

## Detection Efficiency Calculation and Evaluation for Condenser Off-gas Radiation Monitoring System

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### 1. Introduction

Most of NPP (Nuclear Power Plant) has many of Radiation Monitoring System to surveil symptom which is leakage of fission products derived from primary system. Among them, the off-gas radiation monitoring system where is positioned in outline of condenser detects the noble gas which emits beta ray. This system counts beta ray continuously by using beta counter that should be suitable according to the range of radiation level. The detector generally used is a beta scintillation detector for noble gas monitoring samplers [1,2]. It is difficult to determine how much leakage has occurred by only using measured count rates. However, relative leakage rate can be calculated by comparing the count rate between beta count rate at off-gas radiation monitoring system and reactor coolant in primary system. To calculate the leakage rate, activity concentration of reactor coolant has to be converted to count rate. The factor that converts units from activity concentration to count rate is called detection efficiency [1].

The manufacturer that sells the radiation monitoring facility to buyer also provides detection efficiency data of beta nuclides which generated in NPP. However, in most cases, they only provide detection efficiency information for a few typical nuclides like Xe-133 and Kr-85. Considering that the kinds of leaked nuclides depend on the type of plant and operation condition, the number of provided data is insufficient.

Table 1. Beta nuclides leaked from primary system

Nuclide	Beta mean Energy	Half life
Xe-133	100.4 keV	5.24 d
Xe-135	305.0 keV	9.14 h
Xe-137	1693 keV	3.82 m
Xe-138	635.7 keV	14.08 m
Kr-85	250.7 keV	10.75 y
Kr-85m	228.1 keV	4.48 h
Kr-87	1327.0 keV	7.63 m
Kr-88	363.1 keV	2.84 h
Kr-89	1367 keV	3.15 m
Ar-41	463.7 keV	109.61 m

Several MCNP (Monte Carlo N-Particle) studies to verify the coincidence between real environment to

simulation for detecting beta ray have conducted [3-7]. Among them, in case of targeting the purpose which is measuring the count rate, thin plastic scintillator is usually used. Plastic scintillator emits pulses of light when bombarded with beta radiation. The amount of light given off is proportional to the energy of the absorbed beta particle. Therefore, the amount of the deposited energy in scintillator can be determined by using F8 tally which called pulse height tally in MCNP [4-7].

In this study, the experiment at specific geometry and MCNP simulation (MCNP6) for experiment are performed to prove agreement between the experiment and MCNP simulation. After that, condenser off-gas radiation monitoring system is simulated to calculate detection efficiency. Furthermore, trend line of energy response curve that describes the relationship between energy of beta particle and detection efficiency is suggested by using gradient descent method.

### 2. Material and Methods

#### 2.1 Experimental method

Fig. 1 shows experimental setup. The experiment was conducted by using thin plastic scintillation detector (Sorrento, RD-52A-30) which has 0.508 cm (Diameter) and 0.0254 cm (Thickness). Since the preamplifier was embedded in the detector, the output signal from the detector was a voltage signal. It is amplified and shaped through the shaped amplifier. The amplified voltage signals were expressed to channel spectrum via MCA (Multi-Channel Analyzer).

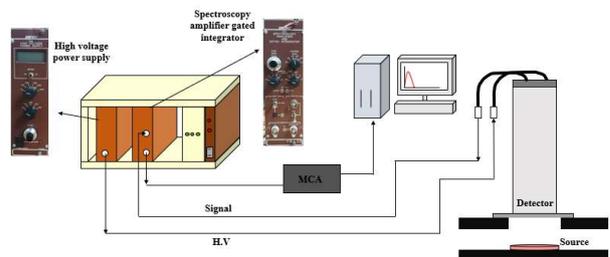


Fig. 1. Experimental setup

In condenser off-gas radiation monitoring system, the detection area where noble gas existed included axial direction and radial direction. Those point was reflected in the experiment. Fig. 2 shows the expression of experimental method. In the axial direction, the

experiment was performed at a distance of 1 cm to 5 cm from the surface of the detector. In the radial direction, the experiment was conducted at distance 2 cm from detection surface by varying the distance into radial direction (1, 2, 3 cm). The calibrated beta source (disk type) was used (Cs-137, Cl-36). Each diameter of disk source is 4.0 and 1.9 cm.

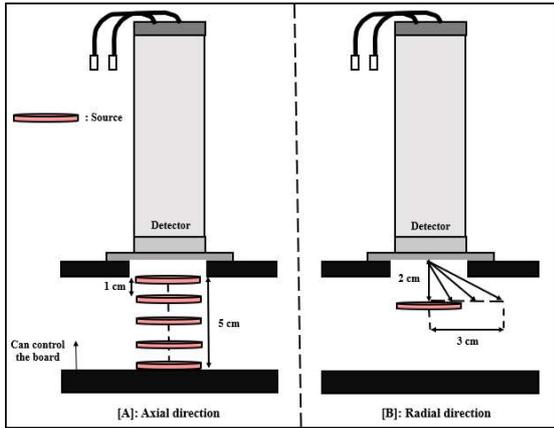


Fig. 2. Experimental method [A]: Axial, [B]: Radial direction

## 2.2 MCNP simulation

In this study, there are two kinds of MCNP simulations. First is simulation for the experiment. We compared the detection efficiency (%) of the experiment to its MCNP simulation data to confirm the agreement of them. As following step, condenser off-gas RMS was simulated. Fig. 3 describes system geometry. The detector was connected with sample chamber where the noble gas was flowing. The detector and sample chamber were surrounded by the 3inch lead shield. The specific geometry in the detector wasn't expressed due to the security reason. We used the a few beta nuclides in Table 1 as a sample. The detection efficiency was calculated by using F8 tally and compared to the data which was supplied by the manufacturer. The nuclides that used were Xe-133, Kr-85, Xe-135, Ar-41, Xe-138, Kr-88 and Kr-87 in Table 1. The input beta energy spectra for all used in MCNP6 simulation was taken from Eckerman [10]

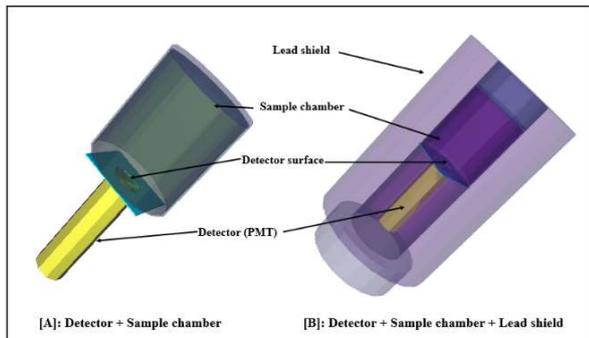


Fig. 3. Geometry for off-gas RMS by using Visual editor

## 2.3 Trend line for energy response curve

When we consider the trend line, it is important to determine which function to be used. The mass absorption coefficient was an empirical parameter that was expressed to the exponential fraction of the transmission and thickness of material as Eq (1): where  $T(x)$  was the transmission coefficient and  $x$  was thickness of target [8].

$$\mu = \frac{1}{x} \ln[T(x)] \quad (1)$$

The mass absorption coefficient was given as Eq. (2) which was proposed by Thümmel [9]. ( $Z$  was atomic number and  $A$  was atomic weight and  $E$  was energy of particle which interacted with target.

$$\mu = 15.2 \frac{Z^{3/4}}{A} \frac{1}{E_{max}^{1.485}} \quad (2)$$

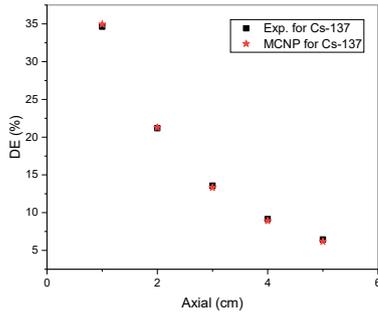
As the electron's energy increased, the probability that electron penetrated the target increased and the amount of energy deposited decreased. And the interaction of electron and target followed exponential function. Since this study focused on detecting the beta ray using thin scintillators, it was right to pay attention to the probability that scintillator and electron reacted rather than the amount of energy deposited in the scintillator. Considering all of the above them, the relationship of detection efficiency with the energy of electron was expected to follow equation (3).  $A$ ,  $B$  and  $C$  were parameters which should be calculated  $E_{max}$  was maximum energy of beta ray. We calculated parameters in Eq. (3) by using gradient descent method and drew a trend line which expressed the relationship between Beta energy and detection efficiency.

$$DE = A \cdot e^{\frac{B}{E_{max}^C}} \quad (3)$$

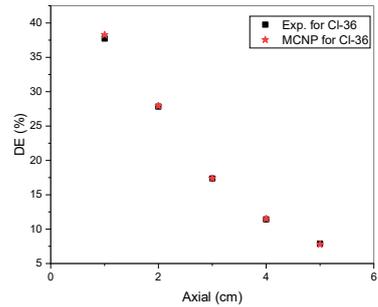
## 3. Result and Discussion

### 3.1 Experiment and. MCNP simulation results

The results of detection efficiency (%) for experiments and MCNP simulation are shown in Fig.4 - 5. When we calculated the detection efficiency, system noise which was under about 50 keV was eliminated. Detection efficiency of the experiment and MCNP simulation was a good agreement for all of cases below 2.6 % of relative error.

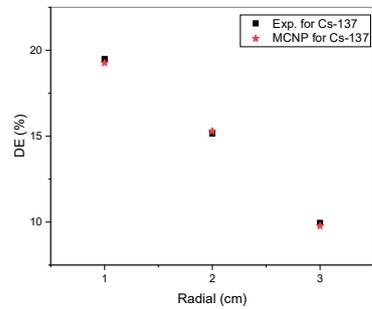


[a]

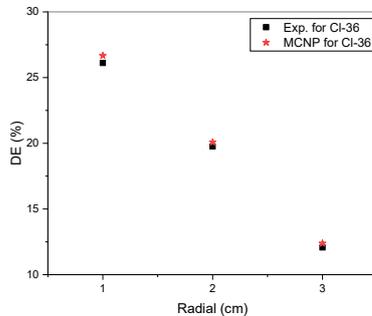


[b]

Fig. 4. Detection efficiency (%) for Experiments and MCNP simulation results (Axial cases [a]: for Cs-137, [b]: for Cl-36)



[a]



[b]

Fig. 5. Detection efficiency (%) for Experiments and MCNP simulation results (Radial cases [a]: for Cs-137, [b]: for Cl-36)

### 3.2 Simulated result for condenser off-gas RMS

We conducted MCNP simulation for condenser off-gas RMS. Fig. 5 shows simulation results and reference which was supplied by manufacturer. Most of MCNP results were a good agreement with references except for Xe-133 that emitted a low energy beta ray. In case of thin scintillation detector, the range of energy dependence was generally known as 0.1 to 2.5 MeV [2] (This was reason why we didn't draw the trend line over the 2.5 MeV). The results of MCNP simulation could depend on source information. The results could be affected by those problems. However, the trend line of MCNP simulation results were suitable for reference data. The detection efficiency decreased over the 2.5 MeV because most of beta rays penetrate the scintillation with deposited only small energy. We expect that the ability to analyze accidents can be increased through accurate calculations of the leakage rate by using trend line.

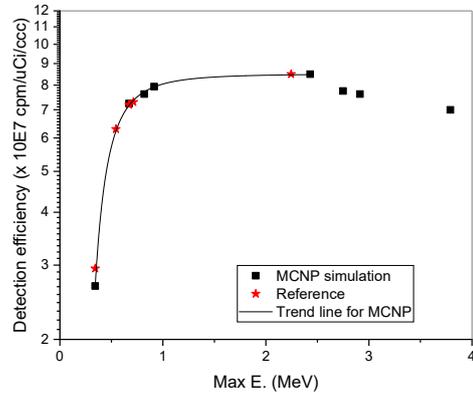


Fig. 5. Detection efficiency according to maximum energy of Beta for MCNP simulation

## 4. Conclusion

In this study, we conducted experiment and MCNP simulation for condenser off-gas RMS and made the trend line for the detection efficiency. The trend line of detection efficiency for this system will be expected to give an accuracy and efficiency for analyzing the leakage rate from primary system. relationship between detection efficiency and shape of spectrum and MCNP simulation for condenser off-gas RMS. In future works, we will evaluate the effect of the distribution of beta spectra on detection efficiency.

## ACKNOWLEDGEMENT

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