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From Nuclear Physics to Isotope Geochemistry: Identifying Anthropogenic Contamination Sources in the Environment

Human activities—whether nuclear (civilian and military) or industrial processes involving naturally radioactive materials (oil and gas production, phosphate mining, and rare earth extraction)—have released and redistributed radionuclides across environmental compartments. This contamination could threaten ecosystems and human health, with risks driven by the persistence, concentration, and geochemical behavior of these radioactive elements and the sensitivity or organisms. Contamination sources can mix, overlap with legacy contamination, or be masked by naturally occurring elements (e.g., ^{238}U). Effective management and remediation of contaminated soils and sites require, first and foremost, a precise identification of these sources.

Isotope geochemistry, at the intersection of geology, chemistry, and nuclear physics, provides relevant methodologies and tools for identifying sources of environmental contamination. By exploring isotopic and elemental "fingerprints,"scientists can trace contamination origins and track their evolution across time and space.

This presentation explores the crucial role of nuclear physics—such as nuclear reactions, isotope production, and decay processes—in isotope geochemistry, helping geochemists interpret isotopic signatures associated with various contamination sources. Nuclear physics is essential for characterizing elemental and isotopic endmembers—such as using reactor physics calculations to estimate fuel burn-up and the resulting isotope/elemental ratios. It also plays a key role in developing high-precision experimental methods for isotope analysis, including advanced mass spectrometry techniques (e.g., ICP-MS, TIMS, AMS) and radiation detection methods (e.g., gamma spectroscopy, alpha spectrometry).

Several examples of contamination sources will be discussed, including uranium mining and milling processes, nuclear power plant accidents/incidents, global fallout, and reprocessing facilities. Emphasis will be placed on understanding the geochemical behavior of these tracers, offering valuable insights for tracking radioactive contamination.

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