Estimation of the uncertainty of N-type HPGe

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1. Introduction

The Compton Suppression System (CSS) is established in order to screen the environmental samples in the Korea Institute of Nuclear nonproliferation and Control (KINAC). The CSS is composed with 2 types of detectors to collect photons such as NaI(Tl) and High Purity Germanium (HPGe).

The uncertainty indicates the reliability of the result for radioactivity which is derived from the each detector. This article details the estimated uncertainty of the HPGe which contributes to the uncertainty of the CSS mostly. The uncertainty could be a result of variances in the detecting system, geometry, and radionuclides targeted. KINAC made a request to the Korea Research Institute of Standards and Science (KRISS) to analyze the calculation process of the uncertainty for confirming the objectivity.

This article shows the calculation process of the uncertainty and the reliability so as to determine uncertainty in the screening of environmental samples.

2. Methods

2.1 The condition of the detector and the electronics

The HPGe composing the CSS in KINAC is the Gamma-X made by ORTEC. The GAMMA-X is an N-type coaxial detector. KINAC selected a carbon fiber endcap to detect photons which have energies between 10 keV and 10 MeV. The relative efficiency of the HPGe is 60%. And the FWHMs which indicate the resolution are 1.1 keV at 5.9 keV and 2.3 keV at 1.33 MeV. The Gamma Vision is adapted as an emulator. And KINAC keep cooling the HPGe with liquid nitrogen due to reducing the probability to affect the uncertainty.

KINAC uses the analogue electronics [1]. The analogue electronics is composed with a High Voltage Supplier (ORTEC 659), an Amplifier (ORTEC 672), and a Multi-Channel Analyzer (ORTEC 927).

The space on the HPGe is limited because the NaI annulus surrounds the HPGe. This limited area makes swipe sample sized 10 cm × 10 cm fold twice. However, there are several cases not knowing in which the location of the nuclides on the sample is not exactly known. This situation brings the uncertainty. Therefore, KINAC calibrated the HPGe's efficiency 5 times in the condition using new 4 cotton papers under the standard source.

2.2 The radionuclides

A mixed standard source on a cotton paper was used. This source is composed of 10 nuclides for calibration. And other three swipe samples were used for estimating the uncertainty. These samples are composed of 13 nuclides, including: ^{134}Cs, ^{54}Mn, ^{65}Zn, and 10 nuclides inside the mixed standard source supplied by KRISS.

Most of these nuclides emit several energies more than one. KINAC selected the energy representing for each radionuclide which is having the highest emission probability (yield). However the secondary yield was selected in the ^{109}Cd case, because of its low efficiency in 22 keV

2.3 The modeling for deriving radioactivity

KINAC derived the uncertainty based on the procedure suggested in the Guide to the expression of Uncertainty in Measurement (GUM) [2]. According to GUM, the first step is determining the parameters which are able to affect the radioactivity. After that, modeling the measurement is implemented.

IAEA derived the radioactivity calculation model from the net counts of the High Resolution Gamma System (HRGS) as detailed below [3].

$$A = \frac{N}{\varepsilon \gamma t_s m\, K_1 K_2 K_3 K_4 K_5} \quad (1)$$

N is the net peak area in the sample spectrum [cts],

ε is the efficiency at photopeak energy,

t_s is the live time of the sample spectrum collection in seconds [s],

m is the mass of the measured sample [kg],

γ is the yield of the gamma line corresponding to the peak energy,

K_1 is the correction factor for the nuclide decay from the time the sample was collected to the start of the measurement

K_2 is the correction factor for the nuclide decay during counting period

K_3 is the correction factor for pulses loss due to random summing:

K_4 is the correction factor for a self-attenuation in the measured sample compared with the calibration sample.

K_5 is the coincidence correction factor for those nuclides decaying through a cascade of successive photon emissions

This modeling is able to adapt for every detector which acquire signals and print out the data as a spectrum, such as the semiconductor detector and scintillator. KINAC used this model for calculating the uncertainty of the HPGe except the parameters such as γ, K_4 and K_5. K_4 was not considered because same geometry adapted for calibration and measurement. Furthermore, K_5 and γ were not considered because the coincidence summing effect could exert influence on each efficiencies at the specific energy. Therefore, radioactivity was calculated not for nuclides but for energy. The activity concentration A [Bq/kg] of a gamma-emitting radionuclide in the swipe sample is calculated as:

$$A = \frac{N}{\varepsilon t_s m\gamma\, K_1 K_2 K_3} \quad (2)$$

K_1 is given as:

$$K_1 = \exp\left(-\frac{\ln 2\, \Delta t}{T_{1/2}}\right) \quad (3)$$

Δt is the elapsed time from the time the sample was taken to the beginning of the measurement [s],

$T_{1/2}$ is the radionuclide's half life [s].

K_2 is given as

$$K_2 = \frac{T_{1/2}}{\ln 2\, t_r}\left[1 - \exp\left(-\frac{\ln 2\, t_r}{T_{1/2}}\right)\right] \quad (4)$$

t_r is the elapsed real clock time during the measurement [s].

K_3 is given as:

$$K_3 = \exp(-2R\tau) \quad (5)$$

Where R is the mean count rate and τ is the resolution time of the measurement system.

KINAC used the direct efficiency instead of the efficiency curve to reduce the impact from the coincidence summing- this is especially case with regartd to ^{137}Cs, ^{60}Co, and ^{88}Y. In this situation, there were no efficiencies for nuclides such as ^{134}Cs, ^{54}Mn, and ^{65}Zn not included in the standard source. KINAC substituted the efficiencies interpolated from efficiencies laid on the nearest energies.

3. Results

3.1 The combined standard uncertainty

Table I is a sample budget of standard uncertainty of the ^{241}Am at 59.54 keV of the sample 1 calculated according to the GUM process. The uncertainty of the efficiency contributes the most, among the parameters to affect the combined standard uncertainty. It exceeds 2% of that recommended by the IAEA for efficiency uncertainty of HRGS [3]. However, KINAC included the geometry uncertainty inside the efficiency, after it was calculated.

Table I: The budget of the radioactivity uncertainty

Quantity	Estimation	Relative uncertainty	Level of contribution
Net count	8470577	0.0005	-
Efficiency	0.24	0.0316	93%
Yield	0.36	0.0014	-
K_1	1	0	-
K_2	1	0	-
K_3	0.93	0.0084	7%
Activity (Bq)		2685.27	
Combined standard uncertainty (%)		3.28	

3.2 Expanded uncertainty

Table II shows an expanded uncertainty of the swipe samples when the coverage factor is 2. The expanded uncertainty of the other nuclides were between 2.78~6.80%. These values are under the uncertainty of the IAEA's screening [4].

Table II: The expanded uncertainty of the swipe sample

Radio nuclides	Expanded uncertainty (%) (k=2)		
	1	2	3
^{241}Am	6.55	6.49	6.52
^{109}Cd	5.87	5.80	5.83
^{57}Co	6.06	5.99	6.03
^{139}Ce	3.83	3.72	3.78
^{51}Cr	3.39	3.12	3.33
^{113}Sn	3.07	2.91	3.01
^{85}Sr	3.39	3.26	3.33
^{134}Cs	4.19	4.09	4.15
^{137}Cs	6.01	5.94	5.98
^{54}Mn	3.62	3.50	3.56
^{65}Zn	3.75	3.68	3.74
^{60}Co	2.78	2.62	2.70
^{88}Y	6.80	6.74	6.77

4. Conclusions

KINAC submitted its results of estimated uncertainty including radioactivity. KRISS suggested that consideration be given to the uncertainty from the coincidence summing. Therefore, KINAC will estimate the total uncertainty of the HRGS and the CSS

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