Quantitative Fissile Assay In Used Fuel Using LSDS System

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Abstract. A quantitative assay of isotopic fissile materials (U235, Pu239, Pu241) was done at Korea Atomic Energy Research Institute (KAERI), using lead slowing down spectrometer (LSDS). The optimum design of LSDS was performed based on economics, easy maintenance and assay effectiveness. LSDS system consists of spectrometer, neutron source, detection and control. LSDS system induces fissile fission and fast neutrons are collected at fission chamber. The detected signal has a direct relation to the mass of existing fissile isotopes. Many current commercial assay technologies have a limitation in direct application on isotopic fissile assay of spent fuel, except chemical analysis. In the designed system, the fissile assay model was setup and the correction factor for self-shield was obtained. The isotopic fissile content assay was performed by changing the content of Pu239. Based on the fuel rod, the isotopic content was consistent with ~2% uncertainty for Pu239. By applying the covering (neutron absorber), the effective shielding was obtained and the activation was calculated on the target. From the assay evaluation, LSDS technique is very powerful and direct to analyze the isotopic fissile content. LSDS is applicable for nuclear fuel cycle and spent fuel management for safety and economics. Additionally, an accurate fissile content will contribute to the international transparency and credibility on spent fuel.

1 Introduction

An isotopic fissile content assay is very important for the reuse of fissile materials through nuclear fuel cycle and the management of spent fuel. The accurate fissile content is a key point to be verified for increased safety and economics in the reuse and management. The pyro processing technology is under development in KAERI, as one option of nuclear fuel cycle, which increases the proliferation resistance. The pyro process produces the source material including trans-uranium to fabricate a fuel rod for sodium fast reactor (SFR). Therefore, the fissile content must be verified before the fabrication of fuel rod. Also, the fissile content is one of the factors to be given for the optimum design of spent fuel storage site.

A real time and non-destructive direct assay of fissile materials in spent fuel is currently big issue in Korea. The research on an interim and a permanent storage for final disposal has been performed. An accurate fissile material content can makes it possible for a maximum burnup credit on spent fuel storage site.

LSDS is under development to analyze the isotopic fissile content in spent fuel. The optimum design was done and the main parameters were investigated and determined for the system working. In the designed LSDS device[1], the source neutron is slowed down in the lead medium and produces continuously slowed down energy. The continuous energy spectrum enters into the fuel area and induces fissile fission with respect to the neutron energy. The fissile fast fission neutron is measured in the surrounding threshold fission chamber to discriminate the fast neutrons in the complex radiation field (intense gammas, source neutron, spontaneous fission neutron and (α, n) reaction).

The fissile assay model was setup and the fissile content assay was performed on the various plutonium contents. The self-shielding was calculated over the slowing down channel[2]. The mechanism for source neutron production was determined including the target. The energy deposition at each target layers by the incident electron was calculated and the produced radiations were evaluated. The effective shielding calculation was performed at the outside wall by applying the neutron absorber surrounding the spectrometer.

2 Assay Model

The detector measurement of fast fission neutron involves information on the fission of U235, Pu239, and Pu241 by the interrogation source neutron, with respect to the neutron energy. The assay model has a property that has linearity[3] between detection and fissile fission. The model is expressed like below,

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

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

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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 fissile fission reaction rate by the source neutron at channel i. In the system, the induced fissile fission neutron is detected by the surrounding threshold detectors. The fission neutron detection has a direct relation to the amount of fissile material. The configuration for the detector, fuel area and source is shown in figure 1.

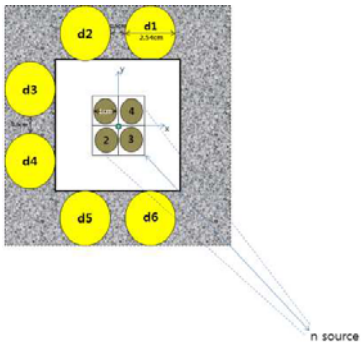

Fig. 1. Geometry of fuel rod and detector for fissile assay.

In the LSDS system, when the fuel is introduced into the assay area. The source neutron is captured in the fissile materials. The self-shielding factor must be applied for the correction of fission signals. The assay energy range is usually selected to involve the fission structures which represent the dominant properties of each fissile material. Figure 2 shows the fission signals before and after the application of the correction factor. In the simulation, the amounts of U235 and Pu241 were fixed to 1wt% and the content of Pu239 was varied from 1wt% to 10wt%. As shown in the figure, before the correction, the fission rate by increasing the amount of Pu239 does not match the amount increase. However, the corrected fission signal shows a well defined fission property with respect to the amount increase. Therefore, the correction in a fission signal is very important to get accurate assay results.

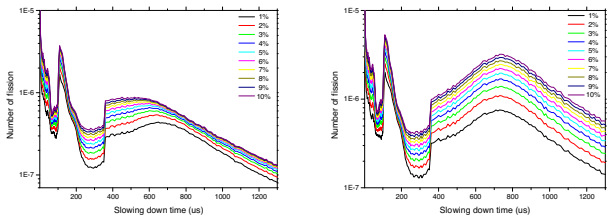

Fig. 2. Fission signal before and after correction by changing Pu239 content (U235 1%, Pu241 1% fixed).

3 Fissile assay

Based on the assay model in equation 1, an isotopic fissile assay was performed in the fuel rod for U235, Pu239 and Pu241. The detection signal in each channel is the sum of the fission by U235, Pu239 and Pu241. Therefore, from the fission signature, the assay range was selected to include each fissile dominant fission signature, 1keV through 1eV. Table 1 shows the summary of the assay results. In the content assay, the well agreed content of uranium and plutonium was obtained. For a change of 3 to 10% in the Pu239 content, the assay was obtained with 2~3% uncertainty compared to the actual value. However, for 1 and 2% content of Pu239, a relatively poor error was obtained. From the assay results, for highly enriched Pu239 cases, more accurate results were obtained. For the U235 assay, the results show good agreement to the actual mass. However, in the Pu241 case, the assay has a relatively low accuracy. The fission signature shows a similarity in the plutonium.

4 Source neutron

The intense source neutron is required in LSDS system to induce the continuous fissile fission. For effective neutron production, one section electron accelerator was decided with the target. The source neutron must be enough to get detection statistics for fission and overcome the radiation background. 30MeV electron accelerator and 500mA current were determined to generate ~10^{12} n's/sec at the target. 5 layered Ta plates were designed with Be at the end of plates[4]. The design was based on how to produce enough neutrons effectively and to cool down the plates without interference of the produced neutron spectrum. Figure 3 shows the total accelerating system to generate the source neutron. In the figure, short two columns were used to reduce the radiation leakage through the wall.

Because high energy electron enters into the target, the energy deposition on each plate was evaluated. In the target, not only electron but also gamma and neutron produced by interacting with electron deposit their energy on each plate. Therefore, the cooling system is considered not to melt down at the plate. The intense electron can penetrate Ta and Be layer and arrive at the lead. From the calculation, the electron is totally stopped at 19cm thickness of lead.

5 Shielding effect and activation

For effective and intense neutron production using electron accelerator, facility shielding is required. The optimum shielding design was done using concrete and borax combination[5]. The neutrons from the target, induced fissile fission and spontaneous fission by spent fuel leak out the spectrometer. The gamma rays are normally shielding in the lead spectrometer. The neutron interacts with the lead and shielding material. From the optimized facility shielding calculation[5], the shielding effectiveness was examined by applying the additional covering around the spectrometer to absorb leaked neutron. The covering (250cm in length and height) consists of HDPE-Borax with a 5cm thickness. Table 2 shows the calculated dose rate at the outside wall surface(cell #7 at figure 4) of the LSDS facility. When the HDPE-borax covers the spectrometer, the dose rate decreases 70% compared to that of the no covering case. Therefore, the application of covering around the spectrometer can reduce the facility wall thickness.

Table 1. Isotopic fissile content assay (U235:1%, Pu239:1%, Pu239: changed).

Mixed (%) U5-Pu9-Pu1	**1-1-1**	**1-2-1**	**1-3-1**	**1-4-1**	**1-5-1**	**1-6-1**	**1-7-1**	**1-8-1**	**1-9-1**	**1-10-1**
U-235	1.01	1.00	1.04	1.00	1.03	0.99	1.01	1.06	1.15	1.23
Error	0.09	0.10	0.12	0.10	0.11	0.11	0.11	0.09	0.12	0.12
Pu-239	1.05	1.82	3.10	4.01	5.09	5.94	7.04	8.00	9.26	10.01
Error	0.02	0.03	0.05	0.03	0.04	0.04	0.05	0.04	0.05	0.06
Pu-241	1.15	1.21	1.18	1.24	1.24	1.28	1.27	1.31	1.28	1.29
Error	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02

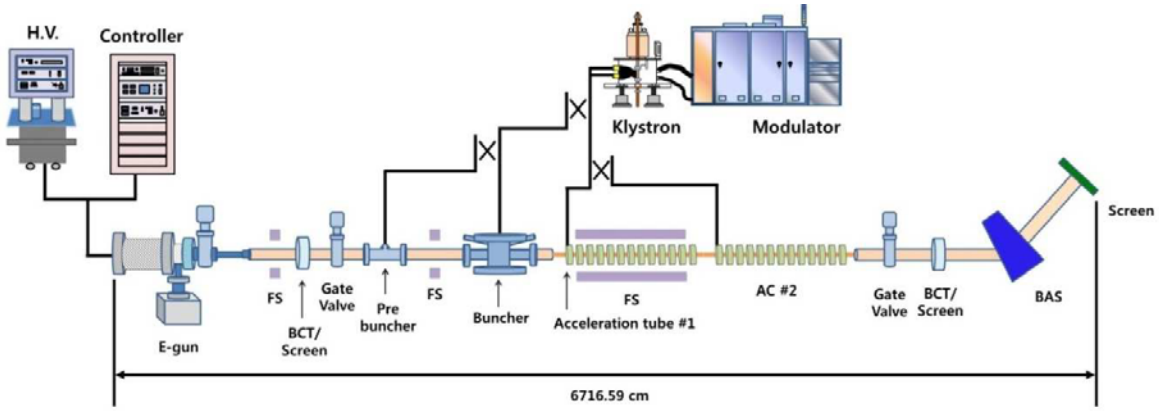

Fig. 3. Electron accelerator system.

Table 2. Dose rate at outside of facility wall by applying covering.

Material and Thickness	Dose rate(μSv/h)		
	Left wall	Right wall	Top wall
No covering	4.48E-02	3.49E-02	4.18E-02
HDPE-Borax (5cm)	1.32E-02	1.11E-02	1.08E-02

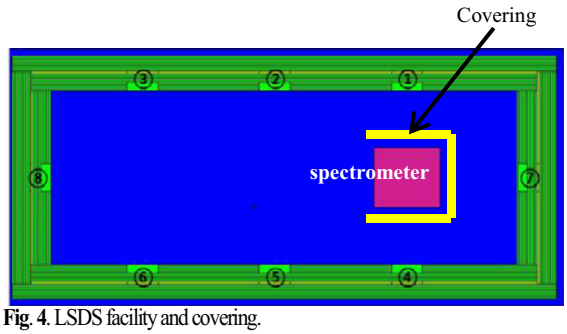

Fig. 4. LSDS facility and covering.

An activation evaluation was conducted on the Ta target. The target is located at the center of the spectrometer. The target should produce the neutron without degradation. The activation will affect the target life time. Table 3 shows the total activity by time after irradiation. After 1 day, the activity decreases drastically and after 90 days, it represents E-3Ci. Therefore, the activity decreases sufficiently based on the cooling time. After 90 days, the radiation can be shielded totally in the spectrometer.

6 Conclusion

In the designed LSDS, a mathematical model for an isotopic fissile assay was setup. The assay model involves all fissile fission signatures. The correction for self-shielding is a very important factor to represent the linear response in the fission. The correction improves the assay accuracy.

The isotopic fissile assay results show very good consistency with the actual mass for uranium and plutonium. In particular, the content for Pu239 was matched well to the actual content. It gives 2~3% uncertainty. The assay was in good agreement with the U235 content, with an ~2% error. However, the result for Pu241 was relatively poor compared to that of U235 and Pu239. In particular, by applying the additional covering shield around the spectrometer, a

drastically decreased dose rate was obtained at the outside wall of the LSDS facility. This will influence the facility shielding size and economics.

The LSDS technique is very promising for an analysis of the isotopic fissile content in used fuel. In the LSDS, direct fissile fission is obtained in the detector. Therefore, the LSDS is very powerful and direct in an isotopic fissile assay. The LSDS is applicable for the nuclear fuel cycle and spent fuel management for safety and economics. Additionally, an accurate fissile material content will contribute to international transparency and credibility for nuclear material utilization and management.

Table 3. Activity change based on cooling time.

Material	Cooling time						
	1s	30m	1hr	3hr	1day	7 day	90day
Ta	Total activity (Ci)						
	3.05E+09	2.92E+09	2.80E+09	2.36E+09	3.96E+08	1.91E+03	1.11E-03

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