Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Fissile Content Assay of Spent Fuel Using LSDS System

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1. Introduction

The accumulation of spent fuel is current big issue. The amount of spent fuel will soon reach the maximum storage capacity of the pools. Therefore, an interim storage must be searched and should be optimized in its design by applying accurate fissile content. When the storage has taken effect, all the nuclear materials must be also specified and verified for safety, economics and management.

Generally, the spent fuel from a PWR has unburned ~1 % U235, produced ~0.5 % plutonium from decay chain, ~3 % fission products, ~ 0.1 % minor actinides (MA) and a uranium remainder. About 1.5 % fissile materials still exist in the spent fuel. Therefore, for re-utilization of fissile materials in spent fuel at SFR, resource material is produced through the pyro process. Fissile material contents in the resource material must be analyzed before fabricating SFR fuel for reactor safety and economics.

The new technology for an isotopic fissile material content assay is under development at KAERI using a lead slowing down spectrometer (LSDS). LSDS is very sensitive to distinguish fission signals from each fissile isotope in spent and recycled fuel.

In an assay of fissile content of spent fuel and recycled fuel, an intense radiation background gives limits the direct analysis of fissile materials. However, LSDS is not influenced by such a radiation background in a fissile assay. Based on the decided LSDS geometry set up[1], a self shielding parameter was calculated at the fuel assay zone by introducing spent fuel or pyro produced nuclear material. When nuclear material is inserted into the assay area, the spent fuel assembly or pyro recycled fuel material perturbs the spatial distribution of slowing down neutrons in lead and the prompt fast fission neutrons produced by fissile materials are also perturbed. The self shielding factor is interpreted as how much of the absorption is created inside the fuel area when it is in the lead. The self shielding effect provides a non-linear property in the isotopic fissile assay. When the self shielding is severe, the assay system becomes more complex and needs a special parameter to treat this non linear effect. Additionally, an assay of isotopic fissile content will contribute to an accuracy improvement of the burn-up code and increase the transparency and credibility for spent fuel storage and usage, as internationally increasing demand.

2. Assay Procedure

In the designed LSDS system, the source neutron having ~0.5MeV mean energy, slows down in the lead medium and induces fissile fission with respect to slowing down energy. Lead medium has a continuous neutron energy spectrum and low neutron capture loss.

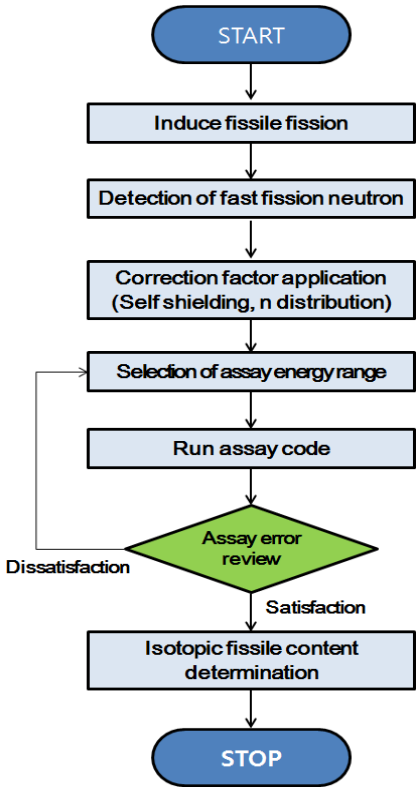

Fig. 1. Assay procedure for isotopic fissile material.

A broad range of interrogation neutron energies is available in the lead spectrometer. In the slowing down neutron energy, the fission characteristics of each fissile are shown below several tens of keV energy. Therefore, the energy between 1 keV to 0.1 eV was determined which was very sensitive to the fissile material fission. However, a good energy resolution in the fission signatures must be also considered simultaneously to distinguish these isotopes from each other. Figure 1 shows the assay procedure. Source neutrons induce fissile fission. The fissile fission neutron induced by the slowed down source neutron is measured by surrounding fission chamber. The detection signal is expressed as

$$\int_{S_{det}} \int_{E_1}^{E_2} \sigma_f \emptyset_f (r, E, t) dE dA,$$

where $_f$ is the fission rate at the detector, $_f$ is the fission neutron arriving at the detector and S_{det} is the detector area. On the system, the induced fissile fission neutron is detected at the surrounding threshold detectors. The fission neutron detection has a direct relation to the amount of fissile material. Nuclear material has the neutron absorption property. The correction for self-shielding must be applied. The source neutron distribution in the assembly is applied as well. The fissile content assay is performed by selecting the assay range including all the dominant fission structure of fissile materials. When the assay error is satisfied, the content is decided.

3. Fissile Assay

The assay model was setup based on the linear response between fission and measurement. The detector measurement involves information of the fission of U235, Pu239, and Pu241 by the interrogation source neutron. The assay model has a property that has linearity between detection and fissile fission. The model is expressed like below,

$$y_i = k\epsilon[\nu_{1i} N_1 < \sigma_{f,1}\phi >_i + \nu_{2i} N_2 < \sigma_{f,2}\phi >_i + \nu_{3i} N_3 < \sigma_{f,3}\phi >_i]$$

Where y_i is the detector signal at channel *i*, *k* is the normalization constant, and ϵ is the detector efficiency. 1, 2, and 3 represent the fissile materials, U235, Pu239, and Pu241 and *N* is the fissile mass. ν is the average neutron yield by the fission of each fissile material, σ_f is the fission cross section and ϕ is the source neutron intensity entering into the fuel rod. Therefore, $< \sigma_{f,1}\phi >_i$ represents the fission reaction rate by the source neutron at channel *i*. The assay model represents that the fission neutron detection has a direct relation to the amount of fissile material. The correction factor is applied to the fission detection value for exclusion of self-shielding phenomenon. The self-shielding factor expressed as below equation.

$$Correction\ factor = \frac{\Phi_s}{\Phi_{ave}}$$

The source neutron energy between 1 keV to 0.1 eV was determined which was very sensitive to the fissile material fission. Two terms of correction factor are calculated using MCNP code. The neutron distribution flux in the rod is considered. Lastly, the fissile content assay was evaluated for the U235:1%, Pu239:3%, Pu241:1% and U235:1%, Pu239:4%, Pu241:1%

4. Results and Conclusion

Table 1 and Table 11 represent the assay results. The fissile contents result came out almost exactly with relative error ~2% in case of Pu239, Pu241 for two different plutonium contents.

Table I: Isotopic fissile content assay (U235:1%, Pu239:1%, Pu239: 3%)

Isotope	Fissile content (wt%)	Error
U235	1.04	0.12
Pu239	3.10	0.05
Pu241	1.18	0.03

Table II: Isotopic fissile content assay (U235:1%, Pu239:1%, Pu239: 4%)

Isotope	Fissile content (wt %)	Error
U235	1.00	0.10
Pu239	4.01	0.03
Pu241	1.24	0.02

In this study, meaningful results were obtained in low enrichment. In the future, the content assay for highly enriched rod will be performed before fabricating SFR fuel to obtain the reactor safety and economics.

Acknowledgement

This work was supported by the Nuclear Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No. 2015032743).

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