Introduction

The nucleosynthetic history of isotopes, their abundances and spatial distribution within the circumstellar disk help us identify the different stellar contributions and mixing processes active in the early Solar System. Among the many isotopes found in nature, short-lived radioisotopes (SLRs) are essential for quantifying the temporal evolution of the early Solar System. A potentially useful short-lived isotope system that has been infrequently studied to date is $^{135}\text{Cs} - ^{137}\text{Ba}$ ($t_{1/2} \sim 2.3$ Ma; [1]) which comprises a volatile parent nuclide and a refractory daughter nuclide and is useful for dating condensation processes and the accretion of planetary bodies. Here, refractory inclusions from Allende (CV3) and NWA753 (R3.9) were analyzed for Ba isotope variability.

Samples

- 4 Allende calcium-aluminium-rich inclusions (CAI 1,2,4,5; Fig. 1)
- 1 Allende dark inclusion (H73)
- 2 Unequilibrated type 3 fragments from NWA753 (H74, H75)

Methods

- Isolation of refractory inclusions from whole rock sample using a dental burr under optical microscope
- HF-HNO$_3$ digestion in sealed non-pressurized Savillex$^\text{®}$ beakers
- Isolation of Ba by column chromatography [2]
- Isotope measurements by Thermal Finnigan Triton TIMS
- Cs/Ba determination by LA-ICPMS
- Ba isotopes are presented using the $\mu$ notation (where $x = 132$, 134-137):

\[ \mu = \left( \frac{^{135}\text{Ba}/^{138}\text{Ba}}{\text{sample}} \right) \frac{1}{\left( \frac{^{135}\text{Ba}/^{138}\text{Ba}}{\text{standard}} \right) \times 10^6} - 1 \]

Results

The Ba isotope data collected from Allende CAI 1 (Type B2), CAI 2 (Type A), and CAI 5 show an excess of $^{135}\text{Ba}$ ($\sim 55$ ppm) with terrestial compositions for the remaining isotopes (Fig. 2). The remaining refractory inclusions possess terrestrial Ba isotope compositions.

Discussion

Origin of $^{135}\text{Ba}$ excess:

1. Neutron capture reactions: All stable Ba isotopes have low neutron capture cross sections thus it is unlikely that secondary neutron reactions could have enriched $^{135}\text{Ba}$ alone. The development of a positive $^{135}\text{Ba}$ anomaly could potentially occur via a neutron reaction pathway from neighboring nuclides, but such a path is currently unknown.

2. Nucleosynthetic anomalies: Incomplete mixing of freshly synthesized material (e.g., presolar grains and nucleosynthetic ejecta) in the solar nebula can explain coupled $^{135}/^{137}\text{Ba}$ excesses [1,3,4]. Estimates of the $^{135}\text{Ba}$ excess associated with a $\sim 55$ ppm $^{135}\text{Ba}$ are made using different production ratios (Fig. 2). If present, the estimated $^{135}\text{Ba}$ excess would be clearly resolvable from the external reproducibility of the standards ($\sim 10$ ppm).

3. Radioactive decay of $^{133}\text{Cs}$ to $^{135}\text{Ba}$: The $^{135}\text{Ba}$ excess is interpreted here to have developed from the decay of SLR $^{133}\text{Cs}$. This contribution is unlikely to have $^{135}\text{Ba}$ occurred via $\text{in situ}$ decay of live $^{133}\text{Cs}$ because there is no correlation between $^{135}\text{Ba}$ excess and a superchondritic Cs/Ba (<0.0015, where chondritic Ca/Ba ~ 0.0795). Rather, we suggested that a transient, high Cs/Ba (> Cl) reservoir existed in the early Solar System when $^{133}\text{Cs}$ was extant, and that in this setting some early condensates recorded the presence of live $^{133}\text{Cs}$ as a $^{135}\text{Ba}$ excess (Fig. 3).

Nucleosynthetic source of $^{135}\text{Cs}$:

The nucleosynthetic source of $^{135}\text{Cs}$ can be constrained by reconciling the predicted astrophysical $^{133}\text{Cs}/^{135}\text{Cs}$ abundance with its abundance in meteorites. The currently accepted value for the $^{133}\text{Cs}/^{135}\text{Cs}$ ratio of solar material is $\sim 4.8 \pm 0.2 \times 10^{-7}$ [1] of the Solar System, however, may be underestimated because live $^{133}\text{Cs}$ could have been extinct by the time the nebula had cooled enough to condense Cs [Fig. 4] if the initial meteorite abundance of $^{133}\text{Cs}$ was indeed higher than is currently thought, it is feasible that $^{133}\text{Cs}$ was added to the Solar System along with $^{44}\text{Ca}$ and $^{26}\text{Al}$ from contamination of the presolar molecular cloud by a single stellar source (e.g., a Wolf-Rayet star).