Nondestructive Quantitative Isotopic Analysis Using Nuclear Resonance Fluorescence

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Abstract

A quantitative isotopic analysis of the natural metallic samples of hafnium (Hf) and tungsten (W) elements is presented. Hf and W targets were exposed to quasi-monochromatic γ-ray beams generated by laser Compton scattering (LCS) at the high intensity γ-ray source (HIγS) facility of Duke University. The γ-ray beams, in the 2.4-3.2 MeV energy range, excited multiple nuclides simultaneously via the nuclear resonance fluorescence (NRF). All excited transitions were employed to analyze the isotopic compositions of the targets. Particularly, the content of the even-mass naturally occurring isotopes of Hf and W was detected with high precision. The uncertainty of the measured abundances is $2.7 - 6.7\%$, while the deviation from the reference values ranges between $0.18 - 1.36\%$.

Keywords: Nondestructive analysis, NRF, Laser Compton scattering γ-rays

1. Introduction

The nondestructive analysis is of paramount significance to many fields, such as nuclear security and nuclear nonproliferation, where an accurate determination of the isotopic content (e.g., enrichment) is necessary without compromising the inspected samples. NRF is a resonant photonuclear interaction that provides a unique fingerprint of each nucleus. Therefore, NRF is anticipated to be one of the most powerful isotopic analyzers. However, studies that test this technique quantitatively are rare. Here, we measure the isotopic abundance of Hf and W elements to demonstrate the potential of NRF as a quantitative isotopic analyzer.

2. Materials and Methods

Hf target (purity of 99.9%, square 2.5 cm on a side and 4 mm thick) and W target (purity of 99.9%, disk 2.5^{ϕ} cm and 4 mm thick) were irradiated by LCS γ-ray beams at the HIγS facility of Duke University, USA. The NRF scattered photons were detected by an array of detectors consisting of 6 high purity germanium (HPGe) detectors [1]. The flux of the incident γ-ray beams was accurately estimated by a combination of measurements of incident γ-ray beam profiles and Monte Carol simulations [1]. The average flux used in the present measurement is approximately 400 γ/sec eV. In total, 21 and 30 transitions of Hf and W isotopes were observed, respectively. Knowing γ-ray beam flux and the NRF cross sections, these transitions were employed to estimate the abundance of 3 Hf and 3 W isotopes.

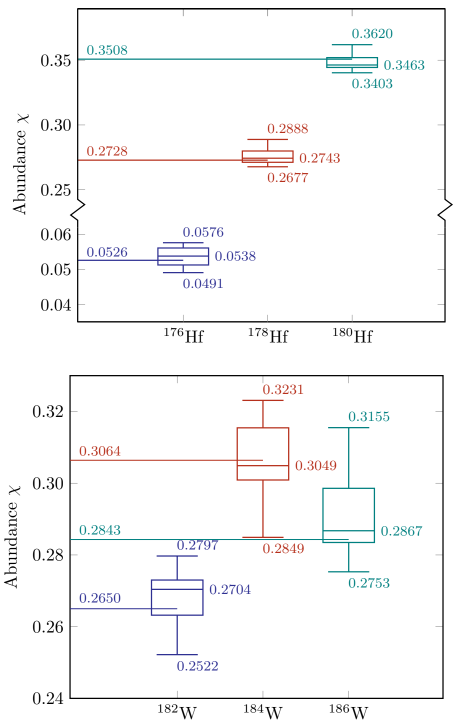

Fig. 1: Distributions of the measured abundances of Hf (top) and W (bottom) isotopes. For each isotope, the minimum, maximum, median, and reference abundances are indicated [1].

3. Results and Discussion

Fig. 1 shows the distributions of the measured abundances of the 6 detected isotopes. The smallest abundance measured in the present work is for ^{176}Hf, weight-averaged abundance, $\chi_{wav} = 0.0521(35)$, with a total uncertainty of 6.7%. The small amount of ^{176}Hf (1.75 g) in the sample produced the lowest counts, which led to high statistical uncertainty. For ^{182}W, $\chi_{wav} = 0.2614(71)$ with a total uncertainty of 2.7%, which is the best obtained uncertainty using NRF method so far. Furthermore, the results attained for ^{184}W and ^{186}W standing at $\chi_{wav} = 0.3033(91)$ and $\chi_{wav} = 0.2848(106)$, respectively, demonstrate that the NRF method could distinguish similar isotopic contents within one standard deviation.

4. Summary

In summary, we demonstrated that NRF method can be used to achieve a comprehensive quantitative isotopic analysis of dense elements such as Hf and W, nondestructively. Although the uncertainties of the measured isotopic contents are still far below those provided by mass spectroscopy, the uniqueness of the signature and the nondestructive nature of the detection can be useful for nuclear security applications.

Acknowledgment: This work is a contribution of the JAEA to the International Atomic Energy Agency (IAEA) under the agreement of the coordinated research program (CRP), J02015 (Facilitation of Safe and Secure Trade Using Nuclear Detection Technology - Detection of RN and Other Contraband).

References

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