Feasibility study on development of underwater beta & Gamma measurement system

SuJung Min*, SangBum Hong, BumKyoung Seo
Korea Atomic Energy Research Institute, Daejeon 34057, Korea
*Corresponding author: sjmin@kaeri.re.kr

Keywords : Liquid Scintillation Counter (LSC), Beta, Gamma, Minimum Detectable Activity(MDA)

1. Introduction

When a nuclear power plant operates normally, there is no difficulty in identifying the radioactivity emitted into the surrounding environment because underwater radioactivity is continuously managed and monitored. However, radioactivity analysis is difficult in abnormal cases such as the Fukushima nuclear accident and the discharge of contaminated water in Japan. In addition, there are concerns about the safety of marine products and the destruction of the marine ecosystem due to the issue of discharge of contaminated water from the Fukushima nuclear power plant. Therefore, there was a need to develop technology that can immediately monitor and quantitatively analyze radioactive contamination, and various underwater radiation detection equipment have been developed. However, commercial equipment is almost impossible to quantitatively analyze beta nuclides. In this study, we investigated/analyzed the status of underwater gamma/beta monitoring technology and identified current issues. And, based on the existing gamma monitoring system geometry, the MDA for each nuclide was evaluated to evaluate the possibility of developing a high-efficiency analysis system for in-situ measurement.

2. Methods and Results

2.1 Domestic and overseas technology/system trends

2.1.1 Gamma measurement

The Korea Institute of Nuclear Safety (KINS) has built a seawater radiation monitor based on NaI(Tl) scintillator and GM-type detector and is using it for a real-time seawater radiation monitoring network. Additionally, the Korea Institute of Ocean Science and Technology (KIOST) and Seoul National University have built a mobile radiation detection system using GAGG scintillator and SiPM-based detectors and USV (Unmanned Surface Vehicle). The Korea Atomic Energy Research Institute (KAERI) is also conducting research to develop a real-time underwater radiation detection system using a NaI(Tl) detector. Commercial underwater radiation detection systems (overseas products) generally use NaI(Tl) detectors, and CeBr3 or LaBr3 detectors with good energy resolution are also used.

Underwater gamma detectors have been developed by Germany's ENVINET, France's Bertin Instruments, Latvia's BSI, and Greece's ito.

2.1.2 Beta measurement

Domestically, Ulsan National Institute of Science and Technology and Korea Atomic Energy Research Institute are developing a system that can simultaneously monitor underwater beta and gamma radiation. The LSC analysis method is widely used for beta particles that have a short range and are difficult to analyze, and many studies are being conducted on improving the LSC analysis algorithm or optimizing the structure. Demand for LSC is increasing in the global market due to its application in various industrial fields. In particular, demand for measurement systems that are small and easy to move and install is increasing depending on the measurement purpose. An LSC that can be used for ultra low level analysis or portable analysis are HIDEX's Triathler LSC model, ULLA LSC, NOKI Technologies' DPM 7001. Among them, the ULLA model is for measuring H-3, C-14, Sr-90/Y-90, Ra-226, and Rn-222. When measured with a 20ml vial for 24 hours, it was analyzed to be approximately 0.3 Bq/L, when measured for 1 hour, it was analyzed to be approximately 1.54 Bq/L, and when measured for 10 minutes, it was analyzed to be approximately 4Bq/L. However, since this equipment weighs about 800 kg, it cannot be used as a portable analyzer. Recently, CEA is conducting research to develop a compact and portable LSC. An inorganic scintillator of CdTe was used together, and the Compton-Triple to double coincidence ratio (TDCR) measurement method was applied to automatically correct quenching and obtain absolute radioactivity levels.

2.2 feasibility Study

2.2.3 MCNP Simulation

To develop a beta/gamma measurement system, gamma and beta simulations were performed based on the shape of the existing monitoring system, and MDA for each nuclide was calculated based on the simulation data.

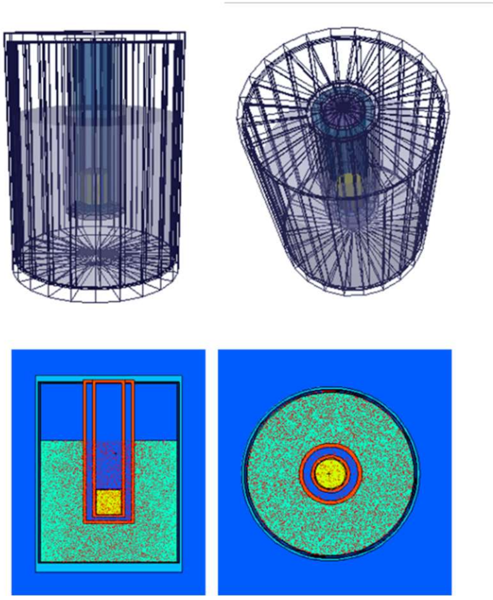

Fig. 1. Geometry configuration for MCNP simulation

MCNP simulation was performed to calculate MDA, and by referring to the system structure used by the Korea Atomic Energy Research Institute (KAERI) as an underwater radiation monitoring system, the geometry was constructed using a 47 to 50 L water tank and a 3-inch NaI(Tl) detector. The upper and lower parts were shielded with 20mm and 30mm lead, respectively, and the detector was protected from water by covering it with a 10mm acrylic plate. The water tank was made of PE material and the thickness was set to 2mm. In addition, simulations were performed for nuclides Cs-137 (662 keV), I-131 (364, 637 keV), Cs-134 (605 keV, 796 keV), and H-3 (6~19 keV).

2.2 MDA calculation

MDA (Minimum Detectable Activity) is a commonly used standard for determining the presence of radioactivity. MDA depends on the background as well as measurement time, efficiency, chemical yield, and sample volume, and the calculation equation is as shown in equation (1).

$$MDA = \frac{2.71+4.65\sqrt{N_B}}{\mathrm{Y}\times\varepsilon\times\mathrm{T}\times\mathrm{V}} \qquad (1)$$

Here, N_B is Background, Y is the emission rate, ε is the efficiency, T is the time (sec), and V is the volume.

As a result of the MDA calculation, it was analyzed that Cs-137 nuclide (662keV) was 0.86Bq/L, Cs-134 nuclide (605keV, 796keV) was 0.5Bq/L, and 1.6Bq/L, respectively, when measured for 1 hour. Additionally, I-131 (364keV, 637keV) was analyzed as 1.8Bq/L and 107.2Bq/L, respectively. The current geometry sufficiently satisfies the MDA standards. In the future, it will be possible to manufacture a more compact and portable system, and it is believed that beta nuclides will also be able to meet MDA.

3. Conclusions

To develop technology for monitoring or analyzing underwater beta/gamma, we investigated and analyzed domestic and overseas technology status.
In addition, MDA was calculated through MCNP simulation with reference to the existing monitoring system structure.

As a result, it satisfies the drinking water standards set by the WHO (10 Bq/L for Cs-137 and 10,000 Bq/L for tritium), so it is believed that the existing system can be made compact and light to make it portable or mobile.

REFERENCES

[1] H.M.Park, G.S.Joo, Development of a real-time radiation level monitoring sensor for building an underwater radiation monitoring system, J. Sensor Science and Technology, Vol. 24, No. 2, 2015.

[2] E.S. Jang, Y.S.Kim, S.Y.Lee, J.S.Kim, Analysis of Minimum Detectable Activity Concentration of Water samples and evaluation of effective dose, J.Korean Soc.Radiol., Vol. 14, No 7, 2020.

[3] J.H.Moon, J.G.Park, S.H.Jung, Y.S.Kim, S.W.Kang, D.M.Oh, Development and performance evaluation of underwater radiation monitoring System, J. Radiation Industry, 14(3), 2020.

[4] W.S.Jeong, A Study of the rapid analysis of Radioactive Strontium in marine samples, Chosun University, 2022.

[5] S.H.Hong, A Study an the factors influencing MDA in radioactivity measurement, Chosun University, 2020.

[6] P.Cassette, V.Todorov, B.Sabot, S.Georgiev, K.Mitev, Uncertainties in TDCR measurement revisited: Contribution of optical effects, Applied Radiation and Isotopes 201, 2023.

[7] P.J.Reddy, R.Sankhla, P.Chaudhury, Application of portable liquid scintillation counter for on-field measurement of tritium in aqueous samples during radiation emergency, J. Environmental Radioactivity, 272, 2024.