Chemical and Isotopic Examination of Nuclear Materials: Adopting a Multi-Faceted Approach to Forensic Investigations

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Despite being well-established and relatively safe, and coupled with its importance as a viable alternative to fossil fuel-based energy, there remains concerns regarding nuclear energy production; these include unresolved solution to waste disposal, risk of nuclear weapons proliferation, and national security. With regards to the latter, forensic analyses of U-rich materials related to the nuclear fuel cycle, such as uranium ores and ore concentrates (UOCs) have relied primarily on trace element (e.g., REEs) and isotopic signatures (U, Sr, Pb).

Some of our recent forensics research for samples related to the front end of the nuclear fuel cycle (natural U ores, UOCs, and fuel pellets) are highlighted, and this has typically involved a multi-pronged approach using both bulk, solution-mode (SM) and micron-scale investigations via laser ablation (LA)-ICP-MS methodologies. The latter have been conducted in tandem with focused ion beam (FIB)-scanning electron microscopy (SEM) analysis of uraninite[1]. We have also identified a new reference material for high spatial resolution analyses of natural U ores[2]. A recent study reporting the trace element concentrations of two nuclear fuel pellets indicates that relative abundances of transition metal impurities are key for providing important insights into their provenance[3]. Novel nuclear forensic approaches include examining the $\delta^{11}B$ and $\delta^{98}Mo$ isotope signatures of uraninites from various ore deposits worldwide. The $\delta^{98}Mo$ values of UOC have been proposed as a nuclear forensic signature due to the ubiquitous presence of Mo in the nuclear fuel cycle, and different production pathways may produce characteristic Mo isotope fractionation[4]. To date, $\delta^{11}B$ values corroborate the importance of continental crust in U ore formation, while Mo isotope compositions define a large range of values (-2.61 to +3.05 ‰), and exhibit correlations with both age and B isotope ratios. Both $\delta^{11}B$ and $\delta^{98}Mo$ compositions of U ores are promising forensic signatures.

[1] Lewis *et al*. (2018) *JRNC* **318**, 1389-1400. [2] Dorais *et al*. (2019) *Geostand. Geoanal. Research*, in press. [3] Spano *et al*. (2019) *J. Nuclear Materials* **518**, 149-161. [4] Rolison *et al.* (2019) *Applied Geochem.* **103**, 97-105.