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Minimum detectable activity evaluation of seawater radioactivity monitoring system using MCNP simulation

Dayeong Lee [a,b], Seongjin Maeng [a,b], Taeho Kim [a,b], Seyoung Yu[a], Sang Hoon Lee[a,b*]
[a]*School of Energy Engineering, Kyungpook National Univ., 80 Daehakro, Bukgu, Daegu, 41566*
[b]*Radiation Science Research Institute, Kyungpook National Univ., 80 Daehakro, Bukgu, Daegu, 41566*
[*]*Corresponding author: lee@knu.ac.kr*

1. Introduction

Due to oceanic dispersion of Fukushima-accident-derived radioactive cesium, seawater radioactivity monitoring has become a world issue of radiation safety. Currently, Korea have used two methods to measure seawater radioactivity. The first is a method of periodically collecting samples from predetermined points and analyzing them with HPGe or NaI in laboratories. The second method is to measure the radioactivity level in real time by installing NaI detector in the marine environment. In this study, an intake-type seawater monitoring system is suggested to quickly check the radioactivity level with better mobility in case of an emergency. The characteristics of the system including the minimum detectable activity (MDA) of various situation are calculated using MCNP simulations. Result comparisons for systems in marine environment and of intake-type are presented.

2. Methods and Results

2.1 System description

The intake gamma ray monitoring system made of detector module with housing and a water tank is surrounded by a lead shield as shown in Figure 1. In the detector module there is a 3 X 3 inch NaI(Tl) scintillator coupled with a PMT. The detector is enclosed in a 5 mm thick acrylic cylinder housing for waterproofing and protection. The water tank is suggested as a cylinder made of stainless steel with a diameter of 60 cm and a height of 60 cm through optimization calculations and for easy mobility in case of an emergency.

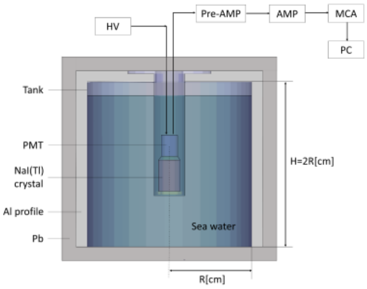

Fig. 1. Layout of intake-type NaI(Tl) seawater monitoring system

The detection characteristics of the system were analyzed through Monte Carlo using the MCNP code.[1] Assuming that there is a detector at the center of the water tank, the detection efficiency for the various volume source were simulated by increased radii and heights of the water tank. As a result, the volume efficiency (volume X efficiency) increased along with the radius and reached equilibrium at a certain level as shown in Fig. 2. Here, the volume of the saturated tank was defined as effective volume. The ^{131}I, ^{137}Cs and ^{40}K detection efficiency of this system (60 cm radius and 60 cm height) account for 95 %, 90 %, and 76 %, respectively, compared to the maximum efficiency in the effective volume. In addition, the optimal detector position was determined with the detector detection surface 18 cm above the bottom of the tank by using MCNP simulation.

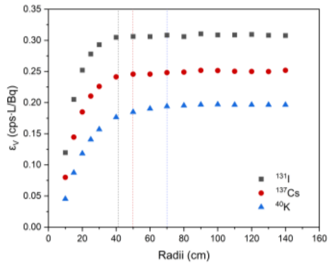

Fig. 2. Detection efficiency saturation for tank radii increase.

2.2 Validation of simulation and system calibration

The energy and resolution calibration of the system was performed using certificated reference disk source (CRM). The source is positioned at a distance of 5 cm from the detection side of detector. The resolution calibration was defined by following equation:

$$\mathrm{FWHM(MeV)} = a + b\sqrt{E + c \cdot E^2} \qquad (1)$$

where E is the energy of gamma ray (in MeV) and a, b, c are calibration parameters. These parameters were used for the “GEB” card in MCNP code. The measured spectrum and the simulated spectrum were compared considering the total number of particles emitted from the CRM. (see Figure 3.)

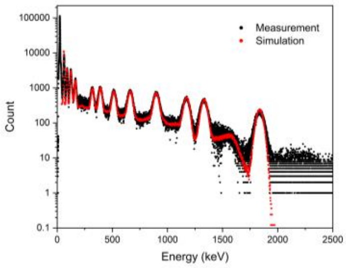

Fig. 3. Comparison between experimental and simulated energy spectrum for CRM source in air.

It is difficult to determine the detection efficiency in the marine environment for all γ-ray energies experimentally, since there are a rather limited number of single-energy, gamma emitting radionuclides that are soluble in water. [2] Therefore, efficiency calibration on the volumetric source was determined using Monte Carlo simulations. To verify the simulation results, 53.7 g KCl was diluted in the tank, resulting in 5.86 Bq/L volumetric activity. The difference between the experimental efficiency value of the system and the simulation is 0.087 %. The simulated volumetric detection efficiency and experimental value are shown in Figure 4. Therefore, we confirmed the reliability of Monte Carlo simulation.

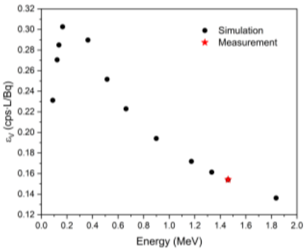

Fig. 4. Efficiency curve calculated using MCNP simulation and measured data for volume sources.

2.3 MDA Evaluation

MDA represents the detector's ability to quantify radiation slightly higher than any background radiation. Mathematically, the MDA is given by the following equation. ($k_\alpha = k_\beta = 1.645$, 95 % confidence level) [3]

$$\mathrm{MDA} = \frac{L_D}{t_s \times \epsilon_v \times I_\gamma} = \frac{2.71 + 4.65\sqrt{B}}{t_s \times \epsilon_v \times I_\gamma} \quad (2)$$

Where L_D is the detection limit, t_s is acquisition time, I_γ is emission probability of gamma rays ε_v is simulated volume efficiency calculated above and B is the area of background continuum under peak.

Due to potassium, one of the main elements of seawater, the concentration of ^{40}K in seawater is higher than that of freshwater. Radionuclides such as ^{131}I and ^{137}Cs have lower energies than ^{40}K and are affected by Compton continuum of ^{40}K. The changes in MDA in fresh water, brackish water, and seawater were investigated by varying the concentration of potassium. KCl was dissolved in water to control the concentration of potassium.

The MDA of radionuclides measured for 1 hour in each situation is shown in table 1. Figure 5 shows the change of MDA for ^{137}Cs by acquisition time. The circle points are data calculated by count rate obtained from 24 h measured data. The star points are data measured for 1 h. The calculated seawater MDA value for 1 h was 0.318 Bq/L in good agreement with measured seawater MDA value for 1 h, 0.321 Bq/L.

Table 1 : MDA of seawater monitoring system measured for 1hour by various situations.

Isotope	MDA (Bq/L)		
	Seawater	Brackish water zone	Fresh water
^{131}I	0.334	0.328	0.296
^{137}Cs	0.321	0.307	0.282
^{40}K	3.133	2.81	2.31

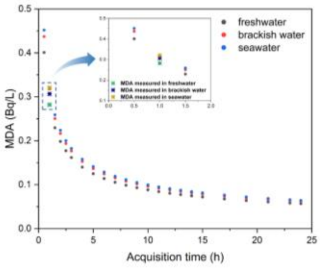

Fig. 5. MDA for ^{137}Cs as a function of acquisition time for different cases.

3. Conclusions

In this study, an intake seawater monitoring system (149 L) was designed using MCNP simulation and system characteristics were investigated. The reliability of simulation was verified using standard sources. In addition, MDA changes in various situations were investigated. As a result, the MDA of ^{137}Cs measured 1hour is 0.321 Bq/L in seawater and 0.282 Bq/L in freshwater. This system has the advantage of being easy to maintain because it is small and an intake method. In the future, MDA evaluation will be conducted on the various detector size and geometry changes of this system.

REFERENCES

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