International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Special Issue 19 (June, 2015), PP. 30-33

A STUDY ON DESIGN OPTIMIZATION OF COMPTON SUPPRESSION DETECTOR FOR IN-SITU MEASUREMENT OF SITE USING MONTE CARLO TECHNIQUES

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***Abstract*—Compton suppression system was established to accurately and precisely measure low-level radiation during in-situ measurement of sites. HPGe detector was selected as the main detector and plastics scintillation detector was selected as the guard detector. Using ^{137}Cs source, while changing the height(h) and width(w) about plastic scintillation detector the gamma spectrum was simulated using the Monte Carlo method. Also each was performance evaluated using reduction factor (RF). As a result the optimum result of height(h) 10cm x width(W) 10cm, –1cm forward disposition of plastic detector size was derived. The reduction factor (RF) according to optimum design condition was 2.97, and a maximum of 5.0 suppression effect was obtained near to the 420keV.**

***Index Terms*—Compton continuum, Compton Suppression system, scatting, Background, Reduction factor, Monte Carlo, Germanium detector, Plastic detector**

I. INTRODUCTION

For in-situ measurement of sites, there needs to be establishment of low-level radiation measurement system. Generally for in situ measurement background is created due to various factors such as natural radioactive nuclide, cosmic rays, and gamma ray by Compton scattering that exist in the earth crust to create complicated spectrum. This creates Compton continuum over wide area on the spectrum to make site contamination radionuclide and radiation measurement difficult. Thus the uncertainty of measurement about low-energy area is increased which lowers reliability. Generally during in situ measurement lead shield can be used as a method to reduce background to lower background by shielding gamma rays. In this case the target peak removal that hinders nuclide analysis is easy but due to the weight of the shield there are problems in application in in situ measurement. On the other hand there is Compton suppression system to reduce background of gamma rays due to Compton scattering [1-2].

After the photon enters the main detector, the gamma rays that escaped due to Compton scattering is detected by the guard detector. Then by using the electronic circuit, background is lowered using a method of not recording the simultaneously detected signal on the main detector signal spectrum. Because this can be used to reduce background without using heavy lead shields, it can be applied to in situ radioactivity measurements [3] such as site measurement. Considering the characteristics of in situ measurement, large or heavy detectors are not appropriate. Also because there needs to be mobility and convenience it should not be weak to mechanical shock or have large volume. For this design and disposition of optimum Compton suppression detector that can be used in in situ measurement is primarily required. However to do experiments on all the situations, there are various limitations. Therefore by diverse guard detector size and disposition simulation according to user desire using the Monte Carlo simulation, time and cost can be reduced.

The study tries to measure accurate residual radioactivity by lowering the minimum detectable activity (MDA) on the low-level area during in situ measurement of sites. For this the study used the Monte Carlo method to conduct simulation according to the size and disposition of Compton suppression detector. The study tried to optimize the size and disposition of Compton suppression detector by evaluating the performance of reduction factor (RF) according to the size and disposition of guard detector.

II. DESIGN OF THE COMPTON SUPPRESSION SYSTEM

To accurately measure and analyze residual radioactivity of sites, it is important to lower the Compton continuum.
For this a detector that has the optimum detection efficiency must be selected.
For the main detector, HPGe detector that can measure the gamma rays of energy resolution and for energy region that has good detection efficiency was used. For guard detector, plastic scintillation detector was used [4]. Plastic scintillation detector has low detection efficiency of gamma rays and has low energy resolution. However it has the advantage that it is low-cost and that the size and shape can be freely produced [5-6].

The scattered gamma rays and the main detector is scattered in random direction. Therefore because guard detector must detect these scattering gamma rays in must be in the form that covers the main detector as much is possible. Therefore the study designed a cylindrical suppression detector as shown in Figure. 1 so that it can surround the HPGe detector considering the mobility and convenience during in situ site measurement.
With the reduction factor(RF) according to the size and disposition changes plastic scintillation detector the performance of the Compton suppression detector was evaluated.
Reduction factor(RF) of Compton continuum for the performance evaluation of Compton suppression detector have defined as follows

$$RF = \frac{n_N}{n_{Cs}} \qquad (1)$$

From the above equation, n_N is the total measured count rate of without Compton suppression system. n_{cs} is total measured count rate with Compton suppression system. Reduction factor(RF) is defined the ratios of reduction of the Compton continuum depend on changing various size of the plastic detector.

A. Design of the detectir size by Monte Carlo

Frist, we designed HPGe detector and guard detector by Monte Carlo Monte Carlo simulation for the Compton suppression system configuration. The size and disposition of Compton suppression detector geometry is shown in Fig. 1.

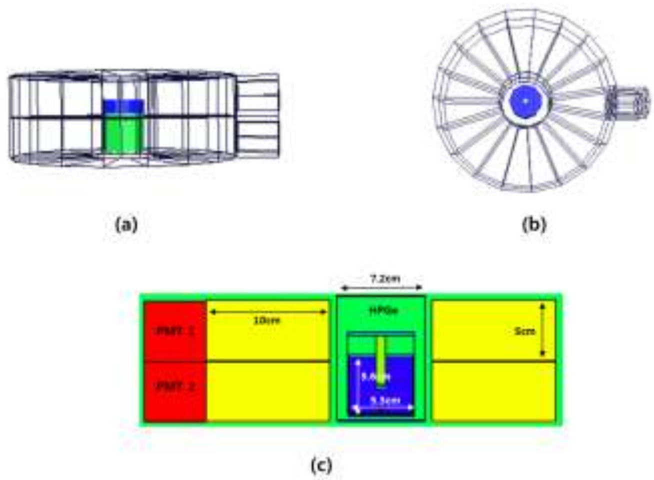


Fig. 1. **Schematic view of the Compton Suppression System used for the simulation**

In this study, the coaxial HPGe detector was used. The Ge crystal is 53mm in diameter and 56mm in length. As shown in Fig. 1, the end of each plastic detector was connected to 2 inch PMT with a light guide.

Conductions for simulation are the distance between the detection surface of the HPGe detector and the source was set to 1m. And four measurement of the residual radioactivity of the site simulation was done with ^{137}Cs surface source(1m×1m). With the point where the detection surface of the HPGe detector and plastic detector met as the reference point, the plastic detector size was gradually changed to conduct Monte Carlo simulation. The plastic detector size started from height(h) 1cm × width(W) 1cm and the changes were given by 1cm until height(h) was 10cm and width(W) was 25cm to conduct Monte Carlo simulation and calculate RF.

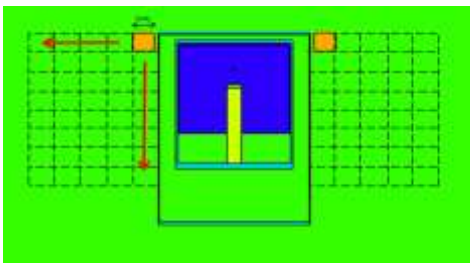


Fig. 2. **Simulation of the Compton Suppression System by Monte Carlo**

B. Disposition of the detector by Monte Carlo

This was conducted to see the changes in reduction factor (RF) according to the disposition of the plastic detector that was optimized for size based on HPGe detector.

First using the Klein- Nishina formula, Compton scattering cross section about ^{137}Cs is calculated. When a calculation is conducted, the ^{137}Cs radiation source has an energy of 662keV, indicating that there is more forward scattering than back scattering. Based on this result, the plastic detector will have to be placed more towards the back side of the detector rather than the ground surface. To verify whether this corresponds with theoretical results, the point at which the detected side of the HPGe detector and the plastic detector coincide was set as the reference base point and the location of the plastic detector was changed. When the plastic detector was located in front of the HPGe detector, it was marked as –, and when it was located in reverse order it was marked as + . From the –5cm point from the ground surface to the +3cm of the back side of the detector, a simulation was carried out in 1cm intervals.
Based on the result the right from the Monte Carlo simulation the performance of the Compton suppression detector according to disposition was evaluated.

C. Other several simulation

To evaluate the detection efficiency for the site using the optimized plastic detector, the following simulation was carried out.

To verify the contamination on the Radionuclide of the site, the detection efficiency was calculated across different depths of site. Then the function was evaluated by comparing the reduction factor (RF) rate for different depths. The dose of radiation that reaches the detector will decrease as the depth increases. The surface of the soil was set as 0, and the detection efficiency and reduction factor for the un-suppression mode and suppression mode at different depths from 0cm ~ - 50 at 2cm intervals were evaluated.
Radio-nuclides with single energy because it has a single peak, even when the background is high there isn't much difficulty in analyzing the spectrum. But, if the radionuclide has multiple energies or if the spectrum has numerous radio-nuclides, then a very complex spectrum appears making it difficult to analyze. Among the many types of radionuclide, if it is many types that emits low energy gamma-rays, the background increases on the Compton continuum and therefore it is hard to analyze the spectrum.
Taking into such a case, in this study a simulation was conducted on a single source and multiple sources to evaluate the function of the Compton Suppression detector.
The single source was set as ^{137}Cs, while for the multiple source, a simulation was conducted using radioactive standard data for the energy fields of 0~2Mev. For each radiation, the surface source was 1m × 1m of surface source.

III. RESULT

The result of the Monte Carlo simulation for optimization of plastic detector size design by changing the height(h) and width(W) by 1cm can be seen in Figure. 3.

The reduction factor (RF) when the plastic exercise is height(h) 1cm × width(W) 1cm, is 1.03. On the other hand when height(h) 1cm × width(W) 25cm, Reduction factor(RF) is 1.20, and in height(h) 10cm x width(W) 25cm which is designed for maximum size, the reduction factor (RF) is 3.53. HPGe crystal Length was 56mm and this was because the count rate where scattered gamma rays are detected according to plastic detector height(h) differs.

With +2cm increase of with the reduction factor (RF) increased by about 0.2 and with +1cm of increase of height reduction factor (RF) was found to rise by about 0.3. This indicates that because the energy of the gamma-ray is high, the detection efficiency is higher for the length of the HPGe crystal than for the diameter. Of course the diameter also has an effect but because the efficiency of the gamma ray due to back scattering, it is more effective for the increase in height rather than in the width of the plastic detector.

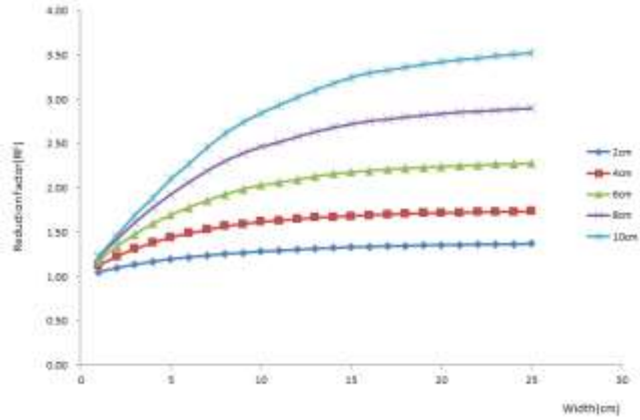


Fig. 3. **Reduction factor(RF) of the Compton Continuum per unit width**

Plastic detector has lower detection capability about gamma rays, as the size of detector increases the reduction factor (RF) of a background increases in proportion. However to obtain high reduction factor (RF) the size of the plastic detector cannot be endlessly increased. Because with the increase in size the weight increases, the applicability during in situ measurement decreases. Therefore there needs to be design a plastic detector of optimal size for convenience in in situ measurement application.

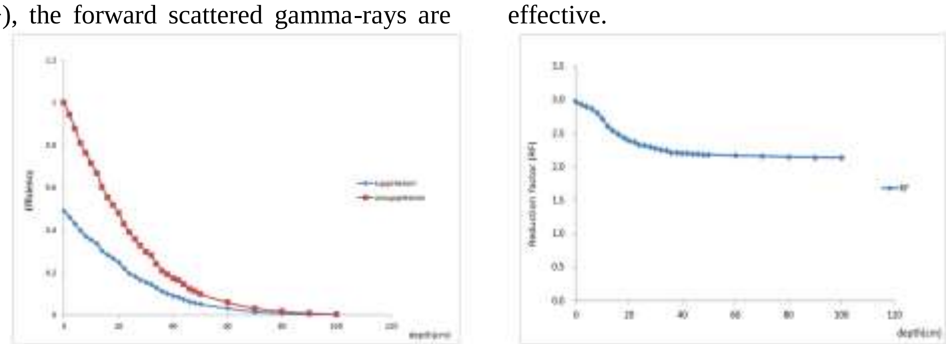
When the plastic detector size is height(h) 10cm × width(W) 25cm, the reduction factor (RF) is 3.53 and in contrast, the point where the mean ratio of change appeared the most dramatically was height(h) 10cm × width(W) 10cm with 2.93, which was about 0.6 difference. However because there is about 4.5 times difference regarding weight, the size of the plastic detector was decided on height(h) 10cm × width(W) 10cm.

In design for the disposition of the plus detector, considering the Compton scattering cross sectional area, performance evaluation of reduction factor (RF) was done moving from –5 ~ +3cm.

TABLE I. BACKGROUND REDUCTION FACTOR(RF) OF DISPOSED OF THE COMPTON SUPPRESSION DETECTOR

	Total Count			**Compton Continuum count**		
	Un suppression mode	***suppression mode***	***RF***	***Un suppression mode***	***suppression mode***	***RF***
-5cm	7966731	4226194	1.89	5761654	2294605	2.51
-4cm	8032957	4114591	1.95	5859766	2183002	2.68
-3cm	8111447	4043460	2.01	5952973	2108191	2.82
-2cm	8139655	3991951	2.04	6006935	2050550	2.93
-1cm	8046448	3945347	2.05	5940709	1999041	2.97
0cm	7845317	3922045	2.0	5744484	1969608	2.92
1cm	7651545	3947800	1.94	5562976	1989230	2.80
2cm	7451641	3985819	1.87	5376563	2017437	2.67
3cm	7221077	4067988	1.78	5154583	2082437	2.48

A review of each spectrum shows that when the plastic detector is placed on the side of the ground surface (-), the back scattering of gamma-ray is removed and therefore the areas with high energy on the Compton continuum are suppressed. Meanwhile, when the plastic detector is located on the back side (+), the forward scattered gamma-rays are removed and therefore the areas with low energy are suppressed. For plastic detector disposition the reduction factor (RF) was the highest at -1cm, and it could be seen that it decreased when it was over +1cm. As it can be seen in Table.1 when it was located 1cm forward it was the most effective.



(a) (b)

Fig. 4. **(a) Detection efficiencies and (b) Reduction factor(RF) of Compton suppression system according to the soil depth**

With ^{137}Cs source, detection efficiency and reduction factor (RF) of un-suppression mode and suppression mode according to soil depth was evaluated.

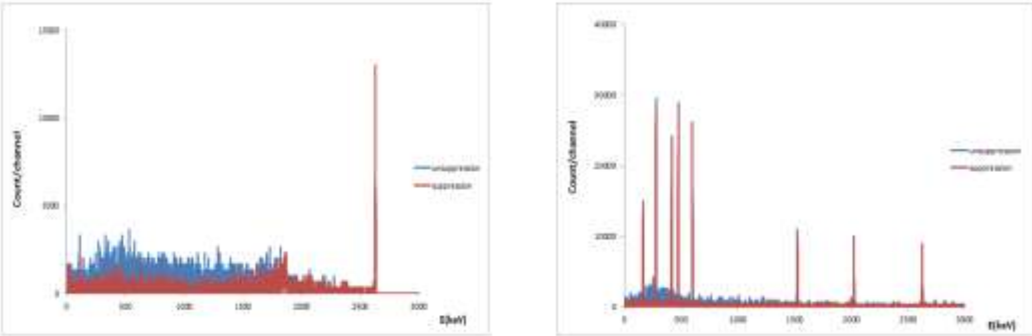
The detection efficiency across different depths of the soil shows the highest value on the surface. Then as the depth increases, the detection efficiency decreases exponentially. Fig. 4's (a) shows that both the graphs for the un-suppression and suppression decreasing along the same pattern. In both un-suppression and suppression, the detection efficiency is cut by half at the 20cm point.

The Reduction factor(RF) across different depths of the soil, too, show the highest value when the radiation source was on the surface. Fig. 4's (b) graph shows that there is a difference in reduction factor up to the 16cm point. But going further, the reduction factor is maintained at a stable level.

From the depth of approximately 20cm, the radiation amount that reaches the detector is decreased by half and at 50cm the detection efficiency is less than 10%.

This indicates that both the dose of the overall radiation detected and the dose that is scattered decrease and affects less the background reduction.

Fig. 5 is the gamma-ray spectrum that is simulated using the ^{137}Cs and multiplex radionuclide in un-suppression mode and suppression mode. As can be seen in the spectrum, the background by Compton continuum decreases. Using the simulation data, the reduction factor could be calculated through the count and detection efficiency on the Compton continuum. Compared to when only ^{137}Cs was used, when multi gamma source was used, the background decreased less. When a single radiation source of ^{137}Cs was used with the size and placement structure of an optimized detector, RF was 2.98, but the RF for the multiplex radionuclide was only 1.74.



< ^{137}Cs >   <multiplex radionuclide>

Fig. 5. **The unsuppressed and suppressed spectrum by ^{137}Cs and multiplex radionuclide source**

This is because that when multiple gamma-rays are emitted, the multiple signals are recognized as compton scattering signals, thus reducing the detection efficiency. During an actual measurement, this can be complemented through changes in the signal processing time in each detector through the TSCA of the circuit system module.

However on the spectrum through Compton suppression low energy area minimum detectable activity (MDA) was lowered and it could be seen that accurate nuclide analysis and residual radioactivity measurement was possible.

IV. Conclusions

In the gamma ray measurement field, reducing background is very important. Furthermore, establishment of Compton suppression system of in situ measurement that can reduce time and cost is necessary. This research is about figuring out the characteristics of Compton suppression in in situ gamma ray measurement system to reduce background of Gamma spectrum. For this Monte Carlo simulation was used to derive the optimum size and disposition of the Compton suppression detector fit for in situ measurement. The size of the plastic detector that surrounds the HPGe detector in the 1m distance between the detector and ^{137}Cs source was derived to be height(h) 10cm × width(W) 10cm. also placing the plastic detector –1cm forward showed the highest reduction factor (RF) about Compton continuum. It could be seen that detection efficiency of total count & peak count of Compton suppression system according to soil depth reduced according to depth.

In the spectrum that was measured using only ^{137}Cs source, the background reduced by 66.4%. However when using multi gamma source it only reduced by about 42%. With the reduction of background the gamma ray peak S/N ratio increased.

Based on this, during in situ application it is thought that due to background reduction it will be possible to acquire accuracy and reliability in analysis of nuclides as well as measurement of radioactivity.

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