Container Design Improvement of Hybrid L-edge/XRF Densitometer for Nuclear Fuel Assay

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1. Introduction

Currently Hybrid K-edge/K-XRF Densitometer (HKED), which uses tuned photon transmission and characteristic X-ray emission to characterize the elemental composition of samples of interest has been employed as a safeguards measurement technique to determine the major actinide (plutonium and uranium) content of nuclear fuel assay.

In this study, the hybrid L-edge/L-XRF Densitometer (HLED) container was improved to determine nuclear material concentrations. The improvement of the sample container was verified by experiment that determining the concentration of a surrogate material such as lead nitrate ($Pb(NO_3)_2$) solution prior to actinide-bearing materials.

2. System Description

The schematic of the HLED is shown in Fig. 1. The equipment is fabricated based on the results of a previous study [1] where the instrument design is determined by Monte Carlo simulation and nuclear material concentration is determined by feasibility study. The HLED prototype consists of an X-ray tube, shields, a sample container, three collimators and two Silicon drift detectors.

2.1 The previous sample container design

The previous sample container was made of Teflon to protect it from corrosion by nitric acid and had a 2 mm-optical path length and 300 μl volume. The window material of the sample container is Mylar (polyester) film with a 6 μm thickness to maximize detection efficiency. [2]

The problem of this sample container is a thermal deformation caused by the heat generated from X-ray tube and silicon drift detectors. This thermal deformation causes the changes of this Teflon sample container thickness that is optical path length. As shown in the calculation equation of material concentrations (1), the thickness D of target material is major parameter. [2]

$$\rho_{Pb} = \frac{\ln[T(E_-)/T(E_+)]}{\Delta\mu D} \quad (1)$$

$T(E_-)$, $T(E_+)$ are transmissions at the energies E_- (Lower than L_{III}-edge) and E_+ (Upper than L_{III}-edge). $\Delta\mu$ is the mass attenuation coefficient difference at upper and lower L_{III}-edges. The previous sample container is shown in Fig. 2.

2.2 The improved sample container design

The improved sample container is made of stainless steel to minimize thermal deformation by the heat from X-ray tube and detectors and to protect it from corrosion by nitric acid. This improved sample container has a 2 mm thickness and 50 μl volume as one-sixth of the previous sample container. The volume of this improved sample container is also minimized to reduce thermal effect. The window material of the sample container is same as previous one. The improved sample container is shown in Fig. 2.

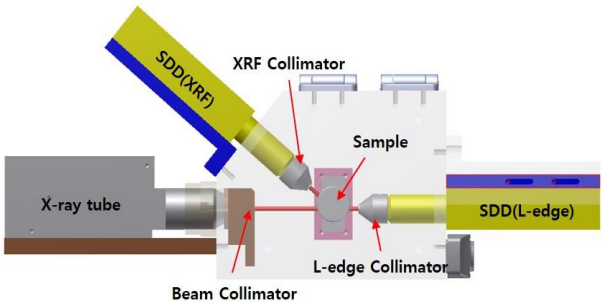

Fig. 1. Schematic Design of Hybrid L-edge/XRF Densitometer

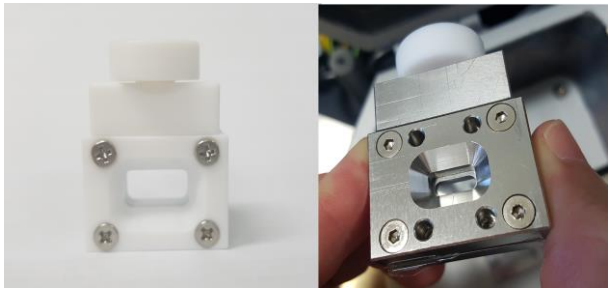

Fig. 2. The previous and the improved sample container

3. Experimental methods and Results

Experiments are performed for lead nitrate ($Pb(NO_3)_2$) solutions with concentrations of 0.01, 0.05, 0.1, and 0.2 g/cm^3 to avoid radiation effects for the performance

Table I: Reference and measured Pb concentration results of the previous and improved sample container

$Pb(NO_3)_2$	Previous sample container			Improved sample container		
	Pb reference value (g/cm^3)	Pb measured value (g/cm^3)	Difference (%)	Pb reference value (g/cm^3)	Pb measured value (g/cm^3)	Difference (%)
0.01	0.00676	0.00771	14.043	0.00654	0.008	22.31
0.05	0.0327	0.03814	16.627	0.03361	0.03351	0.289
0.10	0.0636	0.06993	9.95	0.06771	0.0678	0.136
0.20	0.15576	0.13	19.815	0.14796	0.14772	0.162

evaluation of the equipment. The blanket material is water in order to obtain transmission. The samples are measured for 3 times for 1000 sec respectively. The sample preparation and measurement data are combined to evaluate the density of lead in the surrogate material.

The measuring and calculation methods of the sample concentrations are described in the previous work. [2] Table I shows the results of the reference lead concentration and measured lead concentration of the previous and the improved sample container. The reference lead concentrations were measured by ICP-AES.

Comparing the differences between the previous container and the improved sample container, this results show that the improved sample container is quite precise than the previous one.

The counts are relatively low at lower concentrations. These results imply that low transmission in the spectra below 0.01 g/cm^3 results in low accuracy for both the previous and improved sample container. Therefore, optimal concentration can be considered to be above 0.05 g/cm^3 and below 0.2 g/cm^3 in case of surrogate material. Although the differences in this experiment are higher than that of the ITV (International Target Value) [3] of 0.2 % for uranium nitric acid solution, it is still feasible for the assay of nuclear material solutions. Nuclear materials have different L-edge characteristics compared to lead. Thus more study and experiments using nuclear materials are required.

4. Conclusions

The sample container of a HLED was improved for nuclear material solution assay. This improved equipment has feasibility as the uncertainty from L-edge analysis is near the ITV. The effects of concentration and volume must be considered for the assay of multi-element solution samples.

While experiment of the nitric lead solution provides insight into how the system will respond to samples taken from a fuel assay, more realistic studies are needed to predict the system response to more realistic solutions such as lead and uranium nitric acid solutions.

REFERENCES

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[3] IAEA, International Target Values 2010 for Measuring Uncertainties in Safeguarding Nuclear Materials, Vienna, November, 2010.