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Assessment on Neutron Source Assembly for Fuel Loading after Long Overhaul

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1. Introduction

All Pressurized light-Water Reactors (PWRs) in Republic of Korea uses neutron source assemblies (NSAs) for initial core and reload core fuel loading until their life time. Neutron source assembly provide an enough neutron count rate for ex-core detector to monitor the reactor core criticality.

According to aging of the components of reactor core, many main components (i.e. steam generator or reactor coolant pump, etc.) are being replaced, and maintenance period sometimes takes over 300 days. And, in case of long overhaul (O/H), the strength of neutron sources should be evaluated for safe fuel loading and to satisfy the related regulations.

In this paper, the strength and ability of neutron source assemblies for monitoring of subcritical multiplication after long overhaul is evaluated and new strategy is suggested for safe fuel loading.

2. Methods and Results

2.1 Neutron Source Assembly

The main purpose of using neutron source assembly is to provide a base neutron level to insure that the ex-core detectors of the reactor are available and operational to monitor the criticality inside of reactor core. In term of regulation, neutron sources(NSAs, burned fuel assemblies) in reactor core should provide a neutron count rate at least 0.5 cps to ex-core detector to monitor the criticality during fuel loading and the initial criticality procedures (US NRC Reg. Guide 1.68[1]). Figure 1 shows the location of NSAs and its configuration.

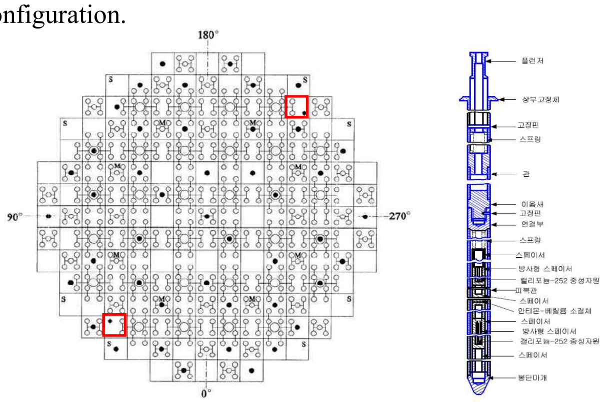

Fig. 1. Neutron Source Assembly Loading Location (Left) and the Configuration (Right)

2.2 Neutron Sources during Fuel Loading

There are three (3) major neutron sources during the fuel loading in reactor core. Californium-252 (Cf-252) is the primary neutron source which formed as Pd-Cf_2O_3 cermet wire in NSAs. Cf-252 is major neutron source at initial core because there are only fresh fuels in reactor core at first cycle. Antimony-Beryllium (Sb-Be) neutron source is also loaded in NSAs and it is photonuetron source which based on (γ,n) reaction. The neutron flux activates Sb-123 to Sb-124 and next gamma-neutron reactions show as follows;

$$^{124}Sb \rightarrow ^{124}Te + \beta + \gamma$$

$$\gamma + ^{9}Be \rightarrow ^{8}Be + n - 1.66MeV$$

Burned fuel assemblies in core are major neutron source to provide a neutron count rate to ex-core detector in case of removing NSAs in reactor core. There are many isotopes which generate neutron sources, Cm-242, Cm-244, Pu-238 isotope, in burned fuel assemblies.

These three major neutron sources play a role to provide sufficient neutron count rate to ex-core detectors.

2.3 Evaluations of Neutron Source Strength after O/H

For the evaluation of ability of each three neutron source, it is needed to compare with below two cases; 1) 30days overhaul (normal O/H case), 2) 370 days overhaul (long O/H case). And, in order to analyze reasonably, we use the cycle information of specific OPR1000 reactor in Korea.

- Reactor Power: 2815 MW_{th}
- Cycle of NPP: 5^{th} cycle.
- Initial Cf-252 Strength: 5.1 $\times 10^7$ neutrons/sec
- Sb-Be composition: 50% Sb + 50% Be
- Sb-Be density: 3.37 g/cm^3
- Operation Information [2]

The neutrons' strength from Cf-252 is calculated by using its half-life. The half-life of Cf-252 source is 2.645 years, so it decays as follows by the time.

$$A_{n,Cf-252} = A_0 \times e^{-0.0218 \times n}, n = month$$

After 5^{th} cycle operation and 30days overhaul, Cf-252 neutron strength is calculated as about 8.3 $\times 10^6$

n/sec. In case of 370days overhaul, the source strength is 6.4 × 10^6 n/sec.

The calculation of neutron source strength of Sb-Be is needed the operation information of the reactor because amount of activated Sb-123 and generation of Sb-124 should be calculated. The Monte Carlo Code, MCS[3], is used for neutron irradiation and activation of Sb-123 during reactor operation and Sb-124 decay during each cycle's overhauls. The neutron source strength of Sb-Be after 5th cycle's operation is about 1.5 × 10^8 n/sec, so Sb-Be's neutron strength of each normal and long O/H cases are 1.06 × 10^8 n/sec, 1.96× 10^6 n/sec, respectively.

Twice burned fuel assemblies are generally used for neutron sources when NSAs remove from the inside reactor core. The simulated fuel assembly is 4.65/4.15% U-235 enriched fuel and calculated as 439 days irradiation → 30days decay → 447 days irradiation. The ORIGEN ARP Code[4] is used for these deletion and decay calculations. The results are showed in Table 1.

Table 1 Neutron Source Strength of Fuel Assembly source

	Initial	30days	370days
Strength	2.83× 10^8	2.68× 10^8	1.76× 10^8
Ratio	100%	94.9%	62.1%

As the result of this calculation, twice burned fuel play a major role among neutron sources in reactor core. However, this evaluation shows Sb-Be source is strongly affected by long O/H. In point of overhaul, Sb-Be neutron source is dramatically decreased as compared with another two sources. Table 2 shows the calculation of three neutron source case, and it shows that Sb-Be can be neglected as neutron sources after a long overhaul case.

Table 2 Summary of Calculations

	30days Strength (Ratio)	370days Strength (Ratio)	Ratio of 370days /30days
Cf-252	8.3× 10^6 (3%)	6.4× 10^6 (13%)	77%
Sb-Be	1.06× 10^8 (28%)	1.96× 10^6 (1%)	2%
Burned fuel assembly	2.68× 10^8 (70%)	1.76× 10^8 (95%)	62%

2.4 Strategy for Fuel Loading after O/H

Normally, NSAs are loaded in fresh fuel and that fuel assembly is the first loading fuel assembly, and neutron count rate of ex-core detector should be available to monitor the fuel loading. Sb-Be in NSAs is dominant neutron sources after 1st cycle, however, as shown in Table 2, the source strength of Sb-be is not enough after long O/H.

In order to satisfy the regulation criteria at long term O/H's case, twice burned fuel assemblies can be used for first loading fuel assembly. Those sources remain strong after long O/H, therefore, it is better to use twice burned fuels instead of fresh fuels at least first seven loadings. And fuel loading sequences and fuel loading locations should be changed to get more neutron count at ex-core detector as shown in Figure 2.

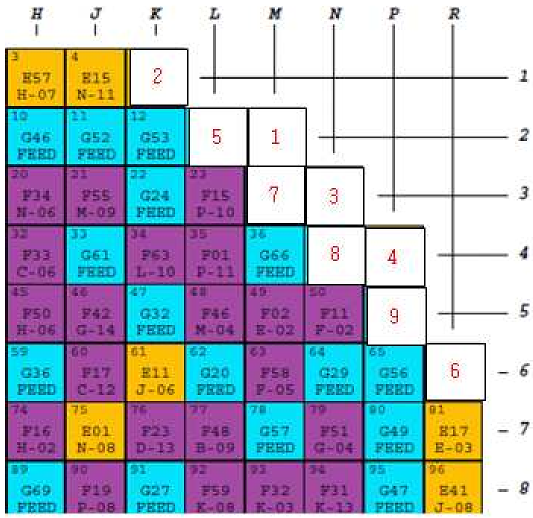

Fig. 2. Fuel Loading Sequence and Location for Long Term O/H Cases

3. Conclusions

In this study, three neutron sources in reactor core for long overhaul are evaluated by using specific nuclear power plant data. In according to analysis of three neutron sources after long O/H, Sb-Be, NSA's secondary neutron source, is mostly affected for long O/H. Its strength after long O/H is not enough for monitoring criticality inside rector core during the fuel loading.

For the safe fuel loading, that fuel loading sequences and location should be considered as using twice burned fuel to satisfy the criteria of monitoring the reactor core criticality during the fuel loading.

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