Estimation of the Strength of Neutron Source Needed for a Nuclear Fuel Rod Scanner by the 1-D Simulation Model

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1. Introduction

Non-destructive test is very useful to check the integrity of the fabricated nuclear fuel rod during the final QA process. A NFRS (Nuclear Fuel Rod Scanner) is used to monitor the difference of the ^{235}U concentrations of the pellets in a fuel rod from the designed value at the end of the assembly line. The scanner is composed mainly with ^{252}Cf as a neutron source, fuel rod moving mechanism and gamma-ray detectors as shown in Fig. 1.

Recently the price of ^{252}Cf goes up rapidly, and also the supply condition in the world market becomes unstable. PNL (Phoenix Neutron Laboratory) has developed a new fuel rod scanner that uses high flux neutron generator [1] instead of ^{252}Cf. To develop a new system or upgrade the present system, it is very important to fix a simulation tool for the NFRS system.

Using a 1-D simulation model, that is developed to calculate the number of detected delayed gamma rays at the detector area of the NFRS depending on different operating conditions such as neutron source strength, scanning speed and moderation structure, the minimum neutron strength needed for the NFRS at KEPCO NF (Nuclear Fuel) [2] is evaluated in this paper.

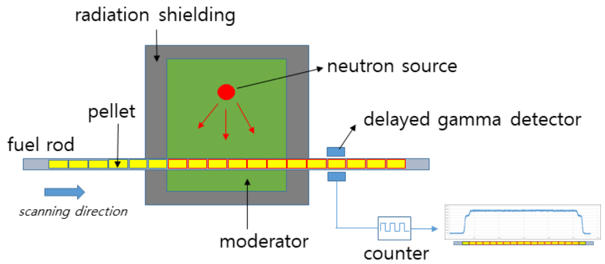

Fig. 1. Schematic diagram of the fuel rod scanner.

2. Methods and Results

2.1 Detection of Delayed Gamma Rays in NFRS

The probability of delayed gamma-ray emission from the fission of the nuclear materials decreases exponentially with time, and the probability of the gamma-ray production reduces at the rate of 1 over tenth especially during 10 seconds [3]. The performance of the fuel rod scanner, that is operated at a fixed neutron strength, is determined by the counting rate of the delayed gamma-rays, and the counting rate at the detector position depends on fission rate and time delay between fission and detection, i.e. scan speed of the fuel rod.

2.2 1-D Simulation Model for the Scanner

A fuel rod passes through a neutron irradiation chamber and detector array in a programmed speed. During in the neutron irradiation chamber fissions of ^{235}U in the nuclear fuel rod are made, and delayed gamma rays from fission fragments are detected in the detector area on the downstream side of the scanner.

The counting rate of the delayed gamma rays with time is the main calculated result of the 1-D simulation model. The various parameters in the simulation with 1-D model are listed in Table 1 including the operational parameters of the rod scanner. The neutron energies are simplified into 2-group such as thermal and fast. During a pellet passes through the irradiation chamber, fissions and delayed-gamma emissions are made continuously with different scenarios, and as it comes out through the exit of the chamber, fission stops. And the number of delayed gamma ray of the moving fuel rod is counted with a short time bin at the detection area. The calculation flow of the counting rate of the delayed gamma rays with 1-D model is shown in Fig 2.

input parameter	· neutron source strength · calculation time-step · ^{235}U concentration
output parameter	· gamma-ray counting
variables	· neutron source position · irradiation length · scan speed · moderation structure
1 dimensional	· calculation at a z-axis
pellet	· material oxidized ^{235}U, ^{238}U
^{252}Cf n E spectrum	· two group (thermal/fast)
Nuclear data library	· SAND2015-7024

Table 1. Parameters of 1-D Simulation Model

2.3 Verification of 1-D Model

To check the reliability of the simulation model, the counting rates calculated by 1-D model and measured by LANL [4] depending on scan speed of NFRS are compared as in Fig.3. The results show that the contour of the curves is almost same even though the absolute counting rates are different because of different counter efficiencies and fission conditions.

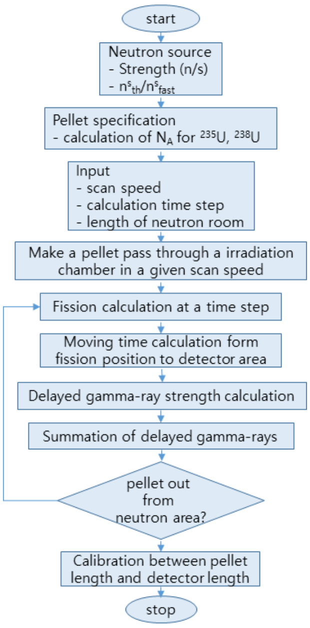

Fig. 2. The calculation flow of the counting rate of the delayed gamma rays with 1-D model

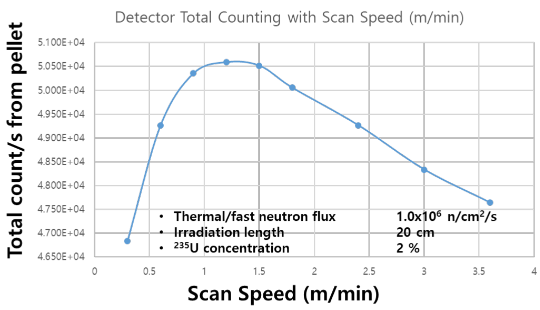

Fig. 3. The counting rates calculated by 1-D model depending on scan speed of NFRS.

2.4 Estimation of the Needed Neutron Strength with ^{252}Cf for the NFRS

The efficiency of gamma ray detection and n_{th}/n_f ratio of the neutron irradiation room are very important parameter in analyzing the NFRS system. The n_{th}/n_f of the KEPCO NF scanner system is determined by the slope of the curve in the graph that shows the counting rate dependence on n_{th}/n_f ratio and ^{235}U concentration as shown in Fig. 4. And the detector efficiency is estimated by comparing counted data and calculated results. The estimated value of n_{th}/n_f ratio and detector efficiency are 0.17 and 0.25 respectively.

Considering these parameters, real count rates that could be earned in the given scanning speed of the NFRS system of KEPCO NF depending on neutron strength, n_{th}/n_f ratio and ^{235}U concentration, are calculated. And with these results various operational scenarios are considered. It is found that the minimum neutron strength of ^{252}Cf for the normal operation of the scanner is 2x10^9 n/sec (Fig. 4) to get 1 % resolution of ^{235}U concentration with 400 counts' difference of the delayed gamma-rays, and the needed neutron strength could be decreased to 1x10^9 n/sec (Fig. 5) by adding a properly designed moderator between ^{252}Cf and fuel rod. Also the requirements of a neutron generator as the alternative source of ^{252}Cf in the future be estimated.

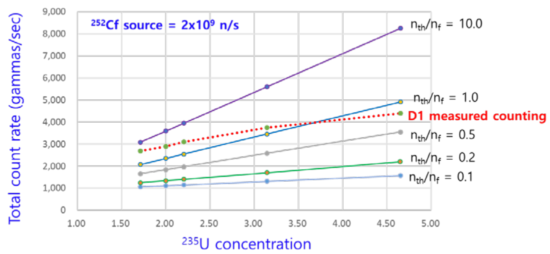

Fig. 4. The counting rates depending on n_{th}/n_f and ^{235}U concentration when ^{252}Cf strength is 2x10^9 n/s.

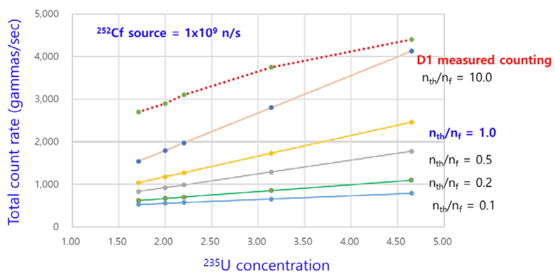

Fig. 5. The counting rates depending on n_{th}/n_f and ^{235}U concentration when ^{252}Cf strength is 1x10^9 n/s.

3. Conclusions

A 1-D simulation model is developed to calculate the number of detected delayed gamma rays at the detector area of the fuel rod scanner depending on different operating conditions such as neutron source strength, scanning speed and moderation structure. By using the developed 1-D model, the minimum neutron strength of ^{252}Cf and other possibilities for the NFRS at KEPCO NF are evaluated.

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