In search of live ^{247}Cm in the early solar system

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Extinct short-lived nuclides provide valuable information on the early history of the solar system. The r-process only nuclide ^{247}Cm decays to ^{235}U with a characteristic half-life of ~16 My and offers enormous potential as a short-lived chronometer, providing constraints on the time interval between the last r-process nucleo-synthetic event and the formation of the solar system. Chemical and physical studies predict significant actinide fractionations in the early solar nebula and Cm-U fractionation could be manifested as shifts in ^{235}U/^{238}U due to ^{247}Cm decay if the initial abundance of ^{247}Cm was sufficiently large.

The potential of ^{247}Cm as a short-lived chronometer was first discussed thirty years ago, and immediately stimulated research in the search for uranium isotopic anomalies in meteorites. Some studies revealed extremely large anomalies in ^{238}U/^{235}U of up to several hundred percent, but others could not substantiate these findings as no anomalies were found. At the time of these measurements, the best attainable analytical uncertainties on ^{235}U/^{238}U were of the order of ±6 permil ($2\sigma_M$). Therefore, epsilon- to permil-level shifts in ^{235}U/^{238}U would not be detected, and ^{247}Cm effects would be further demagnified in samples where Cm and U were not strongly fractionated. The issue of whether or not live ^{247}Cm existed in the early solar system thus remains unresolved.

Given the importance of the ^{247}Cm chronometer, we have renewed the search for isotopic anomalies in uranium and have developed experimental protocols for the precise measurement of ^{235}U/^{238}U by multiple-collector ICPMS (MC-ICPMS). Using a Nu Instruments NuPlasma MC-ICPMS, we are able to resolve variations in ^{235}U/^{238}U at the one epsilon level ($2\sigma_M$) on sample sizes of 10-20 ng of uranium. Data can be acquired on smaller 1-10 ng samples with 2-3 epsilon 2σ uncertainties. High quality U measurements are possible because we have used a high-purity ^{233}U-^{236}U double spike to internally monitor the large (percent-level) but essentially constant instrumental mass bias effects that are inherent to plasma source mass spectrometry. The search for uranium isotopic anomalies in meteorites will ultimately require careful work on small samples (<10 ng of U) from specific mineral phases in primitive objects displaying strong Cm-U fractionations. However, our first ^{235}U/^{238}U measurements show resolvable excursions away from the terrestrial value in some bulk meteorites. We are currently verifying these observations with further experiments.

Apatite (U-Th)/He multi grain-size analysis: A thermal history tool

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(U-Th)/He dating of apatite is a powerful tool to elucidate low-temperature cooling histories and quantify upper-crustal to near-surface geological, tectonic, and geomorphic processes. The Apatite (U-Th)/He system is characterized by a closure temperature of ~65 to 75°C (assuming cooling rate of 10°C/Myr) and a partial retention zone (HePRZ) between ~80 and ~40°C. Several studies have shown that He diffusivity correlates with the physical dimensions of the apatite crystal, indicating that the diffusion domain is the grain itself. This observation suggests that smaller grains are less retentive of He than larger grains and that the analysis of multiple grain size fractions from an individual sample can be used as a tool to decipher thermal histories.

In order to develop this technique, we systematically analyzed multiple grain-size fractions of apatite from a down-hole profile in the Cajon Pass drill hole in southern California. We performed duplicate laser single-grain (U-Th)/He analyses of different grain size fractions (20 - 90 µm in radius) from seven different samples with down-hole temperatures ranging from 28 - 84°C. Our results show a well-defined apatite HePRZ and exhibit a systematic correlation between apparent age and grain size. Whereas samples from above the apatite HePRZ show small grain-size correlated apparent age variations, samples from within the HePRZ display a large dependence of apatite (U-Th)/He ages on grain size. For example, a sample residing at 48°C exhibits a grain-size correlated spread in apparent ages ranging from ~35 Ma (20µm radius) to ~55 Ma (90 µm radius). These data illustrate that grain size sensitivity of apparent apatite (U-Th)/He ages can be used to deduce thermal history information by analyzing multiple grain sizes from a single sample.