Monte Carlo study of characteristics of uranium L-edge from X-ray absorption spectrometry

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1. Introduction

L-edge densitometry (LED) which is specially called X-ray Absorption Spectrometry (XAS) for uranium x-ray analysis is a technique of determination of uranium concentration as a continuous x-ray energy beams transmit a uranium liquid sample for safeguard[1,2]. Compared to K-edge densitometer, since relatively lower energy of uranium L series energy than K series energy, L-edge densitometer does not require a liquid nitride cooling system. Therefore, the L-edge densitometer is appropriate for portable equipment for nuclear material inspection and safeguards at facility sites.

In this paper, the characteristics of L-edge of uranium is studied based on Monte Carlo simulation.

2. Methods and Results

The L-edge densitometer is consists of an x-ray tube, 3M nitric acid solution with uranium and a silicon detector. The schematic figure is as shown Fig. 1. The pure silicon was adopted for simplification of the simulation because the doping concentrations are low and do not affect the deposition energy calculated. The x-ray spectrum incident to uranium solution is used an experimental spectrum data to avoid difficulties of x-ray generation simulation. As shown in Fig. 2, x-ray spectrum is from 30 kV/100 μA and silver anode x-ray generator. The spectrum range is 0 ~ 30kV because of measurement of uranium L series < 22 keV including K_α and K_β line of silver anode, and continuous energy components by bremsstrahlung.

The solution sample thickness is 2 mm based on a fixed flow-through quartz cell. The transmitted energy spectrum through liquid sample is recorded by the silicon detector. The uranium L-edge densitometer is simulated by Monte Carlo method, Geant4 [3].

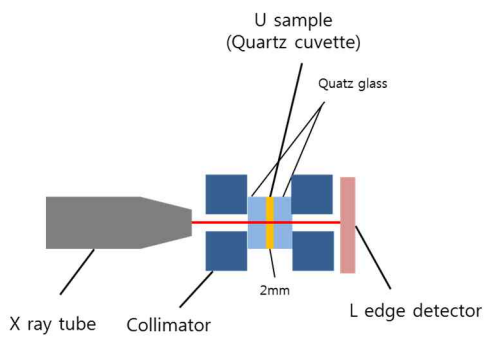

Fig. 1 Schematic description uranium L-edge densitometer

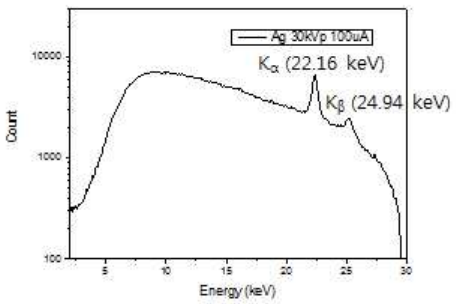

Fig. 2 X-ray tube spectrum with silver anode

Fig. 3 is the simulated energy spectrum of x-ray transmitted 3M nitric acid blanket solution and the uranium nitric acid solution. The uranium density is assumed that uranium solid samples into a nitric acid solution of 3M. The jump of energy spectrum transmitted through uranium solution is observed compared to reference energy spectrum transmitting across liquid nitric acid. The height of the jump of the spectrum determines the sample concentrations. The first jump of the spectrum is 17.17 keV, L_{III} energy (L-edge). Because the height is larger than other two energy jumps, L_{III} jump is used to analysis of uranium concentration.

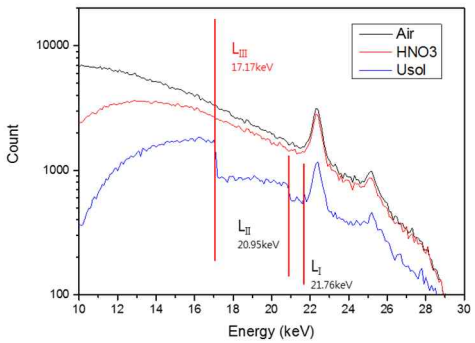

Fig. 3 Transmitted spectrum of uranium solution

Uranium concentrations through transmitted X-ray can be calculated following equation.

$$\rho_U = \ln\left[\frac{T(E_L)/T(E_U)}{\Delta\mu D}\right]$$

$T(E_L)$, $T(E_U)$ are respectively transmission at the energies

E_L (Lower than L_{III}) and E_U (Upper than L_{III}). D is sample thickness (exactly, optical path length) and $\Delta\mu$ is mass attenuation coefficient difference at each transmission energy. Extrapolated fitting in linearized a representation lnln(1/T) vs ln E is applied for determining upper and lower transmission for L-edge. Fitting intervals range from 15.5 – 16.7 keV for E_L and 17.6 – 18.8 keV for E_U. The fitting is shown in Fig. 4.

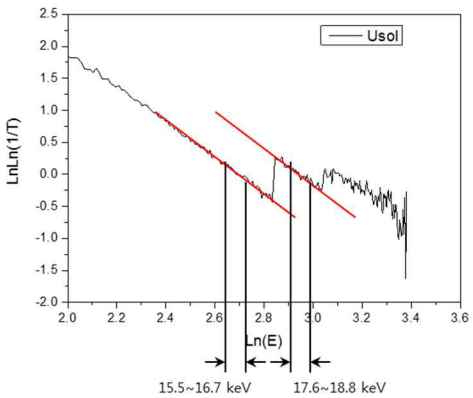

Fig. 4 Extrapolated fitting in lnln(1/T) vs ln E

The height of jump of the spectrum is determined by the uranium concentration shown in Fig. 5. The height of jump is dependent of uranium density. The spectra with high concentrated uranium has large height of jump. However, as shown in Fig. 6, for > 0.3 g/cm^3 concentration of uranium, the uranium concentration cannot be estimated form simulated spectra since the count rate is low and the transmitted spectrum is distorted due to low transmission not as possible to determine the transmission at L-edge from linearization of representation lnln(1/T) vs ln E.

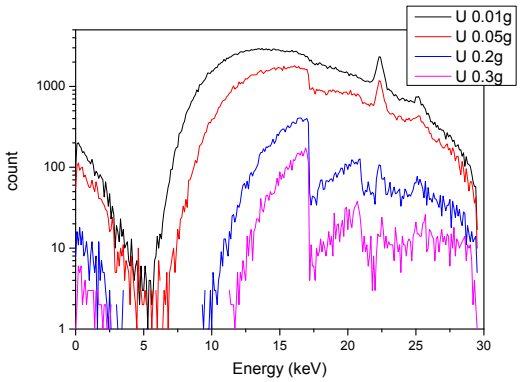

Fig. 5 Transmitted spectrum through uranium solution for uranium density variation

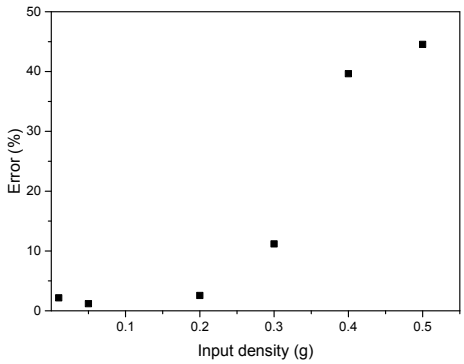

Fig. 6 The calculated concentration cannot be estimated for > 0.3g/cm^3 uranium density

3. Conclusions

In this study, the simulation of uranium L-edge densitometer is performed using Monte Carlo method. L-edge spectrum, such as spectrum jumps, can be confirmed by the simulation. In further study, improvement of counting efficiency through collimation of x-ray, and shielding will be considered for detailed design of L-edge densitometer.

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