which a total inspection had been conducted, the set conservative limiting value was similar yet more conservative than the maximum value of the actual population.

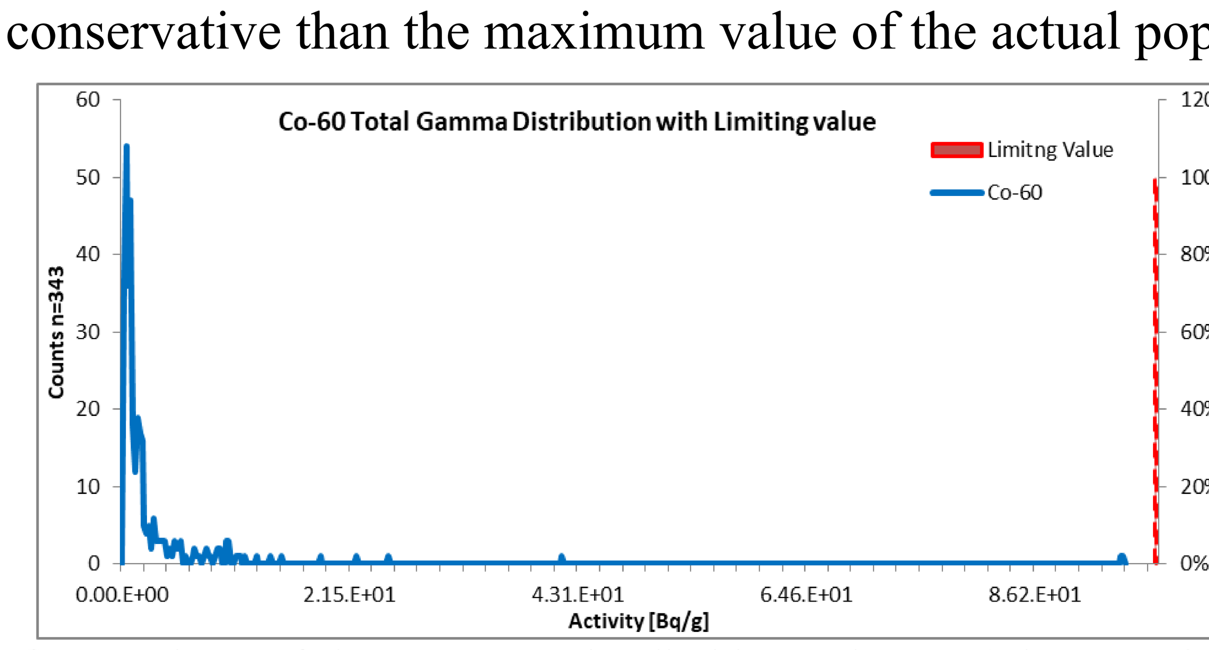

Figure3. Comparison of the conservative limiting value and the population (Co-60)

[Bq/g]	Population Mean	Population Variance	Compare with Maximum value
Samples (N=23)	1.15.E+02	1.66.E+03	**1.67.E+02** (Conservative Limiting value)
Population (N-343)	1.27.E+02	1.46.E+02	**1.27.E+02** (Maximum value)

Table1. Estimation conservative limiting value & Comparison with population (Co-60)

3. Conclusion

- In order to determine the conservative limiting value of the CV stream waste, the population mean was estimated using the cumulative probability normal distribution, and the population standard deviation was estimated using the chi-squared distribution to correct such a distribution. Ultimately, the sum of the estimated values was used for setting the conservative limiting value;
- The risk when deducing the conservative limiting value using a statistical method is the overestimation of the radioactive concentration. Therefore, before using the statistical method, a user should compare the cost of conducting a detailed analysis and that generated when the radioactive concentration increases by applying the conservative limiting value in order to make a strategic decision.

PO3C16