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**ARTICLE**

# In-situ radioactivity measurement for the site release after decommissioning of nuclear power plants

Tadao Tanaka*, Taro Shimada and Takenori Sukegawa

*Japan Atomic Energy Agency, 2-4 Shirakata, Tokai-mura, Naka-gun, Ibaraki-ken, 319-1195, Japan*

According to a basic policy of Japan, nuclear power plant sites are allowed to be released from nuclear safety regulations after the plant are decommissioned. It is necessary to confirm that there is no significant radioactivity remaining on the sites, before the site release. In the present study, we proposed a conservative and reasonable evaluation method of radioactivity remaining on sites of decommissioned nuclear power plant, and confirmed validity of the evaluation method by an in-situ measurement using a germanium semiconductor detector (Ge detector). Cobalt 60 (Co-60) was taken up as one of the typical radionuclides for nuclear power plant. In the evaluation concept, all of Co-60, which is distributed across the area of interest (AOI), were assumed to be the single point source located at the furthest position on the surface of AOI from the Ge detector. In such a configuration, the shortest period needed for detection (SPD) of Co-60 was predicted by the calculation with EGS5 code. The minimum detectable time is most conservative detection limit for the all of Co-60. If the actual measurement time to detect Co-60 distributed across AOI became greater than SPD, the fact supports that there is no significant Co-60 on AOI.

***Keywords: site release; decommissioning; in-situ measurement; Cobalt 60; portable germanium semiconductor detector***

## 1. Introduction

According to a basic policy of Japan, nuclear power plant (NPP) site is allowed to be released from nuclear safety regulations after the plants are decommissioned. It is necessary to confirm that there is no significant radioactivity remaining on the sites, for the site release beforehand [1]. In the present study, we propose a conservative and reasonable evaluation method of radioactivity remaining on sites of decommissioned NPP, and confirmed validity of the evaluation method by an examination.

Cobalt 60 (Co-60) and cesium 137 (Cs-137) are the typical radionuclides for NPP. NPPs through Japan are widely affected by fallout radioactive cesium from severe accident of NPP in Fukushima. Thus Cs-137 is not available for key nuclide to be discharged from NPP. After the severe accident, Co-60 will be most effective key nuclide [2].

The in-situ metrology with portable germanium semiconductor detector (Ge detector) has been applied to measure radioactivity remaining on the sites [3]. The Ge detector has no necessity of the preprocessing and the waiting for measurements, can evaluate in real time on the sites, and can identify the nuclide by emission energy. Moreover, it is a flexible metrology having a lot of advantages, for example to measure the large area and to secure the representativeness [1, 3, 4].

## 2. Concept of the evaluation method

### *2.1. Check process for the site release*

Referential knowledge on radioactivity measurement and evaluation process for the site release after decommissioning NPP was proposed in MARSSIM published from USNRC [1]. Decommissioning entrepreneur must perform final status survey on the area of interest (AOI) after decontamination under decommissioning license plan, in order to prove that there is no significant radioactivity remaining on the sites. Regulatory agency must judge the results presented from decommissioning entrepreneur, from view point of validity of planning, equipment, measurement method, results, analytical method, and so on. Further regulatory agency has to independently check by inspection survey, even if the results presented from decommissioning entrepreneur are acceptable.

On the basis of above process, purpose of the inspection survey by regulatory agency is to reconfirm that there is no significant radioactivity remaining on the sites.

*Corresponding author. Email: tanaka.tadao26@jaea.go.jp

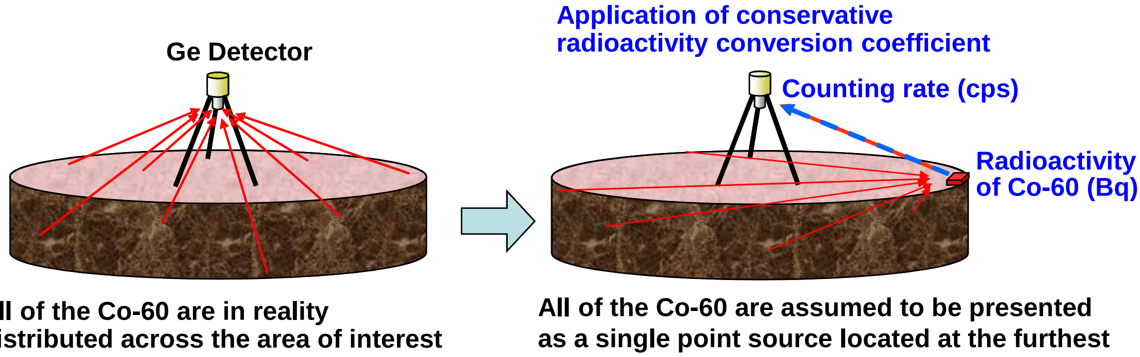


Figure 1. Concept of inspection survey for the conservative judgment.

### 2.2. Premise condition on the inspection survey

As the premise condition on the inspection survey,

- Final status survey on the sites had been carried out by decommissioning entrepreneur, and
- Regulatory agency had judged that there is no significant Co-60 on the sites, by using the results presented from decommissioning entrepreneur.

### 2.3. Evaluation method for the inspection survey

The concept of proposed inspection survey is drawn in **Figure 1**. It is assumed that, Co-60 pollution is attributable to ground surface deposition. All of the Co-60, which is in reality distributed across AOI, are assumed to be presented as a single point source located at the furthest position from a Ge detector on the ground surface of AOI. In such a configuration, the shortest counting period needed for detection (SPD) of the Co-60 point source is predicted by a calculation, as described in the section bellow. If the radiation from Co-60 in AOI is not detected within period longer than SPD, it proves that the radioactivity of Co-60 remaining in AOI is lower than that of Co-60 point source most difficult to detect. The difference from previous method is that it is not necessary to measure exactly the absolute radioactivity.

In actual situation, the Ge detector also counts the radiation from outside of AOI, as shown in **Figure 2**.

The influences of radiation from outside apparently increase with decreasing radius of AOI [3]. Thus, the evaluation concept by the inspection survey is to provide more conservative judgment in actual situation.

## 3. Prediction of SPD for Co-60 point source set up at the furthest position

### 3.1. Prediction method

In general radiation measurement, relationship between detection limit counting rate $N_L$ (cps) and counting time $t$ (sec) can be approximated to Eq. (1).

$$t = a \times N_L^{-b} \quad (1)$$

where $a$ and $b$ represent constants of correlation.

The $N_L$ is dominated by efficiency of detector and intensity of radiation source. Substituting the detection limit counting rate with detection limit radioactivity $A_L$ (Bq) and radioactivity conversion coefficient $K$ (Bq/cps), we obtain

$$t = a \times (A_L / K)^{-b} \quad (2)$$

The $K$ corresponding to configuration in Figure 1 is calculated from the particle transport simulation using the Electron-Gamma Shower code, version 5 (EGS5) [5]. PSD can be theoretically predicted by using $A_L$ and $K$ in each testing condition.

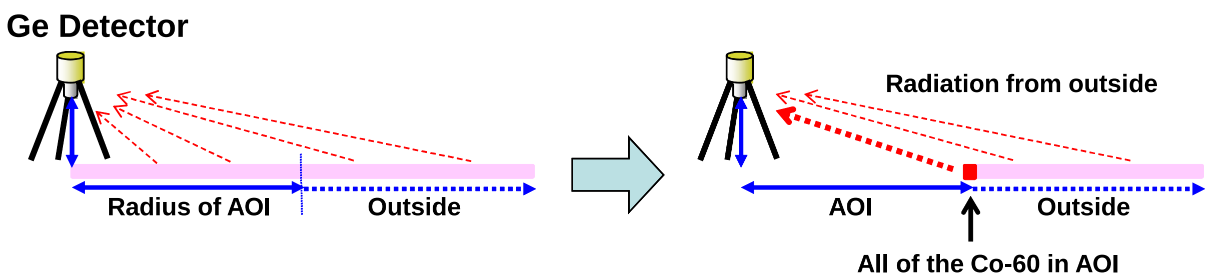


Figure 2. Influence of radiation form outside of area of interest (AOI).

### *3.2. Example for prediction of SPD*

The German regulation criteria of Co-60 radioactivity for site release are 0.03 Bq/g [6]. On the other hand, the clearance level of Co-60 under Japanese regulation criteria is 0.1 Bq/g [7]. These regulation criteria values may be reference of regulation criteria of Co-60 for the site release. If Co-60 of 0.1 Bq/g is uniformly distributed into the depth of 0.54 cm from ground surface in a soil layer of 1.6 g/cm$^3$ in density, there is 2.7 x 10$^5$ Bq of Co-60 on AOI of 10 m in radius. This value corresponds to $A_L$ in Eq. (2). The $K$ corresponding to 1,173 keV (γ-ray emission energy of Co-60) for a Ge crystal (60 mm in diameter, 45.5 mm in height, 30 % in efficiency) is calculated to 3.3 x 10$^6$ Bq/cps by using the EGS5 code.

Average values of $a$ and $b$ in Eq. (2) for the Ge detector have been obtained by fitting Eq. (1) into time-dependent changes of the detection limit counting rate acquired from background measurements, to be $a$ = 2.51 and $b$ = 1.93 [8]. In the configuration mentioned above, SPD is decided to be 313 sec, using Eq. (2) and the obtained $a$, $b$, $A_L$ and $K$ values. If radiation from Co-60 is not detected by actual measurement within 313 sec, it can be conservatively and rationally reconfirmed that there is no significant Co-60 in AOI of 10 m in radius.

## 4. In-situ inspection survey test

### *4.1. Method of inspection survey test*

Based on the configuration mentioned above, an inspection survey test using radiation source was performed in-situ. No Co-60 was detected by background measurement for 12,000 sec in the test site. Radiation source of 2.7 x 10$^5$ Bq was prepared as Co-60 point source. The point source was sealed in a column type polyethylene container of 5 cm in diameter and 5 cm in height. The point source was placed at a fixed distance of 10 m from the Ge detector (Refer to **Figure 3**). The Ge detector was set up at 1 m in height above the ground level. The time-dependent changes of the detection limit counting rate and net counting rate at the peak of 1,173 keV were analyzed.

### *4.2. Results on the inspection survey test*

Time-dependent changes of the detection limit counting rate and the peak counting rate are shown in **Figure 4**. The measurements were carried out five runs under the same testing condition. When the peak counting rate was greater than the detection limit counting rate, it is regarded that the Co-60 point source was detected. The actual detection time was nearly 300 sec in Figure 4. The actual detection time in each test run was decided by according to **Figure 5**, where the peak counting rate exceeded firstly the detection limit counting rate. Average value of the actual detection time through five runs was 326 sec. The predicted SPD (313 sec) was nearly equal to the average value.

According to the evaluation concept, the time A must decrease when the point source is not kept at the furthest position. The point source was moved to distance of 5 m and 7 m from the Ge detector, and was measured. Average value of the time A was also decided to 21 sec in the case of 5 m and 78 sec in the case of 7 m respectively. It was confirmed, by the in-situ test, that the detection time became short clearly in the case that Co-60 was not kept at the furthest position.

The results suppose that the prediction procedure of SPD for radiation source set up at the furthest position was reliable and reasonable.

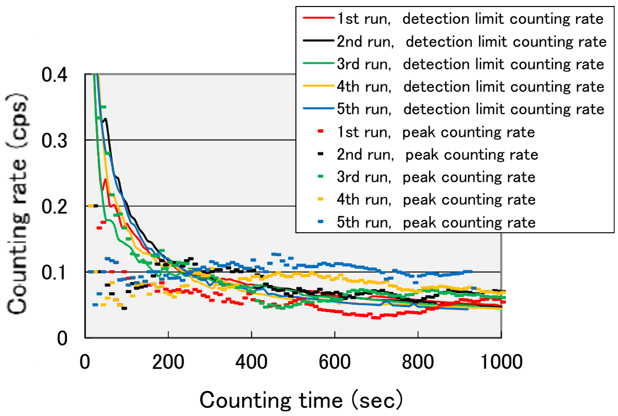


Figure 4. Time-dependent changes of detection limit counting rate and peak counting rate in inspection survey

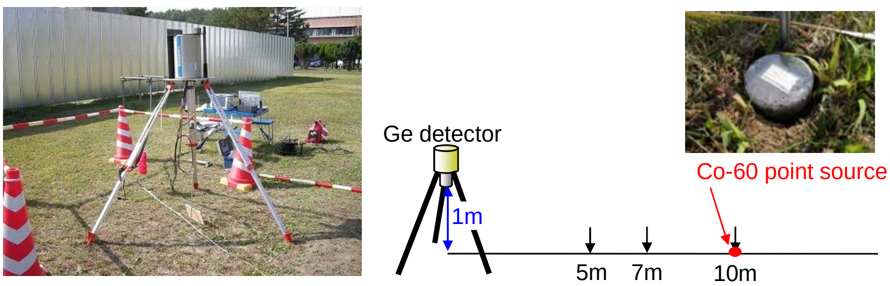


Figure 3. Schematic view of inspection survey test.

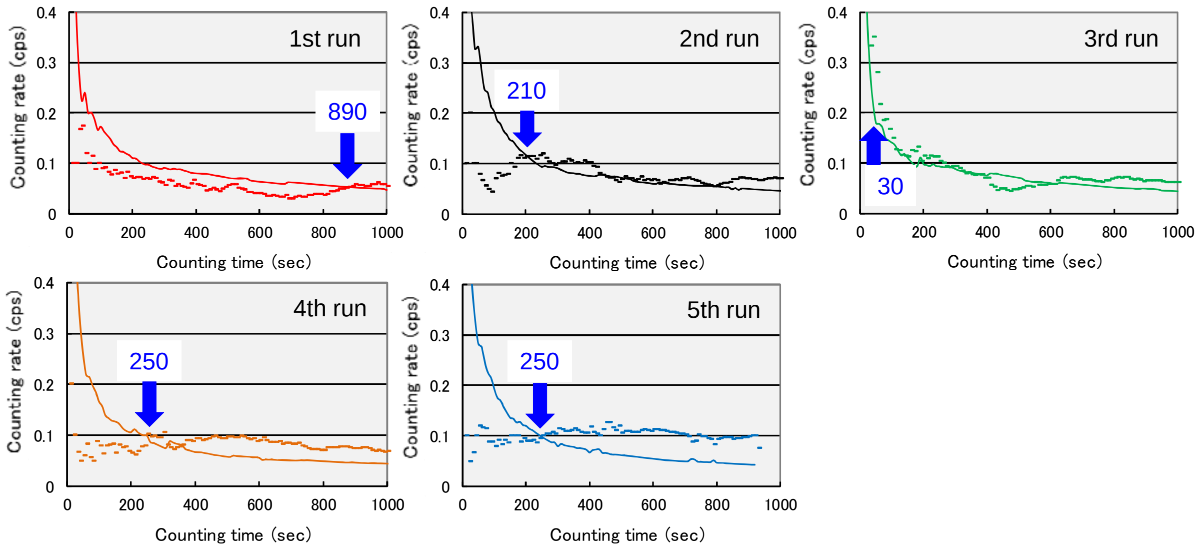


Figure 5. Decision of actual counting time.

## 5. The evaluation procedure for the inspection survey

A standardized procedure for the inspection survey is described as follows.

1) Set up AOI.
2) Set up the referential Co-60 criteria for AOI.
3) Estimation of the total radioactivity of Co-60 on AOI.
4) Set up layout of Ge detector in AOI.
5) Decision of constant *a* and *b* values relating to Ge detector in Eq. (2).
6) Prediction of *K* at the furthest position in AOI by EGS5 code.
7) Decision of SPD.
8) In-situ measurement in AOI.
9) Judgment: if Co-60 is not detected within period longer than SPD, it proves that there is no significant Co-60 in AOI.

## 6. Conclusion

The inspection survey method to check radioactivity remaining on the sites of decommissioned NPP was proposed. The in-situ inspection survey test using the portable Ge detector proved that the proposed evaluation method was reasonable for the conservative evaluation.


## Acknowledgements

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