Measuring Isotopic Abundance using Nuclear Resonance Fluorescence

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Abstract

Nuclear resonance fluorescence (NRF) is a phenomenon that a nuclide-specific γ-ray is resonantly absorbed and re-emitted. This method is considered useful for the nondestructive detection of nuclear materials. In order to demonstrate how accurate the NRF method is able to measure the isotopic abundance, we performed NRF experiments on natural tungsten as a surrogate of nuclear materials at the high intensity γ-ray source, Duke University. Our results show that the relative deviations between the reference and measured abundances are less than ±4%.

Keywords: nuclear resonance fluorescence, nondestructive assay, nuclear materials, abundance measurement

1. Introduction

Nuclear resonance fluorescence (NRF) was proposed as a nondestructive assay technique for nuclear materials [1]. Gamma-ray spectroscopy is a common passive method for the detection of radioactive isotopes in a nondestructive manner, however, in case of nuclear materials, e.g. U-235 the emitted low-energy γ-rays are obscured by self-absorption and/or matrix-shielding. NRF interaction overcomes this limitation because of the high-energy γ-rays involved in the interaction. Here we perform a quantitative test of the NRF method by measuring the natural abundance of tungsten isotopes.

2. Experiment

A tungsten target of 2.5 cm in diameter and 0.4 cm in thickness was irradiated by a quasi-monochromatic linearly polarized γ-ray beam of central energy of 3.12±0.09 MeV for a real time of 7 hours at the high intensity γ-ray source (HIγS) facility, Durham, NC, USA. The flux of the incident γ-ray beam was ~ 3×10^7 ph./sec. Three isotopes of tungsten were simultaneously irradiated within the energy of the incident beam. The isotopes W-182, W-184, and W-186 resonantly absorbed and re-emitted γ-rays of energies 3.163, 3.084 and 3.172 MeV; respectively. The NRF photons were detected by 6 high-purity Ge detectors.

3. Results - Conclusions

Table 1 summarizes the results of the natural abundance of the observed tungsten isotopes. The relative deviation, *R*, between the measured $\chi_{mes.}$ and reference $\chi_{ref.}$ abundances is less than 4% while the uncertainties of the measured abundances are approximately 10%. Most of these uncertainties are systematic which arise from the uncertainties in the integrated cross-section and branching ratios as well as uncertainty in the efficiency of the detectors. Generally, the present results show that the current capabilities of γ-ray sources facilitate the NRF technique to the nondestructive assay of nuclear materials. For better uncertainties, accurate values of cross-section data can be realized by performing further NRF measurements on nuclear materials. This work was supported by the "subsidiary for promotion of strengthening nuclear security or the like" of MEXT.

Table 1. Measured abundances of the isotopes considered in the present study.

Isotope	E (MeV)	$\chi_{ref.}$ %	$\chi_{mes.}$ %	*R* %
W-182	3.163	26.5	27.2	2.4
W-184	3.084	30.7	31.8	3.7
W-186	3.172	28.4	29.2	2.9

References

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