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# Tracing PFAS Sources and Degradation Using Compound-Specific Isotope Analysis

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Per- and polyfluoroalkyl substances (PFAS) are globally persistent contaminants of concern due to their strong C–F bonds and resistance to conventional remediation techniques. Understanding their environmental fate requires robust tools capable of distinguishing between sources and assessing degradation processes. In this work, a novel compound-specific isotope analysis (CSIA) method for carbon isotopes of perfluorinated carboxylic acids (PFCAs) was developed and optimized to provide reliable isotopic fingerprints of PFAS in contaminated groundwater and soils. The main objectives were (i) to improve analytical performance through derivatization and non-linear isotope correction procedures, (ii) to establish an initial isotopic database for common PFCAs, and (iii) to apply the method to field samples to evaluate its potential for plume delineation and source identification.

The study involved the development and optimization of a compound-specific isotope analysis (CSIA) method for selected perfluorinated carboxylic acids, followed by its application to environmental samples. The analytical workflow first included the isotopic characterization of standards for different PFCAs obtained from multiple suppliers, to ensure that the initial isotopic range was broad enough to account for analytical uncertainty and support stable isotope monitoring. The CSIA method was then refined to improve data accuracy and reproducibility, providing reliable isotopic measurements across variable concentration ranges. Once validated, the method was applied to groundwater samples from PFAS-contaminated sites to characterize isotopic patterns. These data were subsequently used to investigate isotopic variability within the contaminant plume and to evaluate the potential of CSIA for delineating source areas and identifying transformation processes.

The initial isotopic database revealed significant compound-specific differences among commercial PFAS formulations, providing a solid foundation for source discrimination. The CSIA method developed in this study was subsequently applied to the first PFAS-contaminated sites ever investigated through stable isotope analysis. Field samples showed measurable isotopic compositions starting from concentrations above the microgram-per-liter range, representing an unprecedented application of CSIA to PFAS contamination. These pioneering results mark the first successful use of CSIA on PFAS in real environmental matrices, demonstrating its strong potential to complement conventional chemical analyses and to enhance our ability to trace contamination sources and evaluate in situ transformation processes.