Simulation of Nuclear Material Weighing System using Multiplicity Measurement based on Fast Neutron Detection

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1. Introduction

The adoption of the Nuclear Ban Treaty (NPT) in July 2017 by the United Nations has raised the international community's interest in verifying nuclear disarmament verification [1]. To verify the dismantling of nuclear weapons, it is important to accurately measure the content of nuclear materials, which are the raw materials of nuclear weapons. Neutron multiplicity measurement is a representative example of nuclear material measurement technology.

Neutron multiplicity measurements use a method of simultaneously counting neutrons produced during spontaneous fission of nuclear material [2]. Conventional neutron multiplicity counters use He-3 tubes, but they have the disadvantage of having a long die-away time and suffering from worldwide depletion. It is planned to build a fast neutron detection-based multiplicity counting device using a stilbene organic scintillator to solve this problem. Detectors based on fast neutron scattering are considered to be able to improve the verification accuracy of nuclear materials by obtaining accurate neutron timing and energy information. Before fabricating the measurement system, this study compared two methods [3] that can derive the effective mass of nuclear material by computer simulation to confirm more effective techniques.

2. Methods and Results

2.1 System design

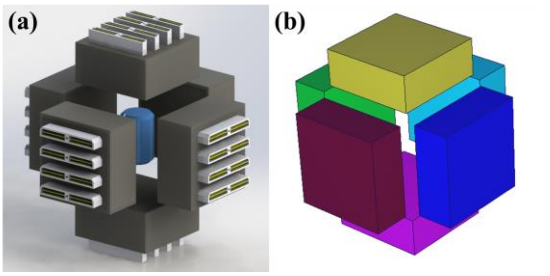

Fig 1. (a) 3D system design to be built and (b) simulation model for the detector arrangement in the shape of a cube.

Figure 1(a) shows the 3D system design, and Fig.1(b) shows the system model for the simulation in this study. Stilbene organic scintillators used for detection of neutron and gamma-ray, composed of 144 pixels with a thickness of 20 mm and are arranged in a regular cubic shape to maximize detection efficiency. To verify the effectiveness of measuring nuclear materials in the system, samples with an effective mass of Pu-240 in the range of 5-100 g were used. Singles, doubles, triples rates were derived by applying multiple measurement methods in each case. For the measured singles, doubles, and triples rates, the effective mass of Pu-240 can be estimated using both one-parameter assay and two-parameter assay. Each mass calibration curve is derived using upon both methods. Table I shows the sample singles, doubles, triples rates used to form the mass calibration curve.

Table I: Measured S, D, and T rates for 10, 30, 50, 70, and 90 g of Pu-240 effective mass samples.

Pu mass [g]	S [cps]	D [cps]	T [cps]
10	2249.853	354.597	40.401
30	6973.320	1172.720	153.800
50	11872.633	2069.167	294.460
70	16908.233	3054.256	471.242
90	22028.471	4079.029	660.038

2.2 One-parameter assay

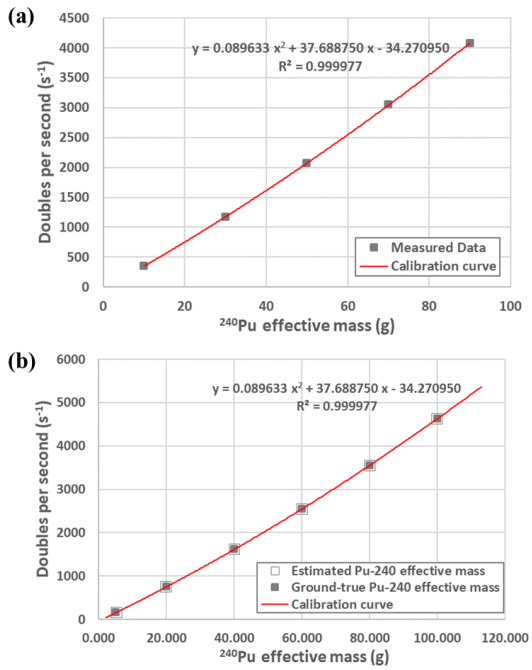

Fig 2. (a) One-parameter assay mass-calibration curve from the reference samples, and (b) validation of the mass calibration curve using one-parameter assay for the remaining unknown samples.

Figure 2(a) shows the results of the mass calibration curve formed by measuring the doubles rate of reference samples with 10, 30, 50, 70, and 90 g of Pu-240 effective mass, and Fig.2(b) shows the result of verifying the mass calibration curve using the remaining samples with different effective mass.

Table II: Difference of the estimated and ground-true Pu-240 effective mass for the one-parameter assay.

Ground-true $^{240}Pu_{eff}$ mass [g]	Estimated $^{240}Pu_{eff}$ mass [g]	Relative Difference [%]
5	5.330	-6.591
20	19.904	0.480
40	39.945	0.137
60	60.016	-0.027
80	80.005	-0.006
100	99.830	0.170

Table II shows the difference between ground-true mass and estimated mass using the one-parameter assay. Except for the ground-true mass of 5 g, it was confirmed that the mass calibration curve obtained using the one-parameter assay with a relative error of less than 1% in all cases was effective.

2.3 Two-parameter assay

Figure 3(a) represents the mass calibration curve obtained from the reference sample using the two-parameter assay, and Fig. 3(b) shows the result of verifying the mass calibration curve using the remaining samples of different effective mass.

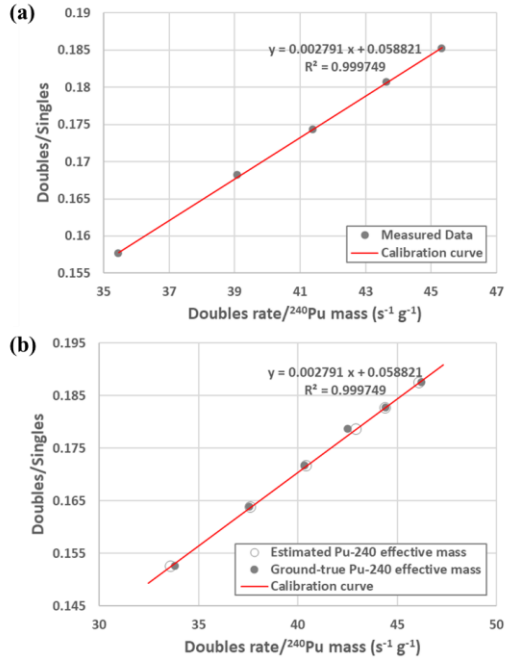

Fig 3. (a) Two-parameter assay mass-calibration curve from the reference samples, and (b) validation of the mass calibration curve using two-parameter assay for the remaining unknown samples.

Table III shows the difference between the ground-true mass and the estimated mass using the two-parameter assay. It was confirmed that the mass calibration curve obtained using the two-parameter assay was effective in all cases, with a relative error of less than 1%.

Table III: Difference of the estimated and ground-true Pu-240 effective mass for the two-parameter assay.

Ground-true $^{240}Pu_{eff}$ mass [g]	Estimated $^{240}Pu_{eff}$ mass [g]	Relative Difference [%]
5	5.038	-0.754
20	19.980	0.102
40	39.940	0.151
60	59.407	0.988
80	80.068	-0.085
100	100.248	-0.248

3. Conclusions

Through Monte Carlo simulation, the difference between mass calibration curves obtained by applying the one-parameter assay and the two-parameter assay was confirmed in the proposed system to be constructed later. In the case of the one-parameter assay, since the mass calibration curve follows quadratic equation, an error occurs mainly in a low mass, but there is little error in the range of heavier mass. In the case of two-parameter assays, the calculation of the 5g sample is relatively accurate. For the proposed neutron multiplicity counter, two-parameter assays will be considered more effective because they main target will be trace samples.

Acknowledgement

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