An Analysis of Energy Spectrum for Detection of Gd and Mo in the Nuclear Fuel

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1. Introduction

When photons with energy greater than binding energy between nucleus and orbital electron interact with an atom, some of electrons are emitted from the atom and other orbital electrons fill the vacancy. Characteristic X-rays are emitted in this process, which are different from each other depending on the kind of materials. It enables us to discriminate materials because each material has specific level of characteristic X-rays.

We have been studied Fluorescent X-ray Computed Tomography(FXCT) system which use characteristic X-rays to verify the kinds of object materials[1,2]. We can acquire the material information as well as geometric information simultaneously through the FXCT system. The system is composed of X-ray or gamma-ray source and two detectors. One detector is a penetration X-ray detector, which is located behind the object to acquire geometric information of the object. Another detector is a fluorescent X-ray detector made with semiconductor arrays. This detector is located on the right side or left side of the object to acquire fluorescent X-ray information and exclude penetration X-ray information. Figure 1 shows diagram of a FXCT system.

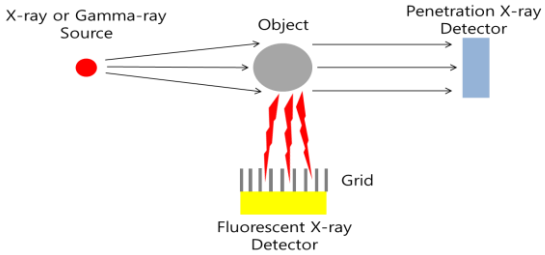

Fig.1. Diagram of the FXCT system. The penetration X-ray gives the geometric information and the fluorescent X-ray gives the material information.

The FXCT system has possibility to be applied to various situations like detecting foreign substances in pipes, analyzing art antiques or electronic circuits, etc. An advantage of the FXCT system is that the sample preprocessing is not required, thus, the system is effective especially when the object should be preserved.

Analyzing components of nuclear fuels can also be one of the non-destructive analysis examples. Nuclear fuels contain the Gadolinium(Gd) due to its large thermal neutron cross-section to adjust the reaction speed in the reactor. Uranium-Molybdenum(U-Mo) alloy has been also studied for research reactors to reduce the use of the high-enriched Uranium(HEU). It is important to verify how Gd or Mo included in the fuel is dispersed uniformly for stable operation of reactors[3].

In this study, we measured energy spectrum of the radiation emitted from Uranium pellets attached with two kinds of metals which can be included in nuclear fuels. We also analyzed the characteristic X-ray peaks to verify the feasibility of the FXCT system for analyzing nuclear fuels.

2. Materials and Method

To measure the uranium energy spectrum and characteristic X-rays, We used a CANBERRA high purity germanium(HPGe) detector due to its finest energy resolution than any other kind of detector materials. A uranium pellet was located 2.5 cm away from the detector window. Gadolinium and Molybdenum were attached to the surface of the pellet for modeling of U-Gd or U-Mo alloys.

The FXCT system requires radiation source enough to generate fluorescent X-rays. In this study, we used Cobalt-57 as a radiation source due to its 122 keV gamma-ray energy which is suitable for the FXCT system. It is also possible that an uranium pellet can be a radiation source itself in this case because Uranium-235 emits 185 keV gamma-rays. The experiment was carried out in three ways according to the source position.

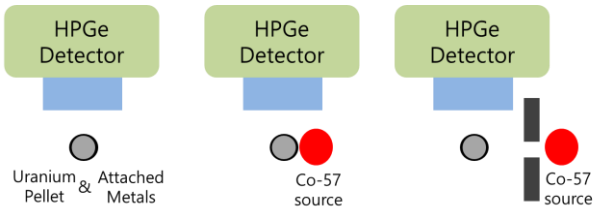

Fig.2. Diagram of the experiments that measuring energy spectrums of uranium pellet and attached materials: (a) only a Uranium pellet (b) Uranium pellet and Co-57 sources adjacent with each other (c) Uranium pellet and Co-57 source which is 12 cm away from the pellet.

We set only an uranium pellet with metals and obtained energy spectrum in first experiment. We set a Co-57 source near the pellet in the second experiment. We also set the Co-57 source 12 cm far from the source in last experiment. Data acquisition time of each

experiment was 45 minutes. We analyzed the characteristic X-ray peaks in the energy spectrum we had acquired to verify the feasibility of the FXCT system for nuclear fuel analysis.

We also measured total counts and area counts to compare the ratio of characteristic X-ray counts emitted from the attached materials to background counts from the Uranium pellets. The total count means the total number of counts in the characteristic X-ray area and the area count means the background-subtracted number of count in the same area.

3. Result

We verified the characteristic X-ray peaks of the Gadolinium while those of Molybdenum were not verified clearly. That means that the ratio of area counts to the total counts was high in the Gadolinium experiments. The reason for this result was caused by the lower photoelectric absorption cross-section of the Molybdenum than that of Gadolinium in the photon energy range of 10~100 keV. Figure 3 shows the result and figure 4 shows the photon cross-section of two materials.

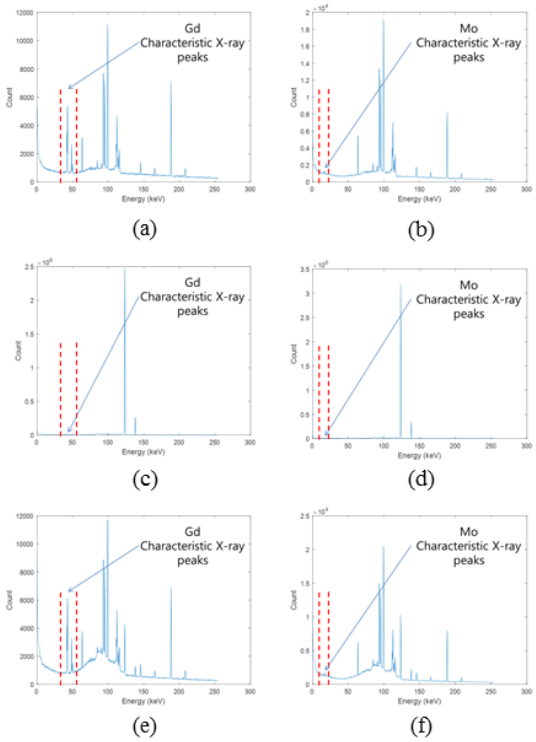

Fig.3. Energy spectrum of Uranium pellets with Gadolinium and Molybdenum: (a) Uranium pellet + Gd (b) Uranium pellet + Mo (c) Uranium pellet + Gd + Co-57(attached) (d) Uranium pellet + Mo + Co-57(attached) (e) Uranium pellet + Gd + Co-57(12 cm distance) (f) Uranium pellet + Mo + Co-57(12 cm distance). The characteristic X-ray peaks of the Gd are discriminated clearly while those of Mo are not discriminated clearly. The characteristic X-ray peaks are not shown in both (c) and (d).

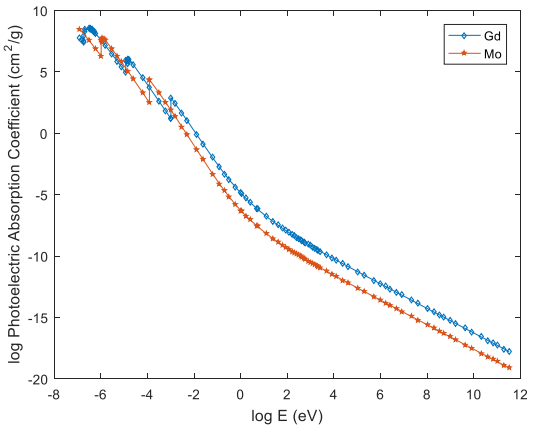

Fig.4. Graph of photoelectric absorption coefficient of two materials. The photoelectric absorption coefficient of Gd is higher than that of Mo in the range from 1 keV to 100 keV (between 0 and 2 along the x-axis).

The ratios of area counts to total counts were the highest when we use the uranium pellet only as a radiation source in both Gadolinium and Molybdenum experiments. The ratios were the lowest when we set Co-57 source just beside the pellet, because the background counts increase due to the photons emitted from the Co-57 source. Table. 1 shows the result.

Radiation Source	Gadolinium			Molybdenum		
	Total Count	Area Count	Ratio	Total Count	Area Count	Ratio
Pellet	14838	8175	0.355	5590	358	0.060
Pellet and Co-57 (0 cm)	60083	26201	0.304	56698	1001	0.017
Pellet and Co-57 (12 cm)	16835	9176	0.353	7316	440	0.057

Table I: The total counts, area counts and ratio of the area counts to the total counts according to material and radiation source type. The table shows that we can obtain the clear characteristic X-ray peaks when we use Uranium pellets only as a radiation source.

4. Conclusion

We measured the energy spectrum of uranium pellets which are attached with Gadolinium and Molybdenum for verifying the feasibility of the FXCT system for nuclear fuel analysis. The characteristic X-ray peaks were verified both of the experiments, however, the peak count was low in the Molybdenum experiment.

The ratios of area counts to total counts were analyzed to verify the changes in the performance according to existence of external radiation source. The ratio was the highest when there is no external radiation source, which means the characteristic X-ray peaks can be easily verified when we use a uranium pellet itself as a radiation source of the FXCT system.

ACKNOWLEDGEMENTS

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