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A Study on the Development of Drum Radioactivity Uniformity Index (DRUX) and Improvement of Drum Scanning Accuracy

J. Ryu [a,b], C. Park [a], J. Park [a*], J. Park [b], G. Cho [b*]
[a] *Radiation Safety Department, KEPCO NF, 242, Daedeok-daero 989 beon-gil, Korea*
[b] *Department of Nuclear and Quantum Engineering, KAIST, 291, Daehak-ro, Korea*
[*] *Corresponding author: jspark@knfc.co.kr (J.P.); gscho1@kaist.ac.kr (G.C.)*

1. Introduction

The KEPCO Nuclear Fuel company (KNF) generates about 1000 radioactive waste drums annually. The generated drums are delivered to the radioactive waste disposal site, where measuring and analyzing the radioactivity of the drums is one of the essential requirements for disposal. The waste generated by KNF is a uranium-contaminated substance, and 185.7 keV is the highest emission rate of gamma rays from uranium. The distribution of uranium in the sample drum is not known in advance. Drum efficiency calibration, especially the segmented gamma scanning method, is performed assuming a uniform distribution of radioactivity but involves a large error if the uranium in the sample drum is not uniformly distributed. Therefore, we developed index to check the uniformity of drum radioactivity and also developed a method of detecting source locations and the efficiency correction method the can applied when radioactivity is extremely localized. The method proposed in this study reduced the drum radioactivity error to within 10%.

2. Methods and Results

2.1 Drum scanner

Drum scanners are equipment that analyzes radioactivity inside radioactive waste drum in a non-destructive manner. Radioactivity analysis is divided into destructive and non-destructive analysis (NDA). Destructive analysis refers to sampling and analyzing samples, and if the justification of sampling techniques is secured, it is more accurate than NDA, but it takes longer to preprocess samples. In situations where a large amount of waste occurs, such as waste generated at nuclear fabrication facilities or nuclear dismantling waste, many drums should be measured within a short measurement time while reducing measurement errors. Therefore, KNF analyzes drum radioactivity using KNF Integrated Drum Scanner (KIDS). The KIDS has the following characteristics.

- Five drums automatic continuous measurement
- Density calibration algorithm for the analysis of radioactive waste with various density (Preparing a ^{152}Eu transmission source)
- A HPGe detector for low energy region gamma-ray analysis
- NaI arrays for high density waste measurement (R&D ongoing)
- Collimator for detector response adjustment
- Efficiency correction by measuring the depth distribution of uranium sources in a drum
- Sector-based spectrum analysis software (Sector-Segment Gamma Scanning, SSGS)

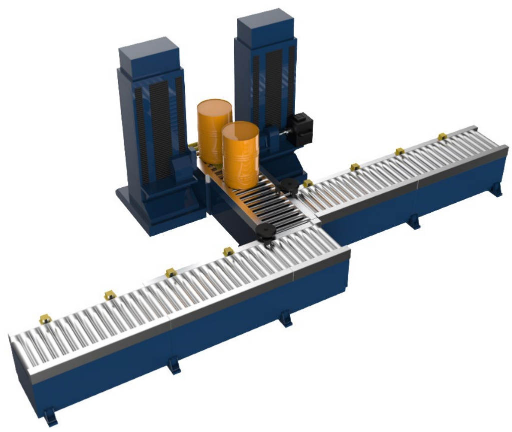

Fig. 1. A rendering image of KIDS.

2.2 Detection system

The KIDS detection system consists of a high purity semiconductor detector (Φ58 × 27.5 mm HPGe crystal, ORTEC) and DESPEC-50 (ORTEC) for data acquisition. It was measured with list mode to see the change in the counts over time, and the list mode was controlled by GammaVision (ORTEC software).

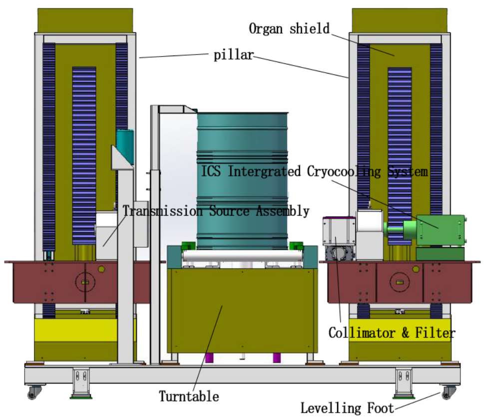

Fig. 2. Components of detection system.

2.3 Uniformity index of the radioactivity in the drum

In SGS drum scanning, radioactivity measurement results vary significantly depending on the degree of uniformity of contamination inside the drum. We developed an index that determines the uniformity of radioactivity distribution in the drum through count ratio at 0 degrees and 180 degrees when rotating the drum. We call it as drum radioactivity uniformity index (DRUX). The DRUX is defined based on the most extreme case where contamination is concentrated in one place (i.e. hotspot). Ideally, if radioactive contamination is uniform, the count at all angles is the same, regardless of rotation. In the case of hotspots, when the contamination position is close to the detector, the count is large and the count is reduced when the source is far away due to drum rotation. In this work, we define the count ratio (180 to 0 degrees) as DRUX. When DRUX is 1, it is uniform, and as DRUX approaches 0, it becomes more non-uniform. The method of estimating source location applied when DRUX is less than 0.6 is described in detail in section 2.4.

Table I: Definition of the DRUX

	DRUX
Uniform	1
Non-uniform	0 to 1
Extremely non-uniform (hotspot)	0

2.4 Results of the source location estimation

The most commonly used methods for drum scanning are the Segmented Gamma Scanning (SGS) and Tomographic Gamma Scanning (TGS) method. SGS is measured by rotating the drum in a circular direction with its central axis fixed, while TGS measures the drum in which the central axis of the drum rotates as it moves in the vertical direction of the detector. SGS mode assumes that one segment of the drum is uniformly contaminated. Due to this assumption, SGS mode converts the total counts measured while rotating the drum into radioactivity. However, in the case of drums that do not undergo homogenization, radioactive contamination is likely to exist locally. According to a prior study [1], if radioactive local contamination exists inside the drum, the error of SGS method according to the location of the hotspot is –82% ~ 325% (at an attenuation coefficient (μ) = 0.12 cm^{-1}). The basic assumption of SGS is that the deviation caused by the hotspot inside the drum should be corrected by rotating the drum, which, as shown in previous studies, does not properly compensate for the radial contamination. In general, commercial SGS system can produce large detection errors because they ignore the effects caused by the source location distribution. In this work, an algorithm was developed to find the radial directional location of uranium in the drum and to correct the detection efficiency in order to reduce the measurement error of the drum scanner.

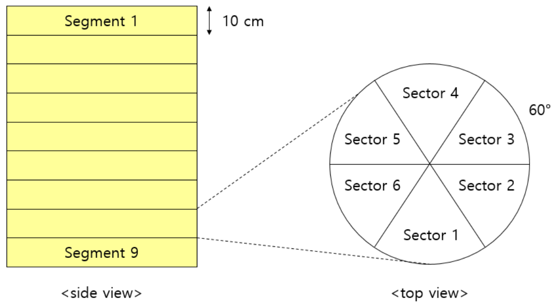

Fig. 3. A schematic of sector-based drum scanning mode.

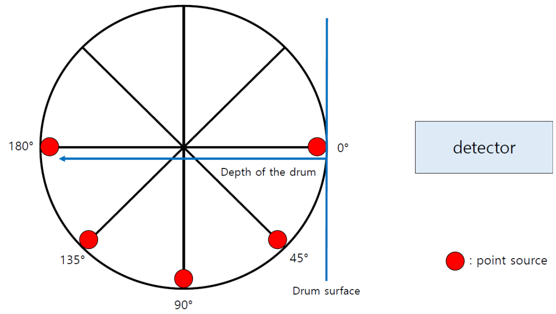

Fig. 4. A schematic of the relationship between the detector, drum and the source position.

To obtain depth information of sources in the drum, a list mode detection was used to record the change in the counts over time [2, 3]. In this context, depth is the distance from the surface of the drum to the diameter direction. If there is a source near the surface of the drum, the distance between the detector and the source changes significantly depending on the rotation of the drum, and if there is a source at the center of the drum, the distance change between the detector and the source is small. The uranium powder (100g, enrichment 4.46%) is located at 5 cm, 10 cm, and 25 cm on the surface of the drum and the net count of 185 keV peak area was measured according to the angle of rotation. A typical gamma spectrum is the x-axis is the energy and the y-axis is the count, while in the list mode detection the x-axis is the time (where the angle between the drum and the detector

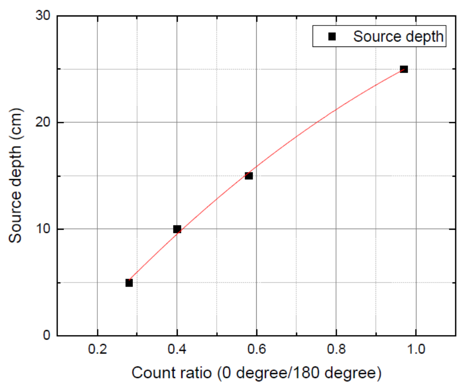

Fig. 5. A source depth estimation function according to list mode detection.

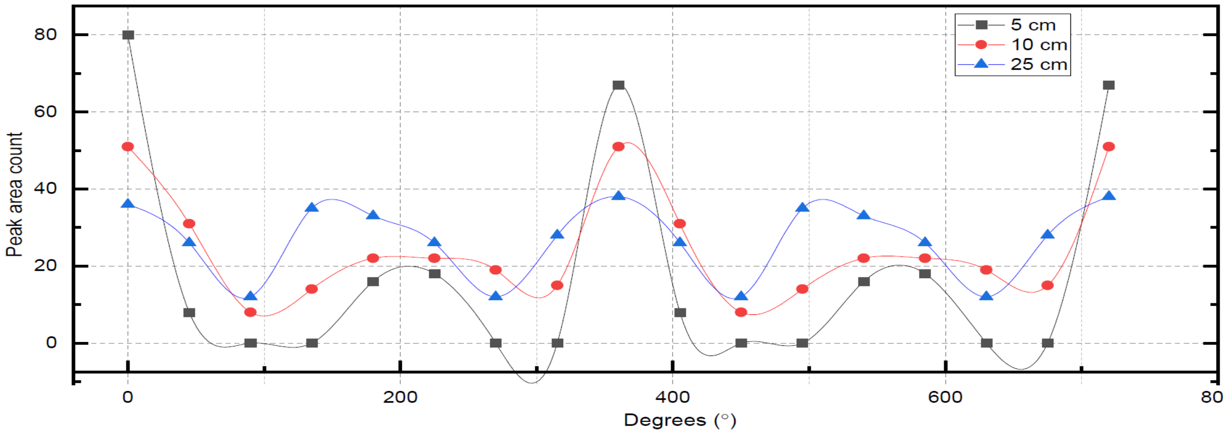

Fig. 6. List mode spectrum according to drum rotation angle

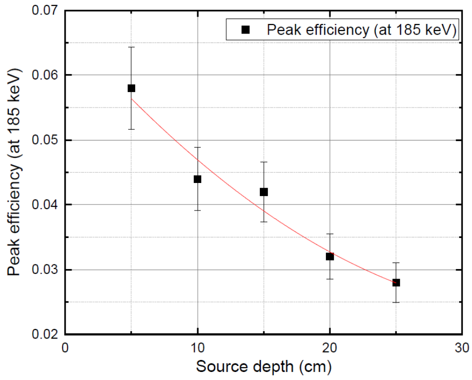

Fig. 7. A peak efficiency estimation function based on source depth.

varies over time), and the y-axis is the count. The list mode measures how the count changes as the source approaches or moves away from the detector. From 0 degrees to 720 degrees (twice rotation), the net counts over time were measured. The regression curve representing the depth of the source was derived as shown in Eq. 1, using the net count ratio at 180 degrees to 0 degrees (DRUX). The peak efficiency according to the depth of the source is obtained by using the location information of the drum radial direction of the uranium source estimated.

$$D = -12.53 \times PR^2 + 44.25 \times PR - 6.17 \qquad (1)$$

$$PE = 0.0679 \times e^{-0.036D} \qquad (2)$$

where, D is depth in radial direction of uranium source, PR is peak ratio of 180 degrees to 0 degrees, and PE is peak efficiency of 185 keV.

In this work, we use the peak efficiency of obtaining radioactivity in the area of 185 keV peak area emitted from ^{235}U, and derive a regression expression that estimates efficiency through source depth (Eq. 2). To evaluate the reliability of source depth estimation curves and peak efficiency estimation curves using drum rotation angles, we measure at depths not used for regression curves. The uranium source (75g of powder) was measured 12 cm away from the surface of the drum. The depth of the source, based on the count according to the angle of rotation, was 14.7 cm. The average count measured six times was 7,636 counts, and the estimated efficiency obtained using the estimated depth information (14.7 cm) and equation 2 was 0.04. Therefore, the estimated radioactivity was 190,761 Bq, reflecting depth information, and the actual uranium radioactivity was 185,000 Bq (Enrichment of uranium was 4.46%), which was estimated at 3.1% error. In addition, experiments on sources at location 5 cm, 15 cm, 20 cm, and 25 cm away from drum surface showed that radiation could be estimated by an error of not more than 10% compared to the actual radioactivity in all cases.

3. Conclusions

We developed an index (DRUX) that provides information on the radioactivity distribution in the drum, and we study the uranium source location estimation method used when the DRUX is less than 0.6. This method estimated radioactivity of the drum in a sector within 10% error. Radioactive information in radioactive waste is an important factor in the disposal of waste. In particular, if waste drums are generated in large quantities, such as dismantling nuclear power plants, there is a limit to sampling and measuring waste, which increases the importance of drum scanners. Segmented Gamma Scanning (SGS), the most widely used drum measurement method among drum scanner's measurement modes, has advantages such as ease of operation and ease of calibration, but there is a large error if the conditions for uniform distribution of radioactive contamination, which is a basic assumption, are not satisfied. We improve existing SGS methods by developing a measurement model that it applicable even in a hotspot situation. In future studies, experimental verification will be carried out to apply the DRUX concept to various contamination situations, and models applied to the state of filling the drums with various densities of waste will be studied.

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